EMERGETIC EVALUATION OF CATTLE REARING IN A MONTADO FARM

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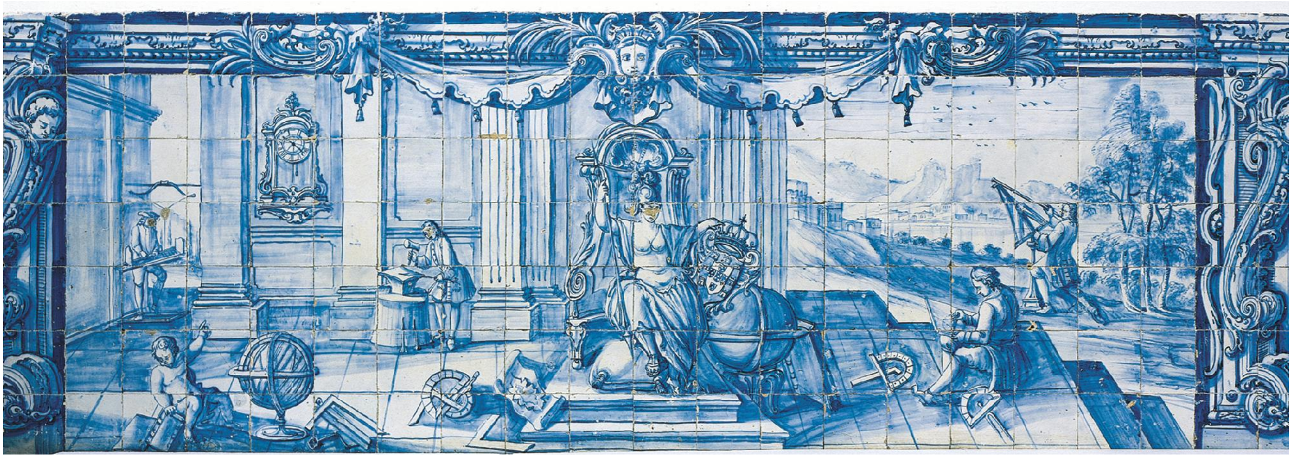

INSTITUTO DE INVESTIGAÇÃO E FORMAÇÃO AVANÇADA

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Dissertação

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To Julia and my parents,

"In fact, the crisis is the result of the overgrowth of financial assets relative to growth of real wealth – basically the opposite of too little liquidity. We need to take a step back and explore some of the fundamentals that growth-obsessed economists and commentators tend to neglect"

Herman Daly and Annelli Rufus, 2008

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FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

POPH

QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL PORTUGAL 2007.2013

Resumo

Avaliação emergética de uma exploração pecuária em Montado

O Montado, em Portugal, é um complexo sistema silvopastoril de uso da terra, tipicamente Mediterrânico, com diversos estratos de vegetação, incluindo sobreiro e azinheira em várias densidades, onde é frequente a criação de gado. Esta actividade pecuária beneficia das pastagens no sob-coberto, de algumas espécies arbustivas e também das bolotas que caem do coberto arbóreo, contribuindo para evitar a invasão da pastagem por matos. No entanto, dependendo da sua gestão, este gado pode comprometer a regeneração do sistema. Nos últimos 20 anos, os subsídios no âmbito da Política Agrícola Comum da União Europeia têm promovido a criação de gado bovino em detrimento de outras espécies e raças mais leves, bem como a intensificação desta produção. Esta intensificação pode impossibilitar a regeneração natural das árvores ameaçando o equilíbrio do Montado. Por esta razão é necessária uma avaliação focada na criação de gado bovino e nos seus impactos sobre o sistema. O objectivo deste estudo foi obter uma melhor compreensão do funcionamento de uma exploração silvopastoril num sistema de Montado, através da aplicação do Método de Avaliação Emergética e do cálculo de índices emergéticos. Pretende-se assim compreender a melhor forma de o gerir, bem como conceber estratégias que maximizem o fluxo de emergia na exploração. Uma comparação deste método com a avaliação económica permitiu perceber em que aspectos esta pode ser complementada pelo método da avaliação emergética. O método da avaliação emergética permite a avaliação de sistemas multifuncionais complexos à escala de uma exploração individual, fornecendo informação extra em relação à avaliação económica como a renovabilidade dos *inputs* do sistema, ou a quantidade de fluxos livres da natureza que é valorada por preços de mercado. Este método permite a integração das *emternalidades* e das externalidades à contabilização económica, transformando uma avaliação tendencialmente separada do seu sistema mais vasto, numa avaliação de um sistema em conexão com aqueles mais vastos nos quais se integra.

Palavras-chave: Montado, emergia, pecuária, multifuncionalidade, intensificação.

Abstract

The Montado, in Portugal, is a complex silvo-pastoral system of land use, typically Mediterranean, with different strata of vegetation, including cork and holm oaks in various densities, and where cattle rearing is common. This stockfarm benefits from the herbaceous layer under the trees, as well as from some species in the shrub layer, and also from the acorns faling down from the tree cover, while contributing to prevent the invasion of pastures by shrubs. Nevertheless, depending on its management, livestock can affect the system regeneration. Over the past 20 years, subsidies of the European Union's common agricultural policy have promoted the cattle rearing at expense of other lighter species and breeds, as well as its intensification. This intensification may impair the natural regeneration of trees threatening the balance of the Montado. Therefore an assessment focused on cattle and their impact on the system is required. The purpose of this study was to obtain a better understanding of the functioning of a silvo-pastoral farm in a Montado system, by applying the emergy evaluation method and through the calculation of emergy indices. It is intended to understand the best way to manage and design strategies that maximize the emergy flow on the farm. A comparison of this method with the economic evaluation allowed to realize in what aspects it can be complemented by the emergy evaluation method. The emergy evaluation method alows the assessment of complex multi-functional systems at the scale of an individual farm, providing extra information in relation to economic avaluation as the renewability of the inputs to a system and the amount of free flows of nature that is valued by market prices. This method allows the integration of the *emternalities* and the externalities to the economic accounting, transforming an evaluation tended separated from its wider system, in an evaluation of a system in connection with the larger ones on which it is incorporated.

Keywords: Montado, Emergy, Cattle rearing, Multifunctionality, Intensification.

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List of Acronyms

AFN Autoridade Florestal Nacional

CAP Common Agricultural Policy

CGE Centro de Geofísica de Évora

EER Emergy Exchange Ratio

EER_N Nonrenewable Emergy Exchange Ratio

EIR Emergy Investment Ratio

ELR Emergy Loading Ratio

ESI Emergy Sustainability Index

ESL Energy Systems Language

EST Energy Systems Theory

EYR Emergy Yield Ratio

GIS Geographic Information System

ICNB Instituto da Conservação da Natureza e da Biodiversidade

IFIAS International Federation of Institutes of Advanced Studies

ISAER International Society for the Advancement of Emergy Research

ISO International Organization for Standardization

LNEC Laboratório Nacional de Engenharia Civil

SEARN Secretaria de Estado do Ambiente e Recursos Naturais

SETAC Society of Environmental Toxicology and Chemistry

SOM Soil Organic Matter

TEEB The Economics of Ecosystems and Biodiversity

UEV Unit Emergy Value

Contents

Preamble

The environmental problems existing nowadays are a good source of inspiration for choosing a doctoral thesis topic. Previously, I worked on a large organic farm and joined a citizen's movement for sustainability, and both of these activities have had a decisive influence on the theme of my doctoral thesis. Therefore, the initial theme of my thesis was related to the expenditure of energy in food production in relation to fluctuations in energy prices.

Also, the fact that I live in the Montado landscape and have worked for several years on the dissemination of knowledge about this system, made it inevitable that this dissertation would focus on farming in the Montado and the production of one of its main outputs, calves. In addition, there is a growing concern among scholars that the present design of the Common Agricultural Policy and its application in Portugal to support beef production is leading to a significant and continuous increase in cattle production in the Montado, most often with negative consequences on the balance of this system.

The literature search on the topic of energy led me to the Emergy Assessment Method. A brief evaluation made me realize that this tool or lens to assess the contributions of nature to society was suited a systemic way of seeing life and thinking about nature.

The capacity for synthesis on the one hand, associated with the rigorous characterization of each system under study and the determination of the values to be used, make emergy evaluation a time-consuming method that requires the collection of a large quantity of data. However, its power to integrate and explain system structure and function is very attractive, and therefore I have selected this pathway to assess the functioning of the Montado system on the farm level, today. This choice required the study of the emergy method in itself, and I have joined the ISAER (International Society for the Advancement of Emergy Research) meetings in the US and Europe three times during my thesis, to get acquainted with the details of the method. This learning effort, together with the lack of sufficient detailed information on all components of the system, and the work necessary to produce the needed data with the required quality, just for one farm, has led to a clearer focus in the final work.

Thus the theme of this dissertation focuses on the study and evaluation of one farm with cattle rearing in the Montado system through the application of the Emergy Evaluation Method, and the evaluation of the results also in economic terms. Comparing emergy with economic evaluation was also fundamental to learn and urderstand major differences of perspectives, focus and results.

1. Introduction

The Montado, in Portugal, is a complex silvo-pastoral system of land use, typically Mediterranean, with different strata of vegetation, including cork and holm oaks in various densities, and where it is common to take advantage of natural or improved pasture and other system resources by rearing one or more livestock species. Among these, the alternatives include the raising of sheep, cows, pigs, goats, turkeys and other species less commonly used. This activity benefits from the herbaceous layer under the trees, as well as from some species in the shrub layer, and also from the acorns falling from the tree cover, while at the same time contributing to prevent the invasion of pastures by shrubs. Nevertheless, depending on its management, livestock can affect the system regeneration. Over the past 20 years, subsidies of the European Union's common agricultural policy have promoted cattle rearing at the expense of other lighter species and breeds, as well as its intensification. This intensification may impair the natural regeneration of trees, threatening the balance of the Montado. The accurate assessment of the balance between its different components becomes therefore urgent. With an economic evaluation is not easy to capture and evaluate all components of the Montado since many of them are not usually evaluated in economic terms. Examples of these components are solar energy, wind, ground water available for livestock and also those which in an economic evaluation are called externalities of economic activity, examples of which include erosion, soil compaction, and reduction in the natural regeneration of the trees. The thesis of this work is that in a system with the complexity and semi-natural character such as the Montado, both the free inputs from nature and the outputs or externalities unaccounted for are important for a more complete evaluation of a Montado able to respond to the challenges to which it is currently subjected. Thus, the emergy evaluation method was used in order to evaluate both the components usually evaluated by economics and those components normally outside these evaluations.

1.1 Objectives

The purpose of this study was to obtain a better understanding of the functioning of a silvo-pastoral farm in a Montado system with cattle rearing as the main agricultural activity, through the application of the emergy evaluation method, and through the calculation of emergy indices. In this way the intention is to gain a clearer idea about the relative importance of the different system components in order to allow the designing of strategies for the sustainable management of the system at the scale of an individual farm. A comparison of this method with the economic evaluation allowes us to realize in which aspects the latter can be complemented by the emergy avaluation method.

Specifically, the following research questions were considered:

- to apply the emergy evaluation method to a cattle rearing Montado farm, as a way of getting an integrating overview of the different components of this system and of their mutual influence,

- to know the relative importance of the different components of this system,

- to distinguish and account nature’s and human work in cattle rearing,

- to find a language with which human work and nature's work can be assess on equal terms and how and to whom the two are remunerated,

- to solve some technical issues related to the implementation of the emergy evaluation method to a multifunctional farm,

- to compare economic and emergy evaluations to determine their potential contributions to understanding a multifunctional farming system in the context of the western Mediterranean basin.

1.2 Organization

This thesis is organized into six sections, followed by references and appendices, where the first section is "1. Introduction". In this section a brief description of the system, and the threats to which it is subject, is undertaken, and the thesis investigated in this work is presented. In this first section, in subsection "1.1 Ojectives", are defined the objectives of this study and in subsection "1.2 Organization" is presented its organization in which it is possible to have a first overview of how this work is organized.

In the second section "2. Concepts & Methods", a description of the concepts and methods used in this evaluation, is made. In this description, the most common methods of the evaluation of resources are identified in subsection "2.1 Available Methods for Resources Assessment". This is followed by a subsection with a description of the method used in this evaluation "2.2 The Emergy Evaluation Method" which is divided into four sub-subsections: "2.2.1 History of the development of the concept of emergy", which describes the evolution in the knowledge of energy and ecosystems that led to the development of the concepts underlying this methodology; "2.2.2 Defining the method" where a more detailed explanation about the way the method is used and applied is given; "2.2.3 Application to general systems" where are described some application fields of this method and the general procedures for its application; and finally the sub-subsection "2.2.4 Application to farming systems" where are described some of the applications of the emergy evaluation method in fields related to farming systems such as cereal production, wine, livestock, dairy farms and agriculture at farm, national and regional scales, among others. The specific procedures adopted in the application of this method in these cases are described generically, since these applications refer to different types of farms and study scales.

Following this second section about concepts & methods is the third section "3. The Portuguese silvo-pasture Montado: system characterization:" where this Montado system is characterized by the aspects considered more relevant for this study. Therein are described aspects of the history of this system from the origin of the Mediterranean climate, to the historical intervention by man and the way the system management is conducted nowadays. Some ecological functions of this system are described as well as the threats that have been putting the system's continuity in question.

The fourth section "4. Empirical Implementation" corresponds to the explanation of how the emergy method was applied to the farm under study. This section is subdivided into three sub-sections that are: "4.1 Characterization of the Holm Oaks Farm" where a characterization of the farm under study is made, with particular emphasis on the features that are of interest to the emergy evaluation; "4.2 The emergy evaluation" with the explanation of how the emergy evaluation method was implemented to the specific case study; and "4.3 The economic evaluation" which describes the way of collecting and the used assumptions in the deduction of the required data for the economic evaluation of farm production system. Since emergy evaluation is the main method discussed in this study it is explained in more detail and, therefore, the subsection 4.2 is still divided in four sub-subsections indicated below: "4.2.1 Determination of the items – raw data, emergy and transformity values" where all the assumptions and calculations carried out for the estimation of the energy, mass or money, related emergy and transformity, associated to each flow or reservoir identified in the farm, were explained; "4.2.2 Determination of renewability factors for the farm items" where all the assumptions and calculations carried out to estimate the renewability factors, were presented; "4.2.3 Co-products" where it was explained how a recurring aspect related with emergy transference accounting throughout the ecosystem, was solved in this particular case study; and finally "4.2.4 Accounting for fuel, machinery and labor on a farm" in which it is explained how some accounting aspects of emergy, linked with the use of machines, working hours and fuels that are used in different activities, were solved for this case study, in a way that allows us to take into account the normal complexity existing in the management of a farm.

Subsection 4.3 also includes an explanation of the determination of the economic values through the use of different resources "4.3.1 Determination of the economic values".

The next section is section five corresponding to "5. Results & Discussion" where the results of the emergy evaluation are presented and the relevant discussion about these results is carried out. This section is divided into three subsections: “5.1 The emergy evaluation of the Holm Oaks Farm”, where the emergy accounting table for the farm is presented as well as the values for the emergy indices resulting from different calculations with the emergy of the items shown in the table. In subsection “5.2 Comparing economic and emergy evaluations” an adaptation was made to allow the comparison between the two evaluation methods. The comparison was made using different methods and new indices.

In its turn subsection 5.1 is divided into two sub-subsections, which correspond to particular aspects of emergy evaluation that had to be solved for this case study: “5.1.1 The different activities of the Holm Oaks Farm” where the different activities are compared against each other and against other farming systems with regard to their contribution to the manager’s income and the impact on the system or the use of resources; and “5.1.2 The renewability of the purchased inputs” where, besides the distinction between renewable and nonrenewable inputs to the farm, renewability factors of the imputs usually considered as nonrenewable , are taken in account. Subsection 5.2 has also three sub-subsections that are “5.2.1 The share of emergy investment and return between the owner and the manager of the Holm Oaks Farm” where the specific situation of a system that has two managers, the owner and the cattle manager, to whom the farm is leased, is addressed; “5.2.2 The bales”, where the actual options for the straw and the straw bales are compared to an alternative hypothetical situation; and “5.2.3 The renewability of purchased inputs and their prices”.

The sixth section, corresponding to the conclusions (“6. Conclusions”), is divided into three subsections where are exposed, more specifically, the findings related to the Montado (“6.1 The Montado”), with the comparison of emergy and economic evaluations (“6.2 Economic versus Emergy evaluations”), and where are also indicated the gaps in current information, and the lines for future research (“6.3 Knowledge gaps and future research paths”).

Section “References” displays the references used throughout this work.

Finally, Appendices” gathers different documents used throughout this work.

2. Concepts & Methods

2.1 Available Methods for Resources Assessment

Agricultural economists use budget and record accounting to evaluate agricultural systems 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 labor can also be evaluated at their opportunity costs, namely based on estimated market value of their alternative allocation (Kramer *et al.*, 2013; Marques, 2012; Naidoo & Iwamura, 2007; Putz, 2000). However, these are often non-tradable goods and services. Hence, agricultural economists find a residual return to these resources all together (Fisher & Kinnard, 2003).

The bio-geophysical system's contribution to economic activities, such as solar energy, rainwater and soil are not accounted for although they constitute factors conditioning agricultural productivity. These resources are appropriated through land property rights and are inadequately or simply not evaluated, representing emternalities of the economic activity (Pillet *et al.*, 2001). Furthermore, the global value of these resources goes beyond use value, including non-use values or its availability and preservation for the future (Dewsbury *et al.*, 2016; Oglethorpe & Miliadou, 2000; Turner *et al.*, 2003). Finally, market evaluation is based on the receiver's utility preferences, whereas natural resources are available at the bio-geophysical system's donor based value (Campbell & Tilley, 2014b).

Throughout the history of the economy several attempts to value bio-geophysical resources were carried out (Ghosh & Mondal, 2013; Kallis *et al.*, 2013; Masiero *et al.*, 2016; Nijkamp *et al.*, 2008; Randall, 2007), so that they could be valued on equal terms with the resources already valued by man.

Some of these attempts have as starting point the neoclassical economics.

MAINSTREAM OR NEOCLASSICAL ECONOMICS makes use of the *market value*, defined by "*what people are willing to pay*" as the main accounting method. The question is that *market value* changes with scarcity/abundance and expected benefits. It is a receiver-type value that, frequently, is not helpful for direct evaluation of natural resources and services (Colander *et al.,* 2009; Slembeck, 1999; Veblen, 1898), namely by responding inversely to the quantity of these resources or services provided. These attempts, whose starting point is the mainstream or neoclassical economics, integrate the group of ENVIRONMENTAL ECONOMICS.

ENVIRONMENTAL ECONOMICS considers the economic system as a subsystem of the ecosystem. This branch of economics puts its emphasis on the evaluation of Natural Capital (van den Bergh, 2001). Despite the attempt to value the resources and services of nature, these methods are focused on the usefulness of these to mankind (receiver-type value) and are valued using money. This creates difficulties in the evaluation of services and goods with no market to serve as a reference (Adolphson, 2004; Cleveland, 1991; Gowdy, 2007; Hall *et al.,* 2001; Hall and Klitgaard, 2006). Some of the methods used in environmental economics are the TRAVEL COST METHOD, the HEDONIC PRICING, the CONTINGENT VALUATION, the VALUATION OF SUBSTITUTION SERVICES, CHOICE MODELLING and COST-BENEFIT ANALYSIS.

TRAVEL COST METHOD is used to estimate economic use values associated with ecosystems or sites that are used for recreation (Hanley, 1995). It is used to estimate the economic benefits or costs resulting from: changes in access costs for a recreational site, elimination of an existing recreational site, addition of a new recreational site, changes in environmental quality at a recreational site. The basic premise of the travel cost method is that the costs incurred by individuals in travelling to the site can be used as a surrogate for prices.

HEDONIC PRICING examines the effect that the environment has on economic decisions through its effect on housing prices or other items, e.g., cars based on their characteristics, location for houses due to the proximity of a natural park or better air quality.

CONTINGENT VALUATION (willingness-to-pay and willingness to accept compensation) is an accounting method where individuals express their preferences by indicating directly or indirectly their willingness to have less of something in order to have more of something else. Individuals can express their willingness to pay for a direct use of something such as a visit to a Natural Park; for an indirect use such as to watch a television program about this Natural Park; to preserve a good or service for future use opportunity (option value) such as botanical biodiversity for future medical use; to preserve a good or service for use by future generations (bequest value) such as the water regulating capacity of the soil; or to preserve something that is considered beneficial even if not used (non-use value) such as polar bears in the Arctic.

The VALUATION OF SUBSTITUTION SERVICES is another method used within the conceptual framework of environmental economics. This method is used to assess the cost that must be incurred in order to: avoid loss or damage to a good or service (Damage Cost Avoided Method); or the cost to replace it with a new one or with a different alternative good or service providing the same benefit when degraded or lost (Replacement Cost Method). All these methods assess the value of goods or services such as pollination, water and nutrient cycling, pollutant dilution, through a comparison with their protection or replacement cost.

COST-BENEFIT ANALYSIS evaluates the net worth of an investment required for the conservation or replacement of a good or service. The aim is to determine if society receives an "economic benefit" from implementing the action.

In this attempt of assess bio-geophysical resources so that they could be valued on equal terms with the resources already valued by man, several biophysical theories of value, based on a broader perspective of the economy, on thermodynamic and ecological principles, have emerged (Cleveland & Ruth, 1997; Farber *et al*., 2002; Gowdy & Mesner, 1998; Hall & Klitgaard, 2006; Liu *et al*., 2010; Patterson, 1998; Pelorosso *et al*., 2016; Sagoff, 2011).

In opposition to environmental economics, wich the lens to evaluate nature is neoclassical economics, ecological economics is included in the wider group of HETERODOX ECONOMICS, alongside with other branches such as socialist, Marxian, institutional, evolutionary, Georgist, Austrian, feminist, social or post-Keynesian economics (Lawson, 2005). In this group of heterodox economics, economists keep their focus on nature, justice and time leading up to issues such as intergenerational equity, the irreversibility of environmental change, and the uncertainty of long-term effects (Faber, 2008).

ECOLOGICAL ECONOMICS refers to an area of transdisciplinary and interdisciplinary research aimed at studying the interdependence and coevolution of human economies and natural ecosystems in space and time (Xepapadeas, 2008). Ecological economists are focused on strong sustainability and reject the idea that natural capital can be replaced with capital of human origin.

ENERGY ACCOUNTING is a methodology that can be integrated also in this broader group of heterodox economics and that is used in energy management systems, where the measurement and analysis of energy consumption is done to improve energy efficiency within an organization (Knox *et al.,* 2000). Some companies use this method to monitor their energy consumption. In this methodology, non-useful work is often considered to be what is responsible for environmental problems.

The BIOPHYSICAL ECONOMICS also integrates this broader group of heterodox economics and is a system of economic analysis based on the biological and physical (in opposition to social) properties, structures and processes of real economic systems (Hall and Klitgaard, 2006). This approach makes clear that resources drive the economy and that for every flow of money there is a flow of energy, emergy or mass flowing in the opposite direction. It is an economics of the donor-type, based on the resources that drive the economy and makes use of measurement units of mass or energy instead of money. Biophysical economists tend to be technological sceptics giving more importance to the precautionary principle. The methods that fit this evaluation system are:

EMBODIED ENERGY ANALYSIS that focuses on the cumulative direct and indirect commercial energy cost of a product in heat equivalents, generally fossil fuels (IFIAS, 1974; Herendeen, 1998). The scale of application is the cascade of processes (in time and space) that lead to a product's creation. This method considers that only fossil fuels can be subject to scarcity whereby all process inputs of material and energy, which do not require the use of fossil fuels or fossil fuels equivalents are not included. Human labor and economic services are considered negligible.

EXERGY ANALYSIS focuses on the appropriate quantification of the ability of resources to supply useful work or to support a further transformation process (Szargut *et al.,* 1988). Its unit of measure is the "Exergy" that is the energy available to do work. This method usually focuses on the local scale of an individual process.

MATERIAL FLOW ACCOUNTING focuses on quantifying the direct and indirect, upstream material cost of a process or an economy and downstream release of degraded matter (Hinterberger & Schmidt-Bleek, 1999; Hinterberger & Stiller, 1998; Schmidt-Bleek, 1993). Its unit of measure is the kg of each material evaluated. This method only focus on what is locally invested or released producing a limited picture of the real process.

LIFE CYCLE ASSESSMENT evaluates the potential impact of a process due to resources use by upstream depletion of resource stocks and downstream damage due to emissions (ISO, 2006 a and b; SETAC, 1993). The unit of measure depends on what is evaluated and the purposes of the evaluation. It does not address economic or social effects.

The EMERGY EVALUATION METHOD focus on the quality of the environmental energies driving natural and human-dominated systems (Odum, 1996). Its unit of measure is the "Solar emjoules" that measures the Emergy, a kind of energy memory (in equivalents of solar energy) that track back the useful energy, with different qualities or power densities, that was spent to produce a good or service. Its scale of evaluation is the biosphere in order to include the processes of resource formation and the short and long scales necessary for the creation of the resource storages. Unlike the other assessment methods representing an anthropocentric (receiver-side) perspective of "value", this method represents a “donor-side” (supply-side) point of view (Brown & Ulgiati, 2004b) where the value of a resource is based on what it takes (time, space, and driving forces) to generate it within the dynamics of the biosphere.

In relation to the methods presented below this is the one that has more deeply committed with an accurate description and evaluation of the systems from the perspective of biogeophysical processes. It focus on a deep understanding of the processes occurring in the systems under evaluation, particularly the transformations that energy undergoes along the trophic chain. It allows the accounting for the losses and concentration processes of the energy in the systems. In this attempt to represent what really happens in nature, it takes into strong consideration the principles of thermodynamics that govern the physical processes. The estimations about the energy available and the emergy are based on the equations that represent the physical and chemical processes. The emergy evaluation has, therefore, been proposed as a way of assessing the contribution of the free flows of the bio-geophysical system to economic products (Cavalett & Ortega, 2009; Chen *et al*., 2014; Cuadra & Rydberg, 2006; Fonseca *et al*., 2016; Ghisellini *et al*., 2014; Odum, 1983; Saladini *et al*., 2016). On the other hand, with this emergy evaluation method it is possible to value on the same basis, both the components from the markets required for the production of outputs (e.g. fuels, labor, and purchased inputs) and the components which normally are not accounted for in the economic evaluation (Pillet *et al*., 2001). These are the reasons under the choice of the emergy evaluation method to study calves production in the Montado system.

2.2 The Emergy Evaluation Method

2.2.1 History of the development of the concept of emergy

After the findings on thermodynamics by Nicolas Carnot (1824 in Raine *et al*., 2006), Rudolf Clausius (1867) and Lord Kelvin (Thomson, 1851), various branches of this theory were applied to other areas of human development beyond the industrial. Natural selection was described, in 1875, by Boltzmann (1974) as the struggle among organisms for available energy.

> *"The general struggle for existence of animate beings is not a struggle for raw materials – these, for organisms, are air, water and soil, all abundantly available – nor for energy which exists in plenty in any body in the form of heat, but a struggle for [negative] entropy, which becomes available through the transition of energy from the hot sun to the cold earth."*

Alfred Lotka translated the principles of thermodynamics to biological sciences developing an energetic perspective of evolution (Lotka, 1922a). He extended, also, his energetic framework to human society suggesting that the dependence of humanity of nonrenewable energy sources could lead to unique and key challenges to society (Lotka, 1922b). These theories made Lotka an important forerunner to the development of biophysical economics and ecological economics, developed later by Frederick Soddy (1926), Howard Odum (1996, 2007), Nicholas Georgescu-Roegen (1971 in Georgescu-Roegen, 2012) and others.

Nicholas Georgescu-Roegen, enriched ecological economics with a new conceptual approach to production/consumption flows based on material and energy fluxes (Georgescu-Roegen, 1971).

Howard T. Odum was strongly inspired by Lotka's theories on the energetics of evolution and developed an Energy Circuit Language or "Energese" (Odum, 1971), extending the dynamical analogies between electrical, mechanical, acoustical, magnetic and electronic systems, to include ecological systems (Olson, 1958). He developed a general systems theory, Energy Systems Theory (Odum, 1983; 1994) and an Energy Systems Language (ESL) with which he represented natural and human-dominated systems along with their interfaces. In the evaluation of human systems, Odum extended this assessment to the economic system, making use of the same unit of measurement used to assess natural systems (solar emjoules or sej). He 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 up, directly or indirectly, to make a service or product (Amaral *et al*., 2016; Brown & Ulgiati, 2004a; Campbell, 2016; Odum, 1996). Instead of money, emergy analysis uses solar energy as an alternative common denominator (Odum, 1996).

2.2.2 Defining the method

Emergy Evaluation (Odum, 1996) is a method that takes a systems approach through the study of how available energy flows through systems. It recognizes that the Earth is subjected to three main sources of available energy: solar, tidal and internal Earth energy and that these primary energy inflows combine to create a diverse array of secondary flows, e.g., the wind, rain, tides, tectonics, that the ecosystems use in different proportions. Available energy is commonly defined as the ability of a system to perform work and it is a premise of Energy Systems Theory, EST (Odum, 1983; 1994) that the available energy captured by a system determines the amount of structure that can exist within it and the speed at which processes can function (Odum, 1983; 1994). The term “emergy” is used to mean “energy memory” of one type required to make another type of energy with higher capacity to do work. Actually, the dispersed solar energy annually received by the Earth is the main energy souce considered with this purpose, whereby its unit is the solar emjoule, sej (Odum, 1996). When evaluating a system, the emergy evaluator starts by converting all the inputs, outputs, flows through the system and storages of energy, materials, money, labor or information to this common basis, expressing them all in emjoules of solar energy that is required to produce each of them, that corresponds to the solar emergy of the items (Odum, 1996). For some years it was used the term *embodied energy*, but the confusion with other evaluation methods lead to the creation of the emergy word (Odum, 2002). In the process of operating an entire ecosystem, much of the available energy dissipates, but the remaining available energy tends to concentrate and feeds back to promote more complex work. In each successive step of a trophic chain, or a chain of processes, the energy tends to concentrate, a characteristic which is called, in the emergy evaluation method, Transformity (Figure 1). It can be said that the transformity grows within the ecosystem creating a hierarchy of energy. In this context, Solar Transformity is the solar emergy required to make one joule of a service or product. A product’s solar transformity is its solar emergy divided by its available energy (Odum, 1996). Its units are solar emjoule per joule (sej J^{-1}) if dealing with energy. But it is also possible to find transformity values to materials and money, and then the designation used is specific emergy (sej/g) if dealing with materials, or emergy to money ratio

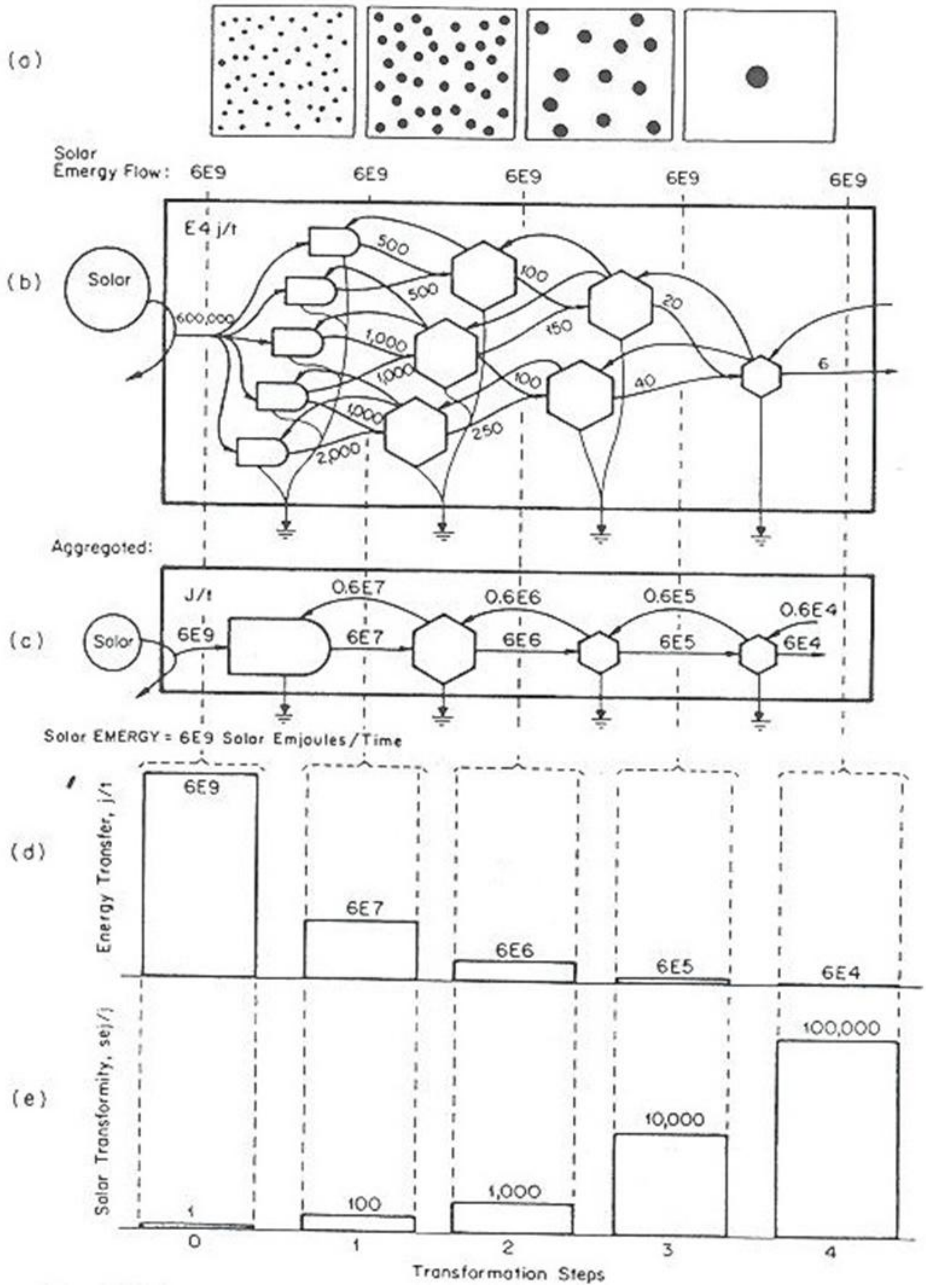


Figure 1 – Energy transformation hierarchy. (a) Spatial view of units and their territories. (b) Energy network including transformation and feedbacks. (c) Aggregation of energy networks into an energy chain. (d) Bar graph of the energy flows for the levels in energy hierarchy. (e) Bar graph of solar transformities. Adapted from Odum (1996).

(sej/$) if dealing with money. To designate these values in general the more generic Unity Emergy Value (UEV) is used representing the solar emergy required to make one joule, gram or dollar, of a specific service or product.
This chain of transformations leading to energy dissipation and transformity growth, generates a universal hierarchy of the ability to perform work which can be seem in, for instance, the solar energy, the energy contained in a pasture, a beef and a farmer's labor. This energy hierarchy can be observerved also between solar energy, charcoal, coal, petroleum, electricity. In both cases some processes lead to the concentration of the energy and this is the reason why it is possible do a lot of different and sophisticated things with 1000 J of electricity (as make a computer work) but not with 1000 J of coal.

Since the emergy evaluation method focus on energy flows and storages, while applying it, a set of rules governing energy must always be present - the thermodynamic laws. Remembering, these rules are:

First law – The energy can neither be created nor destroyed. In any process the total energy output is equal to the heat supplied to the system minus the change in the internal energy of the system.

Second law – Energy exhibits entropy and, in the real world, some energy always escapes, leading to inefficiency.

Third law – Says that all the processes cease as temperature approaches absolute zero. This is the temperature at which molecules cease movement, cease producing kinetic energy. In other words, with absolute zero temperature there is no energy.

Odum has established another principle of thermodynamics, which was the maximum power principle (Odum, 1995) stated as - during self-organization, system designs that develop and prevail are the ones that maximize power intake, energy transformation, and those uses that reinforce production and efficiency (Figure 2). This has been proposed as the fourth principle of energetics in open system thermodynamics.

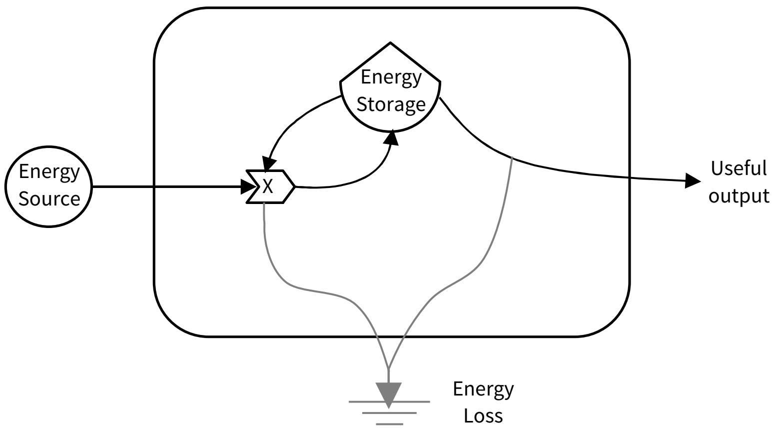


Figure 2 – The maximum power principle in ESL (Adapted from Odum and Odum 2000).

2.2.3 Application to general systems

ESL (Odum, 1983; 1994) was used for the construction of all diagrams in this study (Figure 3). In this language each symbol has a particular meaning and a mathematical translation that can be used in a broader sense to characterize and simulate very different systems (Odum and Odum, 2000).

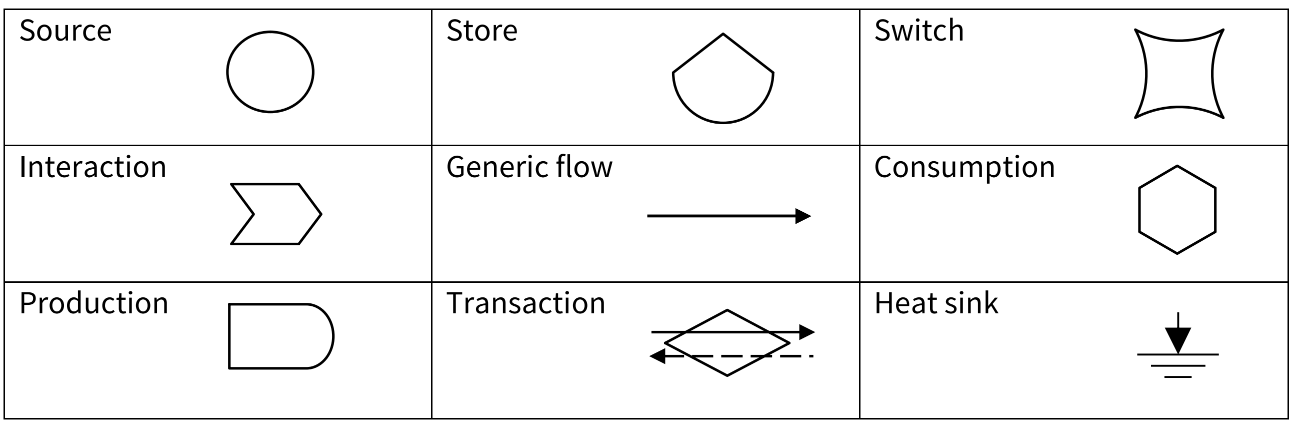
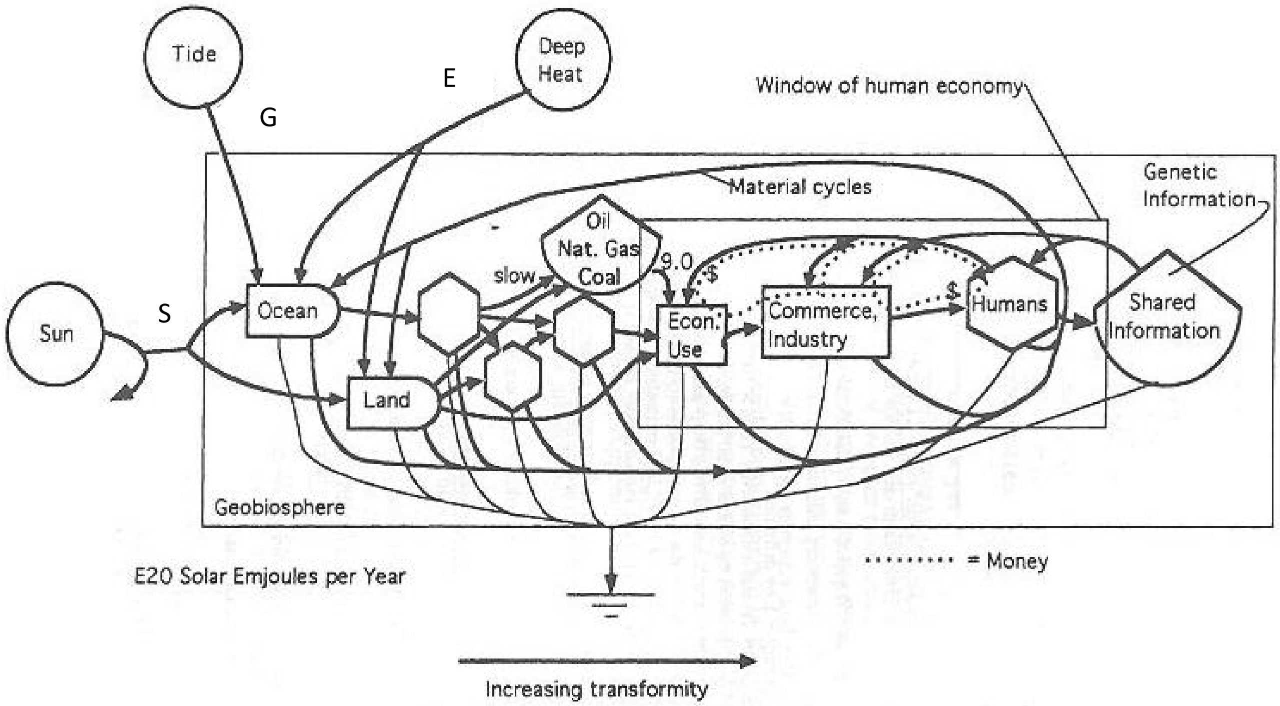


Figure 3 – Energy Systems Language (Odum 1983, 1994) used in the construction of all diagrams of this study.

The emergy baseline for the Earth is used for the determination of the transformities of the products of all planetary processes. The emergy baseline of the Earth depends on the equivalences established between the independent sources of available energy (solar radiation (S), deep Earth heat (E) and the gravitational attraction of the moon and sun (G)) received by the Earth, when considered in a system of two equations and two unknowns, used to determine that value of the planetary emergy baseline (Campbell, 2000) (Figure 4).



Total global emergy flow - 1.2E+25 sej y^{-1} (Campbell, 2016)

Figure 4 – Independent sources of available energy (solar radiation, S, deep Earth heat, E, and the gravitational attraction of the moon and sun, G) received by the Earth. Adapted from Odum (2007).

The three independent sources, S, E, and G, can be used in different combinations to determine the equivalence between them through evaluating processes in which each source creates a similar product (e.g., the baseline used in this paper is found when both the solar energy and gravitational attraction of the moon and sun contribute to creating the geopotential energy of the world oceans and both solar energy driving erosion and the deep heat flow from the Earth contribute to geotectonic processes). Recently, the planetary baseline has been updated according to new considerations of past values used in the calculations and evolution in knowledge about Earth's geophysics and the manner in which these energy sources interact (Campbell, 2016).

However, it is possible to directly compare the values of the emergy indices obtained in studies with different baselines by multiplying the transformities by the respective conversion factors and then recalculating the results.

The emergy evaluation method has been used at several scales as the universal (Brown *et al.,* 2004), the planetary scale (Brown & Ulgiati, 1999; Campbell, 2000; 2003; 2016; Sweeney *et al*., 2007), ecosystems scale (Campbell & Tilley, 2014a), at states and countries scales (Campbell *et al.,* 2005; Campbell & Ohrt, 2009; Ulgiati *et al.,* 1994), at farm scale (Agostinho *et al*., 2004; 2008; Cavalett & Ortega, 2009; Cuadra & Rydberg, 2006; Diemont *et al.,* 2006; Fonseca *et al.,* 2016; Ghisellini *et al*., 2014; Jaklič *et al.,* 2014; Lefroy & Rydberg, 2003; Liu *et al.*, 2004; Wright & Østergård, 2015) and at the scale of the life cycle of individuals (Odum, 2007, pp.228) and even the scale of chemical processes (Odum, 1983).

It also has been applied to different types of processes namely, erosion (Cohen *et al*., 2006), mineral cycles (De Vilbiss & Brown, 2015), formal education at country (Campbell & Lu, 2014) and school level (Fonseca *et al*., 2014), building materials (Buranakarn, 1998), resources (Buenfil, 2001), economies (Oliveira *et al.,* 2013); livestock production (Rótolo *et al*., 2007), information production, reproduction and communication (Abel, 2012; Odum, 2007).

The energy systems language diagram at earth scale is presented in figure 4. Figure 5 presents the ESL diagram in a Pine Plantation, at ecossistem scale.

In these two ESL diagrams (Figures 4 and 5), several symbols appear repeatedly (Figure 3). The energy sources to the system at study are presented from left to right, over the box that defines the boundaries of the system, in ascending order of transformity. Thus, to the more diffuse energy sources such as "Solar radiation" and "Rain", other more concentrated sources follows, as "Fuels", "Phosphates" and "Machinery", and finally these sources, such as goods, services, governance mechanisms, taxation, and the economy, providing from the more humanized systems. The ones with higher transformity correspond to a feedback or investment in the system, by man, in order to maximize the power, outputs or emergy that cames from it, for their own benefit, and according to the maximum power principle aforementioned.

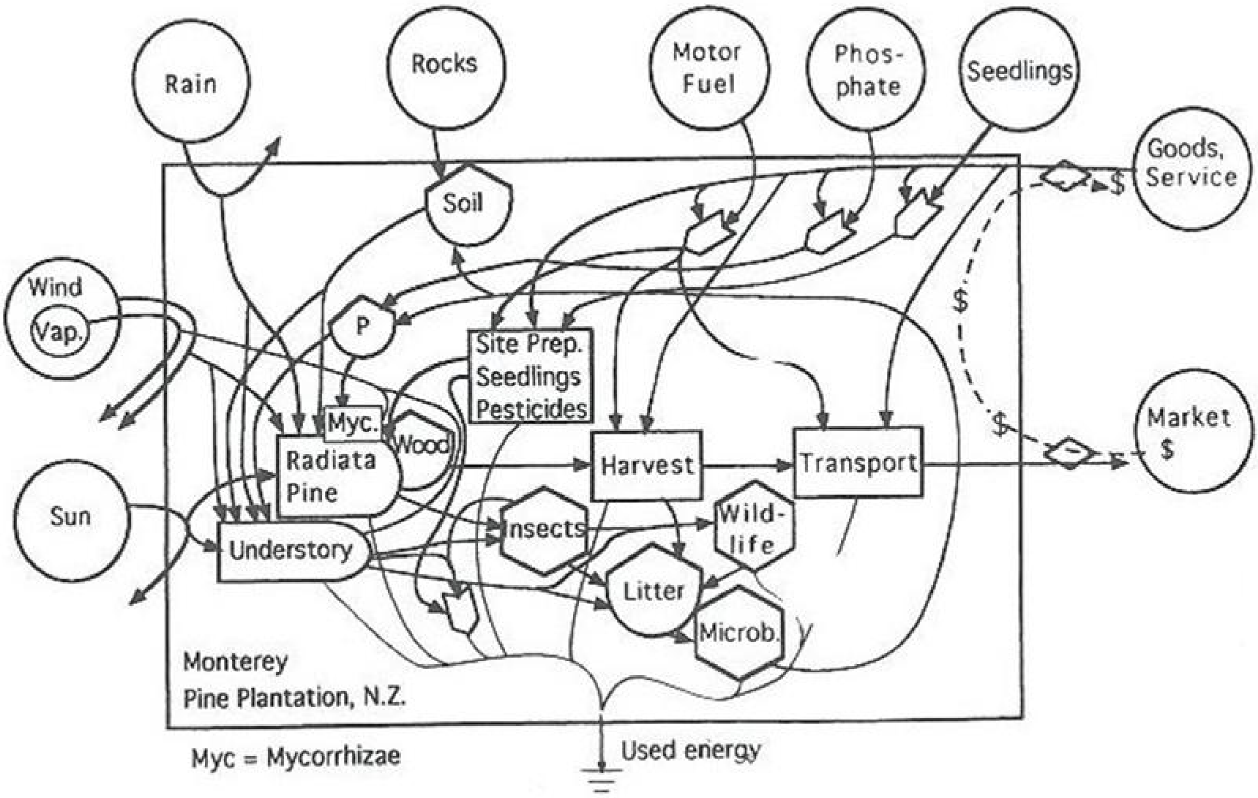


Figure 5 – ESL diagram for a Pine Plantation Adapted from Odum (2007).

Inside the box representing the systems boundary, the several symbols are presented also from left to right by growing transformity. The first components are the ones responsible for capturing the dispersed energy from solar radiation, usually through the process of photosynthesis. The corresponding symbols have a bullet shape, even if they do not correspond to producers, and can represent trees, grass, phytoplankton, solar collectors and windmills, among others. These system components carry out a first process of concentrating the disperse energy available. After this first processing level, the energy will exist in a more concentrated form, stored in the carbon bonds of the constituent materials of plants or in the charge of a battery. In the process, some energy was lost only to maintain the structure, in methabolic work of the plants or maintenance work of solar collectors, in addition to some losses in the form of heat. These losses, presented in each step of the system and corresponding to the above mentioned second law of thermodynamics, are represented by the symbol of heat sink or used energy in the lower part of the scheme and leaving out the system. After these first components, the consumers are represented by the hexagonal symbol, and they can be primary or secondary consumers or be located higher up in the food chain. What these consumers do is to use the stored energy in the materials consumed from the previous trophic levels and use it for maintenance of its own metabolism and structure. Again this will cause the loss of some of this energy as heat, but the end result will correspond to materials with more concentrated energy or with a higher ability to work. Miscellaneous boxes correspond to processes that are not described and usualy are important subsystems. The symbol representing a tank appears frequently and may correspond to groundwater, the content in soil organic matter, bales, charge in batteries, carrots in a grocery. The interaction symbol represents the conjugation between two forces to generate a productive output as the use of a pump to extract water, or the weight of the cattle over the soil causing its compaction.

If the economic system is also under analysis, the exchanges will be represented by a diamond-shaped symbol with an arrow representing the product that is being exchanged. If it is exchanged by another product or service a countercurrent arrow, below the first one, will represent the product or service. If it is a money exchange, it will be represented by a dashed pathway (Figure 6).

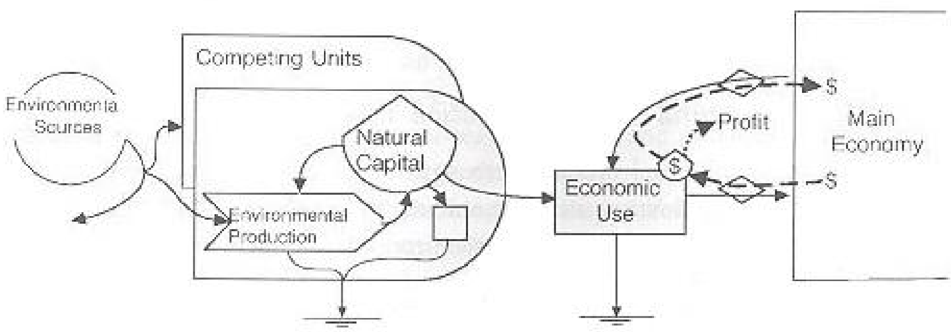


Figure 6 – Systems diagram of the economic use of environmental products. Adapted from Odum (2007).

To each symbol presented before corresponds a value or a function that explains how much emergy is available to the system at study and which kind of processes occur on it.

The emergy accounting method is implemented in a three-phase process: designing and evaluating a diagram that represents the reality under study, using the ESL descrived above, computing emergy into a table and determining and analyzing indices (Campbell & Ohrt, 2009; Odum, 1996).

In the first step, the boundaries are defined as the inputs and outputs to the system. Included in these inputs are the renewable and nonrenewable resources available in the farm contributing for the productive process under analysis, and the resources provided by the economic system (purchased inputs), generally regarded as nonrenewable, and finally the services. With the diagram it can be easily depicted which flows are and which are not accounted for in the economic evaluation. This diagram can be summarized in an aggregate ESL diagram, as in the one presented in Figure 7, for a clearer evaluation of the kind of inputs and flows existing on it.

Between them it is possible to identify purchased resources and services (F) that come from outside the system and can be valued by a pricing scheme and through emergy estimation. Renewable and non-renweable resourses are also identified and distinguished. If they come from the local environment they are free resources to which is difficult to give a price but that are evaluated through emergy estimation.

Emergy evaluation is done in an aggregate emergy table format, as the one presented in Figure 8, which can be used in the calculation of indices. Rows are organized according to broad categories of local renewable inputs (R) and local nonrenewable inputs (N) and purchased goods and services (F). In the columns are exhibited the raw units of each item and its transformity, the item's emergy, and sometimes, the emdollar value. Emergy and transformity values with and without services are presented, because the calculation of services is more variable, sometimes from country to country. Often the emergy of each item is presented without services and so these values can be used in different contexts. A column with the "references" used as the source for transformity values is also presented, in order to allow its verification, update the baseline, or use another value, if necessary.

For each item and column is presented real data for the case study and the chosen period.

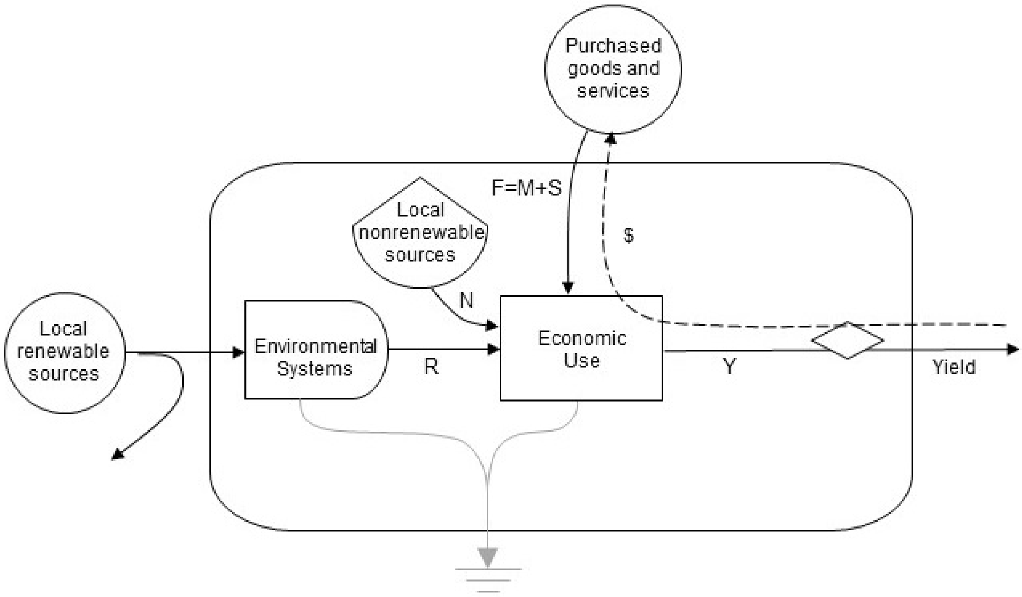


Figure 7 - Aggregate Energy Systems Language diagram describes a process based on renewable inputs received in the system (R), local nonrenewable inputs (N) and inputs purchased from outside (F) that include goods (M) and services and labor (S). Symbols: energy source (circle), environmental production system (bullet-shape), storage (tank), lines with arrowheads (pathways carrying energy, material, or information), rectangle (general purpose symbol, in this case economic use) and heat sink (arrow to ground). Source: (Brown & Ulgiati, 1997; Odum, 1996, p. 83).

Items	Raw data (Unit y^{-1})	Units	UEV (sej $unit^{-1}$)	Emergy (sej y^{-1})	%	UEV (sej $unit^{-1}$)	Emergy (sej y^{-1})	Reference for UEV
Renewable inputs (R)			(with services included)			(without services)		
1 Solar radiation								
2								
Sum all renewable inputs								
Nonrenewable inputs from within the system (N)								
11								
Sum free inputs (I=R+N)								
Purchased Inputs (F)								
Total purchased materials from economy (M)								
Labor and services (S)								
Feed back from Economy (F=M+S)								
Y = R+N+M+S								
Output (Y)								
Total of outputs								

Figure 8 – Overall structure of an emergy accounting table.

Indices or ratios between different components provide relevant indicators in terms of the contributions of different types of inputs and about the sustainability of the system. Formulas use aggregated components from the emergy accounting table. Table 1 summarizes the main emergy indices and corresponding formulas used in emergy evaluation.

Table 1 - Main emergy indices and formulas used in emergy evaluation. (R) renewable inputs received by the systems, (Y) total of the inputs used, (F) purchased goods (M) and services (S) used in the system and that include labor, (N) local nonrenewable inputs; (I) free inputs to the system corresponding to the sum of the renewable inputs plus the local nonrenewable inputs received by the system (I=R+N).

Emergy Indices		Formulas
Transformity (Tr)	The ratio between the emergy of the output divided by the available energy of the products. It is an indicator of the efficiency of the production process for an item and of the quality of the products (Lu *et al*. 2006)	Y/E
Renewability (%R)	Indicates the percent of the total energy driving a process or system that is derived from renewable sources (Diemont *et al*., 2006). It represents a first measure of system sustainability. The lower the fraction of renewables used, the higher the pressure on the environment. In the long run, only processes with high values of this index are sustainable.	R/Y
Emergy Yield Ratio (EYR)	Is a measure of the net contribution of a process to the economy beyond what is required for its own operation (Odum, 1996).	Y/F
Emergy Investment Ratio (EIR)	Is the ratio of emergy fed back from outside the system to the indigenous emergy input (both renewable and nonrenewable) or the ratio of purchased to free emergy (Brown & Ulgiati, 1997). It gives an evaluation of whether the process is a competitive user of the emergy that is invested in comparison with alternatives (Brown & Ulgiati, 2004a), being often used as an indicator of the competitiveness of an economic investment in the process area or region.	F/(R+N)
Environmental Loading Ratio (ELR)	Is the ratio of nonrenewable and imported emergy to the renewable emergy used. It can be considered as a measure of potential ecosystem stress due to production activity (Brown & Ulgiati, 1997).	(F+N)/R
Emergy Sustainability Index (ESI)	Is the ratio of the emergy yield ratio to the environmental loading ratio. It measures the potential beneficial contribution of a process to the economy per unit of environmental loading generated by the process (Ulgiati & Brown, 1998).	EYR/ELR

At the end of the evaluation it is possible to have an idea of how the system used the available emergy, with greater or lesser efficiency, the degree of dependence on renewable and nonrenewable emergy, if the human investment in a particular natural system is rewarding compared to other types of investment, among other considerations.

2.2.4 Application to farming systems

The recognition of the importance of the energy on farming production processes resulted directly from the "energy crisis" of the early 1970s. The OPEC oil embargo of 1973 resulted in a large number of studies on the use of energy in food production and criticism about the inefficiency of its use (Fritsch et al., 1975; Hirst, 1974; Pierotti et al., 1977; Pimentel et al., 1979; Rawitscher & Mayer, 1979; Steinhart & Steinhart, 1974; Van Arsdall & Devlin, 1978). In the decades following the end of the Second World War, the agricultural system, overall, in developed countries had been completely redesigned through numerous inputs of synthetic pesticides, inorganic fertilizers, extra irrigation, and heavy, powerful and sophisticated machinery, under the Green Revolution, with large productivity gains. However, all these new technologies were highly dependent on the availability of cheap fossil fuels. Both at the farm, but also at the distribution and consumption levels, the food chain had become increasingly dependent on cheap fossil fuels with food items coming from increasingly long distances, with the corresponding cooling chain that allows food to support long distances and long periods of time until they are distributed to end consumers, but which is also highly dependent on high energy costs. The growing use of the airplane for food transportation and the availability of all kinds of food items out of their production season are practices that also lead to high energy consumption since aircraft use much more energy than transport by land or sea and because the production of fruits and vegetables out of season, is made possible by means of heat that requires energy or transportation from distant areas of the globe (Paxton, 1994).

Fossil fuels, including oil, coal and natural gas, are almost nonrenewable energy resources with a big impact on the biosphere and whose reserves are gradually reducing worldwide.

Some methods were developed to evaluate the energy expenditure of the agricultural systems, already exposed on section “1.1 Available Methods for Resources Assessment”.

The evaluation of farming systems is an area of study by excellence for application of the emergy evaluation method. It has resulted, already, in a significant number of publish works about the theme. Thus emergy methods have been used to evaluate and analyze farming systems in Australia (Lefroy & Rydberg, 2003), Mexico (Diemont *et al.,* 2006), China (Liu *et al.,* 2004), Argentina (Rótolo *et al.,* 2007), Brasil (Agostinho *et al*., 2004; 2008; Cavalett & Ortega, 2009), Nicaragua (Cuadra & Rydberg, 2006) and Portugal (Fonseca *et al*., 2016) between other countries.

Agostinho *et al.* (2008, 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 Chianty 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 Cavallet & Ortega (2009) that focus on soybean production in Brasil, Cuadra & Rydberg (2006) that studied the coffee production in Nicaragua. Other studies focus on livestock systems as Jaklič *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 Autralia while Liu *et al.* (2004) focus on grain production systems in two different provinces of China.
When focused on agricultural systems, the emergy evaluators assess the energy flows through the system, inventorying energy inputs and outputs, and the different transformations that energy suffers within the system by performing work. The corresponding emergy values are also accounted and some indices determined as a way to evaluate the system’s performance and to compare with other systems (Odum, 1996). Between the inputs to the farming systems, emergy evaluators usually take into account the kinetic energy of the wind, the geopotential energy of

the rain, the chemical potential of the rain, the evapotranspiration, the trees' or crops' biomass, the eroded topsoil, but also the human flows as the fertilizers, machinery, fuels, seeds, fences, medication, and services that may include contracted or owner's labor, subsidies, taxes and a land use permit (the rent) if the land is leased. However, in relation to the rent, we will consider, in this work, that it serves as a payment for the manager to access the set of free inputs of the farm. Thus, if the rent was accounted, together with these free inputs, a double counting will ocurr. So, throughout this work, the emergy linked to the rent will not be accounted, or it will be accounted just as a way to economically evaluate these free inputs.

The outputs of the farm or the process under analysis are usually also evaluated.

3. The Portuguese silvo-pasture Montado: system characterization

Montado is a traditional silvo-pastoral system that can be found in the Iberian Peninsula and North of Africa in a total area that covers 3.5 – 4.0 Mha of this territory (Olea & San Miguel-Ayanz, 2006). In Portugal it occupies all area south of the Tagus River being dominant in the Alentejo region. It is similar to the "dehesa", which in Spain is distributed by the southwest region (Bernaldez, 1991; Joffre *et al.,* 1988; Joffre *et al.,* 1991).

This is a system build up by man intervention on the original Mediterranean oaks forest. This oak forest developed since 3 M years ago (Late Pliocene) with the closure of the Isthmus of Panama and the corresponding change of the Atlantic currents (Bingre & Damasceno, 2007; Di Castri 1991). The Mediterranean climate arose thereafter in 4% of the planet surface (Walter, 1973) in five regions (parts of the Mediterranean Basin, central Chile, California, southern Africa and southern and southwestern Australia) between parallels 30° and 40° North and South, exhibiting a pattern of hot, dry summers and cold and humid winters (Di Castri, 1991).

Vegetation is dominated by woody shrubs with evergreen leaves that are small, stiff and sticky (sclerophyllous). Small trees can be present in different proportions as well as an understory of annuals and herbaceous perennials. This original vegetation usually called "chaparral" in California and Portugal, "matorral" in Chile and Spain, "maquis" in France, "heath" or "mallee" in Australia, "fynbos" in South Africa (Di Castri, 1981) was subject to different intervention processes by the human communities (Di Castri & Mooney, 2012).

In Portugal, the "chaparral" was composed of cork oaks (*Quercus suber*) and holm oaks (*Quercus rotundifolia*) and other oaks (as *Quercus faginea*), mixed with olive trees (*Olea*), mastic (*Pistacia*) and *Phillyrea* since the Late Pliocene to which are added the *Pinus* in the Pleistocene (1.8 M years), and shrubs of the genus *Erica*, *Genista*, *Cytisus*, *Cistus* and *Ulex,* in the Holocene (since 13.000 years) (Bingre & Damasceno, 2007).

Despite the presence of hominids in the Iberian Peninsula since about 1.2 million years ago (Garcia *et al.,* 2011), only during the Neolithic Revolution, about 8000 years ago, the man has begun to grub the Mediterranean forest of oaks to begin practicing a burned based itinerant agriculture. The traces of erosion caused by man's use of fire as a technique for obtaining pastures and hunting and the introduction of new species such as the vine and some domesticated cereal are visible from 6500 years ago, accompanied by a progressive deforestation (Mateus & Queiroz, 1993). With its continuity, this intervention has caused an intense deforestation in the landscape, which was evident for about 3000-1500 years ago. But at this time also occurred the expansion of agricultural areas and meadows created by man, accompanied by a selective clearing with protection of the cork oak and wild olive tree (Mateus & Queiroz, 1993) leading to the creation of the first Montado systems.

The first written references to this system, where the name “Montado” appears clearly, is the Visigoth code in the seventh century, that prohibited the cutting of cork oaks and holm oaks and stipulated penalties for those who cause damage to the Montados (Barros, 1950). But throughout the Portugal history several protection laws for the Montados appear in “forais” and numerous postures regulating the activities that were developed there (Fonseca, 2004).

The transhumance has been, for a long time, strongly associated with the Montado prior to agriculture itself, when the nomadic prehistoric communities accompanied the migrations of wild herds (Ceresuela, 1998). This reached its maximum between the fifteenth and seventeenth centuries and it was so important for the Montado creation that even the term Montado has its origin on a fee that was charged to livestock coming from outside to feed of grasslands (Fonseca, 2004).

The way in which the Montado were managed, before the appearance of agricultural machinery, was through the "roças" where the scrubland (which were called often as manure or dung) were burned with a regularity of 5-8 years. Over the ashes it was usual to sown wheat, barley or rye, as the soil was more or less rich in organic matter and the climate was more or less cold. This management practice was alternated with cattle grazing allowing the delay of shrubs development and was the reason for frequent references to the practice of hitting the holm oaks with sticks, during the period of acorn production (Fonseca, 2004). Cork was harvested on May/June months since at least the VII century. Due to frequent wars and two major plague outbreaks in the fourteenth and seventeenth centuries, only in the eighteenth century Montado started to occupy most of the Alentejo region.

Populations have always developed, throughout history, multiple activities on this ecosystem. The scrubland were used as firewood, to feed the animals and fertilize the soil with their ashes after burned, on which were later sown cereals and obtained pastures for cattle. But these scrublands were also used to create bees from which honey and wax was obtained, different game species, aromatics and medicinal plants that, before the development of modern medicine, played an important role (Fonseca, 2004). From these shrubs areas the populations still collected wild fruits as the fruits of the strawberry tree, wild plums and pears, asparagus, mushrooms, among others (Pinto-Correia & Fonseca, 2009). From the trees, acorns were used to feed animals and people, the foliage was also used to supplement animal feed and some wood was extracted to be used for charcoal or to be burn directly as a way to heat houses. The latter use has been responsible for the destruction of vast areas of Montado, particularly in the Serpa region (Fonseca, 2004). The wood was also used for multiple purposes including for the construction of ships and caravels in the period of the Portuguese discoveries and as fuel to bake the biscuit that was going in the same long trips. The cork was used as bricks to build houses, to make furniture, floats and seals. There are records of their export by boat to England since the fourteenth century. Pastures were used to sow grains of different qualities according to the types of soil and climate, usually to make bread, to create pastures for livestock and even draft horses and cattle. Since the Midle Ages it was a tradition that groups of workers from the north of the country come to the Alentejo for the harvests and still today, the houses of the farms have the "home of people" on which these workers ate and slept. The owners of the holdings were mostly absentee owners living in cities (Fonseca, 2004).

Currently, the management of the Montado was modified on certain points. The use of agricultural machinery increasingly powerful, first pulled by working animals (until the sixties of the last century) and after this period by means of combustion engines, has caused that the shrub control passed to be done through their utilization, by tillage (Canteiro *et al.*, 2011;

Santana *et al.*, 2011). By this way more area was cleared and the process of destruction of the trees was accelerated the by destruction of the soil (Ferreira, 2001; Ribeiro *et al*., 2004) and of the protective mycorrhizal network. On the other hand the use of fire as a means of controlling shrubs stopped completely and Montado is today, one of the ecosystems where it is observed a lower number of forest fires comparing to the number of fires occurring in pine and eucalyptus forests (Barros & Pereira, 2014; Guiomar *et al*., 2015; Moreira *et al*., 2009; Silva *et al*., 2009). Coinciding with the rise of mechanized harvesters in Alentejo and, due to lack of human work that resulted from it, among people coming from the north, an important emigration movement occurred between these populations (Brettell, 2014). The transhumance virtually disappeared in Portuguese Montado, homesteads are nearly all surrounded by fences so herds are almost never accompanied by a shepherd since the danger of the livestock escape is very small. The use of acorns for human feed has been reduced to a curiosity although the several and more recent attempts to reintroduce this element in the local cuisine. The cork is not anymore used to make bricks for construction, once it is more valued and used in more sophisticated applications. Medicinal plants harvesting and beekeeping are now minor activities with the advent of the medicine and the cheap sugar importation.

Hunting, the management of pastures to raise livestock, the cork, and the use of some wood for charcoal, are activities that maintained their importance in the region and, although some simplification on the way of the system is exploited, it keeps its overall structure.

Based on what has been described before it is possible to say that the Montado is a system that results from a transformation of the original oak forest by reducing trees density and by the management of shrubs in order to get pastures for livestock grazing, cork, wood for charcoal and even hunt. Its natural regeneration is done letting the bushes grow in certain parcels until it reaches the knee height. Then, the saplings and young trees are marked with a colored ribbon and shrubs are cut without affect the first ones. This parcels, where the bushes are left grow, are the ones that provide shelter for many game species and are responsible for an important resource for the ones that exploit it. These areas with shrubs are also included in the Montado, once they make part of the join management that the farmer makes of the trees and of the resources that he can get from the system, being critical for its regeneration. In this way, the land use corresponding to the Montado not always coincides with the land cover, because an area that may appear abandoned can be part of a deliberate management process to promote trees regeneration and increase hunting.

As a result of human intervention Montado acquires today a structure where different levels may be present depending on the type of management promoted. The forest stand has a park structure composed by an open tree stratum in different densities that can vary between an almost closed canopies area to about 10 trees per hectare. The tree stratum is dominated by holm oaks (*Quercus rotundifolia*) or cork oaks (*Quercus suber*), both in pure and in mixed stands, which may be accompanied by other oaks as *Quercus pyrenaica*, *Q. broteroi*, in some specific areas. On the understory these systems exhibits one or two vegetation levels. The schrub layer develops in certain parcels, stony areas or steep slopes and may be composed by high shrubs as *Quercus coccifera*, *Arbutus unedo*, *Viburnum tinus*, *Myrtus communis*, *Rhamnus alaternus*, *Phillyrea angustifolia*, medium shrubs as *Quercus lusitanica*, *Cistus ladanifer*, *C. populifolius*, *C. monspeliensis, Ulex* sp., *Erica arborea* and *E. australis*, *Calicotome villosa*, and finally low shrubs as *Asparagus* sp., *Cistus salvifolius*, *C. crispus*, *Halimium* sp., *Genista tridentata*, between other species (Canteiro *et al.,* 2011). The pastures' layer can be composed by natural or improved pastures (Pinto-Correia *et al.,* 2011b). The most representative perennial species in terms of biomass produced in natural grasslands are *Poa bulbosa*, *Trifolium subterraneum*, other *Trifolium* sp., *Parentucellia latifolia*, *Bellis annua* and *B. sylvestris*, *Erodium botrys*, *Gynandriris sisyrynchium*, *Leontodon tuberosus*, among others. Between the annuals is possible to found species like *Ornithopus* sp., *Astragalus* sp., *Vicia* sp. These *Poa bulbosa* pastures adapted, over time, to regular and moderate grazing by sheep with appropriate stocking rates. When these pastures are not grazed or are grazed at lower stocking rates it is possible to see the development of secondary communities corresponding to the successional recovery steps of the forest with *Ulex* sp., *Cistus* sp., *Genista* sp. development between other species. But if the stocking rates are higher, the pasture enriches itself with nitrophilous species as *Onopordenea acanthi* or Polygonum sp. (ICNB, s.d.)

In addition to these characteristics, the Montado shows a wide diversity of typologies according soil, climate and topography conditions (Godinho *et al*., 2014 a, and 2014 b). The Montado can be found on the many different types of soils, from the sandy and deeper soils to the schists of incipient soils, as well as it may be located in slopes or in low areas. Further, it is found on the more dry and extreme weather of the inland areas, where winters are colder and summers warmer and moisture is lower than in the coastal areas, and it is also found closer to the coast where the influence of the ocean is stronger and the Mediterranean type climate is less extreme, here, often in mixed stands with pine trees. In the more dry areas with clay soils, the holm oak is better suited, in the more humid areas with well-drained sandy soils, mostly cork oak is found. Climate and soil conditions have also influence over the annual growth rates of the trees, and over the cork and acorn production (Paulo *et al.*, 2014).

The changes taking place in the Montado distribution have shown so far to be related with the variability in the natural biophysical conditions, but management along time also have high relevance for these changes (Almeida *et al*., 2016; Ferreira, 2001; Fonseca, 2004; Godinho *et al*., 2014a, 2014b).

Besides the multi-activities aforementioned, the Montado system plays a diverse range of functions that fall within the scope of ecosystem services and include biodiversity conservation, the preservation of soil quality, and the regulation of the hydrological cycle, among others (Aronson *et al.,* 2009; Coelho *et al.,* 2012; Godinho *et al.,* 2011; Plieninger, 2007; Pulido *et al.,* 2001), landscape preservation (Pinto-Correia *et al.,* 2011a; Surová *et al.,* 2011, 2014), and recreational services, such as ecotourism (Bugalho *et al.,* 2009; Coelho & Campos, 2009; Joffre *et al.,* 1999; Sá-Sousa, 2014). As a result of the recognition by the European Union, of the multiple functions performed by the Montado at the ecosystem scale, these are currently recognized as high nature value farmlands (HNVF), according to European classification criteria (Almeida *et al*., 2013; Pinto-Correia & Godinho, 2013), and thereby included in Annex I of the European Union Habitats Directive (92/43/CEE). Thus, this system is often characterized as "multifunctional" as a way to highlight the activities carried out there, as well as the multiple functions it performs, at the ecosystem level (Pinto-Correia & Primdahl, 2009; Pinto-Correia & Vos, 2004).

This system displays another feature which is the close interrelation between its various components, representing a challenge for both, managers, researchers and policy makers.

Livestock management, as well as the use of more or less heavy machinery can cause soil compaction, with effects on mycorrhiza, trees roots and the survival of the saplings and young trees (Dinis *et al.* 2015; Sales-Baptista *et al.,* 2015). The maintenance of shrubs in the Montado promotes the mycorrhizal network that exists on the ground (Azul *et al.,* 2010), both by the effect of shadowing and thereafter, maintaining lower temperatures in the first layer of soil, more suitable to the presence of soil life; but also due to the presence of the shrubs roots where the same mycorrhizal fungi linked to trees roots associates (Mediavilla *et al.,* 2015). The presence or absence of shrubs is strongly influenced by the type of livestock management. Cattle rearing generally delays shrubs growth but these are essential for the survival of new settlements. Moreover the presence of livestock allows increasing levels of soil organic matter by dung deposition (Harrison & Bardgett, 2008). Traditionally, tree crown cover was reduced so that more light can reach the pasture required to feed livestock. On the other hand the shade of the trees protects the pastures of intense heat in summer, while the falling leaves fertilizes the soil and the hydraulic lift mechanism maintains the upper soil layers wet by the root uptake of groundwater (David *et al.,* 2007; Kurz-Besson *et al.* 2006), so the pasture is sometimes largely benefited under the trees. The cork harvesting benefits from the livestock presence since the shrub control performed by the animals has a positive impact in cork quality. This complexity, own of natural systems, remains a feature of this semi-natural system where man has not yet introduced important simplification mechanisms.

Given what is described above, the management of a holding with Montado poses several challenges to managers. They can allow the shrub layer to develop during certain periods in order to promote hunting and trees regeneration, but usually they keep these shrubs under control through soil tilling (Canteiro *et al.* 2011; Santana *et al.* 2011). They can also choose to make new tree plantations or to divesting on having a balanced settlement concerning the presence of different age classes. As the dominant tree species is the holm or cork oak, the owner may have as major activity, raising cattle, fed on pastures and acorns from holm and cork oaks, or cork harvesting, which, because of the high value of the cork in the market, is often explored in exclusive. Desirably the management of this system is based on an extensive use of the resources, particularly with regard to the carrying capacity of the system, with several studies indicating that the appropriate amount of animals per hectare should be kept below 1 animal or less, with respect to cattle (Calvo *et al.* 2012; Godinho *et al*., 2014a; Plieninger, 2007). Different livestock species can take advantage of the natural or improved pastures and of the acorns that fall from the trees, among which one can find cattle, sheep, goats, pigs or turkeys from indigenous or more productive, but usually heavier, breeds. Thus, the manager usually gets his yearly income from rearing one or more livestock species and from hunting which, according to the kind of contract, can provide a more regular income or any. More irregular income provide from wood sales (highly variable according management options) and cork, each nine years. One way to reduce this irregularity is the division of the holding in different parcels of cork and wood harvesting wherein for each year, a lower part of cork or wood is harvested, thus dividing the income for more years. The manager can also take profit from the honey, aromatic plants, the mushrooms, and the potential for trails on nature, bird watching, between other activities – but very often these externalities of the system are used by other people, not related to the farm and according to individual agreements with the land owner (Barroso *et al.,* 2012a).

When managed in an extensive way, the Montado maintains a semi-natural character with good adaptation to the natural constraints of the Mediterranean climate and soil as also as a good resilience to changes in management practices, as can be seen by the centuries of the history of this system, described above (Fonseca, 2004; Pinto-Correia & Fonseca, 2009;).

As a result of this semi-natural character, holdings in Montado have important renewable energy flows contributing to manager income. To the renewable energy flows that feed the agricultural systems in general, such as solar radiation, rainfall and soil nutrients join, in the Montado, others in the form of nutrients provided by acorns, natural grassland, shrubs or litterfall, but also in the form of materials such as cork, wood, and food for human consumption as game animals. Thus, with the addition of a relatively small amount of inputs from human labor or the economy it is possible to obtain an important set of resources in a balanced way (Fonseca, 2004).

However, since a few decades ago, this system has undergone several threats that put in question its balance. From the various attempts to transform the Alentejo in a major producer of cereals in Portugal (since 1821 until the end of the Second World War), the Agrarian Reform of 1975-1979 with the progressive introduction of heavy machinery that allowed the agricultural work where it was not possible before, various measures have led to its area reduction (Ferreira, 2001; Pinto-Correia & Godinho 2013). However, since the integration of Portugal in the European Community in 1986, a "set-aside" policy imposed by Common Agricultural Policy led to rural and agricultural abandonment and the proliferation of shrubs and the consequent large fires 2003 (Ferreira, 2001). More recently, the payments coupled to livestock rearing under the transposition made by the Portuguese government of the rules of the Common Agricultural Policy, caused a growth in cattle population that tripled between 1986 and 2003 (Almeida *et al*., 2016; Pinto-Correia & Godinho, 2013; Matos, 2006). In the Montado system this means increasing the opportunities for the occurrence of overgrazing. Sheep decreased dramatically and goats almost disappeared, while Iberian pigs are also present, but only in a few farm units (Matos, 2006).

Different livestock species and breeds can cause damage to the system in dissimilar ways, namely by excessive dung deposition, eating the saplings and breaking the young trees, defoliation, trampling (Dobarro *et al*., 2013; Sales-Baptista *et al*., 2015) and indirectly through soil compaction (Bilotta *et al.*, 2007; Dinis *et al*., 2015). In general, when plant resources become scarce, herbivores change their grazing behavior, increasing foraging on grass alternatives, such as tree leaves and shrub twigs (Sales-Baptista *et al*., 2015). Such behavior can damage saplings thereby impairing the natural, random tree regeneration, which is one of the traits of the traditional Montado.

As a result of these influences land cover considering Montado has been declining over time (Pinto-Correia *et al*., 2011; Pinto-Correia & Godinho, 2013; Godinho *et al*., 2016a) in tree density, leading to clearances in the forest cover which subsequently turn into larger open patches and the progressive opening of the Montado cover. This ongoing process has led to the disappearance of 49 413 hectares of Montado between the years 1990 and 2006 (Pinto-Correia & Godinho, 2013).

Besides the trend towards intensification in some areas, other are subjected to an extensification and some areas of marginally productive land are even abandoned (Costa *et al*., 2009; Pinto-Correia, 1993; Pinto-Correia & Mascarenhas, 1999).

The maintenance of the viability of this system depends largely on understanding the range of mechanisms involved in maintaining balance among the diverse factors of production (e.g. soil, livestock, vegetation, biodiversity, agricultural practices, and European policies) at the level of human intervention in the system – the farm level (Fonseca *et al.,* 2016). Being a system with a strong human component, the whole economy at the farm level has a strong influence on management choices and practices.

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

Given the complexity of this system many authors have been engaged to its study. They used different approaches and focused on distinct aspects as the carbon cycle including atmosphere, trees carbon and organic matter at soil level, nutrients dynamics between the tree, the shrubs and the soils (Simões *et al.,* 2012), the fungus and mycorrhizas (Azul *et al.,* 2010), the biodiversity of birds, insects, mammals (Carvalho *et al.,* 2011; Godinho & Rabaça, 2010; Pereira *et al.,* 2012), the water use by trees (David *et al.,* 2007), the history of the system (Ferreira, 2001; Pinto-Correia & Fonseca, 2009), its management (Coelho, 1994) and its general characterization (Potes, 2011; Pinto-Correia *et al.,* 2011b) and landscape preferences of different user groups (Surová & Pinto-Correia, 2009). More recently some studies focus on the evolution of the Montado through the use of satellite images (Godinho *et al.,* 2016a, 2016b). Other authors address the effect of cattle presence in the Montados (De Oliveira *et al*., 2013; Nunes, 2007) and its relation with natural regeneration of the trees (Sales-Baptista *et al*., 2016; Ribeiro *et al*., 2010). Potes (2011) took a broad approach to the sustainability of the Montado system by studying separately its ecological, economic and social components as different production systems. However, an integrated study of the different components of this multifunctional system aimed at evaluate the sustainability of the various agricultural production methods is lacking, as well as a study of the energy fluxes within this system. Rosado *et al.* (2009) performed an environmental evaluation of the traditional extensive beef production farming system used in the Montado, considering all the production costs, including purchased energy and materials, hours of labor and the calculation of some environmental indices. But some environmental aspects of the system were not considered such as the effect of solar radiation, the soil, the effects of the wind and other free energy fluxes. These inputs to farming systems are studied in a biophysical context and not on the same basis that are valued the inputs from economy. When economic aspects are included in a Montado study, the component of the free inputs providing from nature, is not included or is included through opportunity costs or property rights. But in a semi-natural system, where the free inputs from nature are an important component for the Montado outputs, an evaluation of the entire production system using an ecological perspective of systems evaluation instead the economic perspective of the willingness to pay, will allow new insights into the activities developed in Montado.

4. EMPIRICAL IMPLEMENTATION

4.1 Characterization of the Holm Oaks Farm

The Holm Oaks Farm is located in the central part of the Alentejo region of Portugal, in the Montemor-o-Novo municipality (Figure 9). The farm was not identified at request of the owner and so the fictitious name of Holm Oaks Farm has been chosen for its identification.

This farm is mainly dedicated to cattle production, activity developed not by the owner but by a tenant that pays a rent to the owner. This manager receives also the right to hunt. The farm´s owner still receives the revenue from cork.

In its location, the farm receives an average solar radiation of 5.37E+13 J ha^{-1} y^{-1} (Centro de Geofísica de Évora - CGE) and an average wind speed of 2 m s^{-1} (CGE). This region has an average temperature of 15.86 ºC (289.01 ºK) with a maximum of 46 ºC (319.15 ºK) in the summer and a minimum of -11 ºC (262.15 ºK) in the winter months (Instituto Português do Mar e da Atmosfera - IPMA). The average precipitation is 609.40 mm (LNEC, 2002).

The Holm Oaks Farm is an enterprise of 168 ha with 59 ha occupied by Holm oak trees (Table 2 a)) and 2 ha of cork oak trees (Table 2 b)) on the highest elevations. Tree crown cover is about 36%. Open areas, producing mainly natural pastures, occupy 64 ha (Table 2 c). An area of 24 ha of open pasture is presently showing natural regeneration, after 30 years of deforestation (Table 2 d).

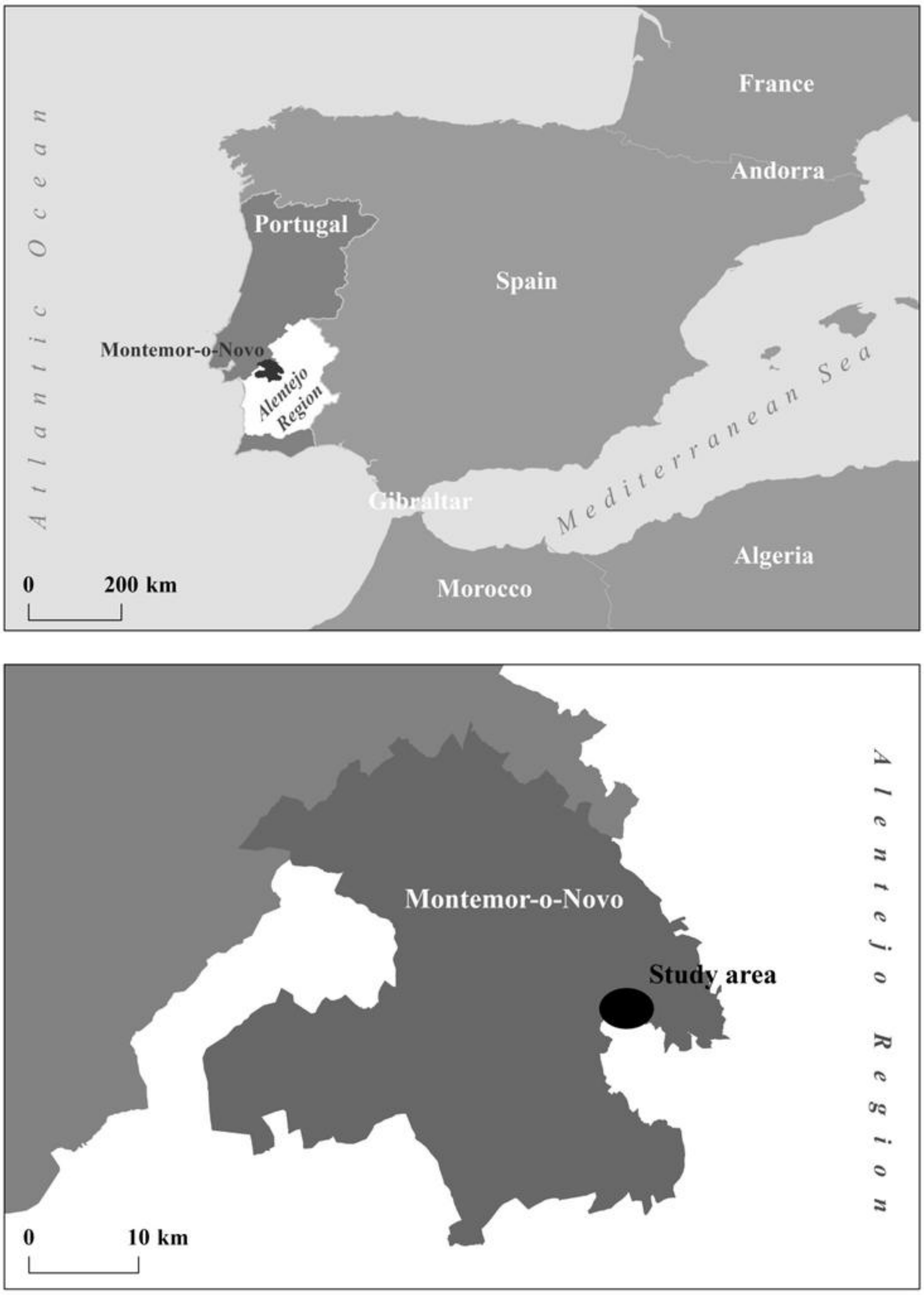


Figure 9 - Map with the location of the Holm Oaks Farm.

Two additional open areas (43 ha) (Table 2 e)), are fertilized and used to produce hay as a supplement of cattle grazing.

Table 2 - Land cover scheme in Holm Oaks Farm where a) corresponds to Holm oaks area, b) to cork oaks area, c) to the open areas between the trees, d) to the regeneration area, and e) to the open areas that are fertilized and used to make bales.

<table>
<tr><td rowspan="4">168 ha</td><td rowspan="2">61 ha – tree cover</td><td>59 ha – Holm oaks a)</td><td>24 ha – regeneration area d)</td><td rowspan="3">125 ha – natural pastures</td></tr>
<tr><td colspan="2">2 ha – cork oaks b)</td></tr>
<tr><td colspan="3">64 ha – open areas between trees c)</td></tr>
<tr><td>43 ha –</td><td colspan="3">Open areas, fertilized and used to make bales e)</td></tr>
</table>

In Figure 10 it is possible to have a satelite view of the Holm Oaks Farm and its main occupations.

An analysis of the levels of soil organic matter (SOM) gave the highest level (5%) in the parcel with cork oaks. This area receives additional manure, because it is located on higher ground, which is exposed to the wind and where the cattle usually go to refresh themselves (personal communication of the manager). The mean value of SOM for the whole farm is 4%, which is a high value for this region where average levels are around 0.5 to 2% (Teixeira *et al.* 2008).

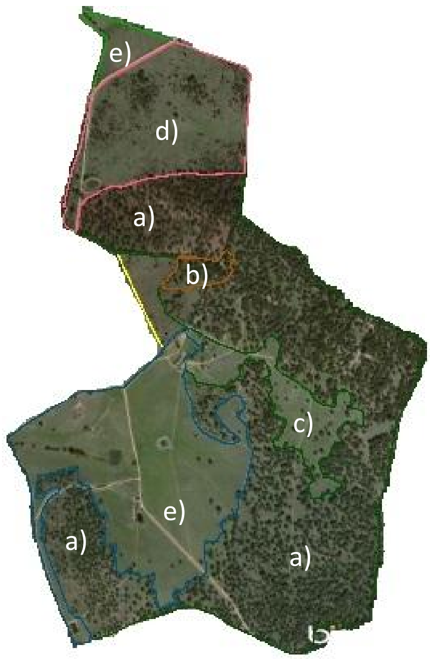


Figure 10 - Aerial photograph of Holm Oaks Farm, with the limits and delimitation of the land use using the letters of Table 2.

The farm has 6 ponds with a total surface area exposed to evaporation of about 3558 m2. Three of the ponds are supplied by ground water. In one of them the manager uses a pump to take water for cattle during the three driest months of the year. The farm is divided into 8 paddocks with poles and wire fences, of which 13,500 m were installed by the current manager. All the area of the farm is located over Orthic Luvisols with moderate to low water permeability. The farm is on a sloped area with up to 48 % lying between 345 m and 250 m and it is divided into 8 parcels with pole and wire fences.

The herd has 2 bulls and 80 cows with an annual fertility rate of 90%. Calves are a cross between Saler and Limousin breeds and are small animals that present higher percentage of selling on the market. They are sold in a cattle auction at 200 kg weight and an average age of 7 months.

The cattle's diet is based on natural pastures in 125 ha (Table 2 a), b) and c)), acorns from the Holm and cork oaks (Table 2 a) and b)), hay, some shrubs and tree leaves. Calves are nursed exclusively until the 4th month when they start a transition to an adult diet.

To ensure the success of the hay crop and to provide extra feed for the cattle, open pasture (Table 2 e)) is fertilized annually with a phosphate (Superphosphate 18%) in a proportion of 150 kg/hectare without tilling the soil.

Other work to operate the farm includes making 23.6 km of firebreaks around each parcel and each pond twice a year and pruning the young trees since they have 10 to 12 years old.

The farm's owner inherited the farm choosing to rent it to a local manager. Each 9 years, the owner takes about 7000@ of low quality cork, where an @ is a measure for cork that corresponds to 15 kilograms. Hunting rights are managed by an hunting association and the firewood is used to pay for the work of pruning the trees. In 1996, when the manager started to apply European Union Agro-environmental measures on the farm, he could no longer mobilize the soil, but cattle continued using the area. The practices he uses to protect the trees, which were not used by the previous farmers, are to provide enough feed so that the cows do not eat too much woody vegetation, such as the saplings (Sales-Baptista *et al.,* 2016), and not pruning oak trees until they are large enough to survive the cattle's habit of scratching on them. Young Holm oaks are spiny shrubs, which protect the young tree trunk from this damaging habit of the cattle of scratching their bodies on them (managers' statement). The analysis of his practice to forego pruning the trees until they are older has some importance, considering the fact that the main problem with the presence of cattle as a part of the Montado ecosystem is that insufficient regeneration of trees occurs on farms where cattle are raised (Plieninger, 2007; Pulido *et al.,* 2001).

4.2 The emergy evaluation

In the farm at study, the system boundary is defined horizontally by the limits of the farm. The upper limit is 1000 meters above the surface corresponding to the geostrophic boundary layer, where it was assumed that the trees roughness no longer affects air flow. The lower limit corresponds to the base of the crust, 28 km deep (González *et al.,* 1998), because it is under the crust, in the mantle, that uplift by isostatic rebound is accomplished (Figure 11).

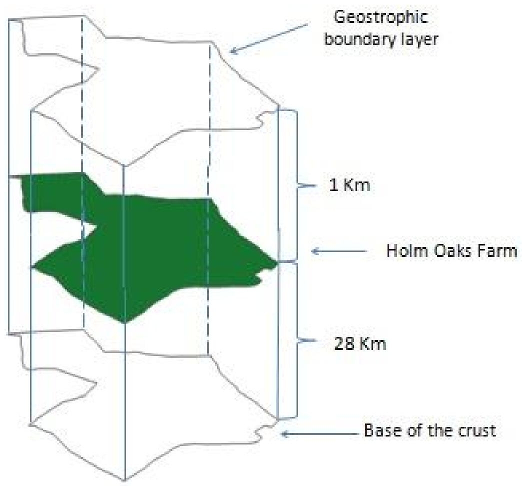


Figure 11 - Boundaries of the system studied in this approach (not to scale).

The spatial boundary of the case study was defined, as previously described, and also the temporal boundary – as the year 2012. The emergy diagram for the Montado farm is shown in Figure 12. Inside the box, that represents the system boundaries, there are a number of flows that describe the interactions among holm and cork oaks and shrubs, juvenile oak trees, natural and improved pasture to graze and pasture for hay, soil organic matter, mycorrhizae, superficial, groundwater and ponds, cattle and money.

Figure 12 also represents several types of resources from outside that are used in the farm. Thus, we can identify in the above-mentioned figure (see also Table 3 for a legend) sunlight that

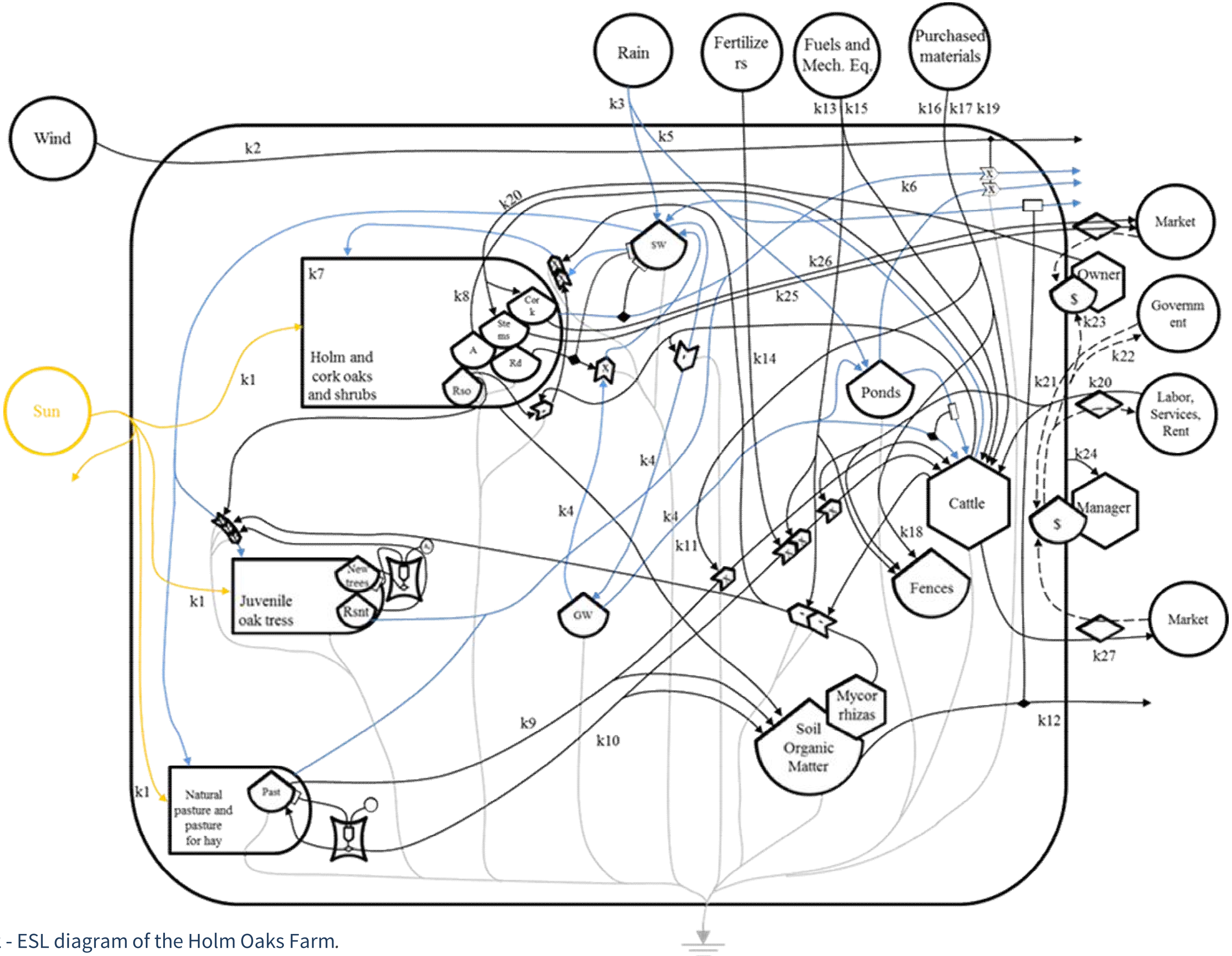


Figure 12 - ESL diagram of the Holm Oaks Farm.

goes into different ecosystems (k1), wind (k2), the chemical potential of groundwater (k4) rain, the geo-potential energy absorbed (k3) and the chemical potential (k5), evapotranspiration (k6). These are considered local renewable resources. Another renewable sub-component considered within the system is the total nutrients mobilized by native 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 nonrenewable resource.

Purchased inputs are arranged by product destination (e.g. hay bales, cattle, other uses). Other inputs also come from outside the system and include fuels (k13), fertilizer (k14) and mechanical equipment (k15), plastic (k16), feeding trough (k17), materials for fences (k18), and veterinary medication (k19). Finally, services include labor 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 permit (k23). Output flows are also represented, including hunting (k24), firewood (k25), cork (k26) and calves (k27), indicating the distribution between manager and owner.

Table 3 gives the definitions for the forcing functions, storages and pathway flows shown on the ESL diagram in Figure 12.

Once the system has been formulated, a collection of all required data to carry out the calculations for the emergy evaluation were assembled.

Data on productivity, management, water use and other inputs were collected directly on the farm and by consulting the manager during several visits to the farm. Since the history of the farm became explicit, other questions arose. Some local enterprises provided data, concerning ponds and fences construction, several services associated with hay, bales, cork or firewood, seeds and veterinarian services as indicated below.

Table 3 - Legend to the ESL diagram pathway flows.

k1	Solar radiation	k14	Mechanical equipment operation
k2	Wind, kinetic absorbed	k15	Fences, wood depreciation
k3	Rain, geo-potential absorbed	k16	Fences, wire depreciation
k4	Ground water, chemical potential inflow	k17	Plastic purchased
k5	Rain, chemical potential inflow	k18	Feeding trough depreciation
k6	Evapotranspiration	k19	Medication given
k7	Trees biomass growth	k20	Labor applied in the different activities
k8	Acorns consumed	k21	Subsidies received
k9	Natural pasture consumed	k22	Taxes paid
k10	Bales of hay stored and eaten	k23	Land use permit purchase
k11	Erosion, topsoil	k24	Hunting for the manager
k12	Fuels used	k25	Firewood harvested
k13	Fertilizers applied	k26	Cork sold
		k27	Calves sold on the market

Soil organic matter determination required specific lab analyses of the soil for which 70 soil samples were taken from the farm unit, corresponding to 7 plots identified in order to cover all the variability of the farm situations, with regard to the soil quality.

Climatological data was derived from (http://www.cge.uevora.pt/pt/component/cge_bd/?cge_bd_e_first=mit) and given directly by the Geophysics Centre of Évora when indicated.

The biomass and growth of trees was determined by field measurements of a number of trees representing each plot identified in a procedure explained below.

Some simplifications in the representation of the system were assumed, which are considered to have little impact on final results but greatly facilitate the evaluation. The most important simplifications are:

a) Some shrub areas were not accounted as also some hedges, although these have a role in the presence of game species and as protection spaces for wildlife;

b) Part of the area for the production of hay for bales is also grazed, in a certain period of the year, but for simplification purposes, and because it is a small area, it was considered that this area was destined exclusively to hay production;

c) The subterranean clover sowing, done in the farm, was made only in the poorest soil areas but, since cattle have access to all areas of the farm and benefit from pasture increase anyway, this sowing was diluted throughout all t the grazed area used by the cattle;

d) For the estimation of the hours of work in each activity it was considered the average year, instead of considering exactly what happened in 2012, which was an unusually dry year.

Other data were obtained from existing spatial information in the Digital Atlas of the Environment (http://www.apambiente.pt/index.php?ref=19&subref=174) and treated using a Geographic Information System (Quantum GIS Lisboa Desktop 1.8.0 version and the Quantum GIS Valmiera Desktop version 2.2.).

4.2.1 Determination of the items – raw data, emergy and transformity values

The main components of the farm system, the raw data quantifying flows, the units, the unit emergy values (UEV) and the emergy of the flows were compiled in the emergy accounting table.

Some transformities and specific emergies previously determined under similar conditions to those of this study were used to obtain the best estimate of the emergy values for products or services of the farm system. In other cases, when a UEV was not available or it was derived for very different conditions, a determination for this case study was made. Both UEVs taken from other evaluations and calculated in this study are indicated above with reference to the origin of the value.

The 1.2E+25 seJ y^{-1} planetary baseline (Campbell, 2016) was used; therefore, values from other studies were transformed to the chosen baseline. For example, values calculated relative to the 9.44E+24 seJ y^{-1} baseline (Odum, 1996) were converted to the 1.2E+25 seJ y^{-1} baseline by multiplying the value by 1.271. In a similar way, to convert values from the 15.83E+24 seJ y^{-1} baseline (Odum, 2000) to the 1.2E+25 seJ y^{-1} baseline, original values were multiplied by 0.758. Table 4 compiles the previous baselines and the conversion factors by which the transformities must be multiplied to obtain the corresponding values in the actual baseline.

Table 4 – Compilation of the previous baselines and the conversion factors by which the transformities must be multiplied to obtain the corresponding values in the baseline 1.2E+25 seJ y^{-1}.

Baseline (seJ y^{-1})	Conversion factor
9.26E+24	1.296
15.83E+24	0.758
9.44E+24	1.271
15.2E+24	0.789

All the money values were collected in euros (€) and converted to United States dollars relative to the year 2005 through applying a conversion factor of 1.143 (http://www.x-rates.com/calculator/ and http://www.usinflationcalculator.com/). This unity of measure for the money was used to make it easier to use other data estimated for Portugal by other researchers as the Emergy to Money Ratio (Oliveira *et al*., 2013)

Next, it will be exposed in detail how the energy values were estimated, as the related emergy and transformity linked to each power function, flow or system storage. The items and numbers presented correspond to those in Table 3 and represented in Figure 12. They will be the same presented in the emergy accounting table similar to Figure 8. The idea is that one can follow clearly, through the application of the methodology, the way each item represented in the initial diagram and identified as important in the system, was calculated. Reasonings, formulas and accounts made to obtain the energy values, emergy and transformity of each item vary greatly between them, despite the manner of obtaining them being fairly established within the emergy evaluation method. Because of this it was decided to integrate these calculations in the text accompanied by explanations enabling an understanding of the reasoning adopted.

1. Solar radiation

According to the Geophysics Centre of Évora, the farm receives an average solar radiation of 6.47E+13 J ha^{-1} y^{-1}. The Explanatory Note I referring to the Solar Radiation and produced by the Secretary of State for Environment and Natural Resources (1988), indicates an average albedo in Portugal Continental of 17%. According to this data and using the energy formula indicated below the emergy of the solar radiation is 9.02 E+15 seJ J^{-1}.

Incident solar radiation absorbed over land	6.47E+13	J ha^{-1} y^{-1}	Centro de Geofísica de Évora
Albedo	17%		SEARN, 1988
Farm area	168	ha	
Energy formula	(area)(avg. insolation)(1 – albedo)		
Energy	9.02E+15	J	
UEV	1	seJ J^{-1}	
Emergy	9.02E+15	seJ J^{-1}	

2. Wind, kinetic

An average annual wind velocity of 2 m s^{-1} was considered for the Mitra Meteorological Station in the year of 2012 (http://www.cge.uevora.pt/pt/component/cge_bd/?cge_bd_e_first=mit at 25-07-2013) once an average data for the years between 1971 and 2000 doesn't exist for this station. This is a geostrophic wind that does not come into account with friction; it is a wind speed at which the effect of the surface is not felt. To estimate the value of the wind near the surface, the value of the geostrophic wind should be multiplied by a coefficient of friction, which should be different depending on the surface. Reiter (1969) estimated that the winds over land are about 0.6 of what the pressure system would generate in the absence of friction. This is the coefficient of friction to forestall areas. The drag coefficient on land was estimated by Garrat (1977) as being 2.00 E-03. The number of seconds in a year was estimated as being 31557600 s y^{-1}. The unit emergy value already estimated for the wind on land (Campbell & Erban, 2016) was 1240 sej J^{-1} in the 1.2E+25 baseline. According to these data and using the energy formula to estimate the energy of the wind, the emergy associated to the average wind passing through the farm corresponds to 6.33E+15 sej y^{-1}.

Average annual wind velocity	2	m s^{-1}	Data collected in http://www.cge.uevora.pt/pt/component/cge_bd/?cge_bd_e_first=mit at 25-07-2013 for the Mitra Meteorological Station and the year of 2012 (average data for the years between 1971 and 2000 doesn't exist for this station).
Area	1.68E+06	m^2	
Air density	1.3	kg m^{-3}	
Drag coefficient on land	2.00E-03		(Garrat, 1977)
Winds over land	0.6		(Reiter, 1969) Winds over land are about 0.6 of what the pressure system would generate in the absence of friction
Geostrophic wind velocity	3.33	m s^{-1}	
Seconds in a year	31557600	s y^{-1}	
Energy formula	(area)(density)(drag coefficient)(geostrophic wind – gradient velocity)^3(seconds in a year)		
Energy	5.11E+12	J y^{-1}	
UEV	1240	sej J^{-1}	(Campbell & Erban Emergy Synthesis 9, 2016, in the 1.2E+25 baseline)
UEV (baseline 2016)	1240	sej J^{-1}	
Emergy	6.33E+15	sej y^{-1}	

3. Rain, geo-potential absorbed

To estimate the geo-potential energy of the rain absorbed in the farm, the average elevation difference over the farm's area was estimated. Usually it corresponds to the mean value between the highest point and the sea level at zero meters, but once this farm does not make any contact with the sea, this average elevation was estimated as the mean value between the highest point and the lowest point of the farm, from where the rain water leaves the system and finishes its geo-potential work in the farm. These height values were found with Quantum GIS support.

According to these data and using the energy formula to estimate the geo-potential energy of the rain absorbed in the farm, the associated emergy corresponds to 2.06E+14 sej y^{-1}.

Average elevation difference over the farm's area	47.5	m	
Flow of water	12500	m^3 y^{-1}	
Water density	1000	kg m^{-3}	
Gravity	9.81	m s^{-2}	
Energy formula	(area)(rainfall)(avg. change in elevation)(density)(gravity)		
Energy	5.82E+09	J y^{-1}	
UEV	27344	sej J^{-1}	(Odum, 1996, p.309, in the 9.26E+24 baseline)
UEV (baseline 2016)	35434.99	sej J^{-1}	
Emergy	2.06E+14	sej y^{-1}	

4. Ground water, chemical potential for cattle

To estimate the chemical potential for cattle of the ground water, an estimation was made of the total water consumed by cattle in an average year from the groundwater supply from the ponds and pumped water.

To make this estimation, the construction of a diagram representing the water flows (in liters) in the Holm Oaks Farm, was a good help (Figure 13). For this estimation the evapotranspiration from ponds found by Rodrigues (2009) was used.

Daily consumption of water by adult cattle	20	L day^{-1}	Personal comunication of Roberto Santos, Agrocerteza
Number of adult animals in the farm	82	animals	
Days in a year	365.25	day y^{-1}	
Annual consumption of water by cows or bulls	599010	L y^{-1}	
Daily consumption of water by a calf	10	L day^{-1}	Personal comunication of Roberto Santos, Agrocerteza
Calf stay on the farm	213.5	days	
Number of calfs in the farm	72	animals	
Annual consumption of water by calves	153720	L y^{-1}	
	153.72	m^{3} y^{-1}	
Total of water consumption by cattle	752730	L y^{-1}	
	753	m^{3} y^{-1}	
Groundwater supply from the ponds and pumped water	527000	L y^{-1}	
	527	m^{3} y^{-1}	

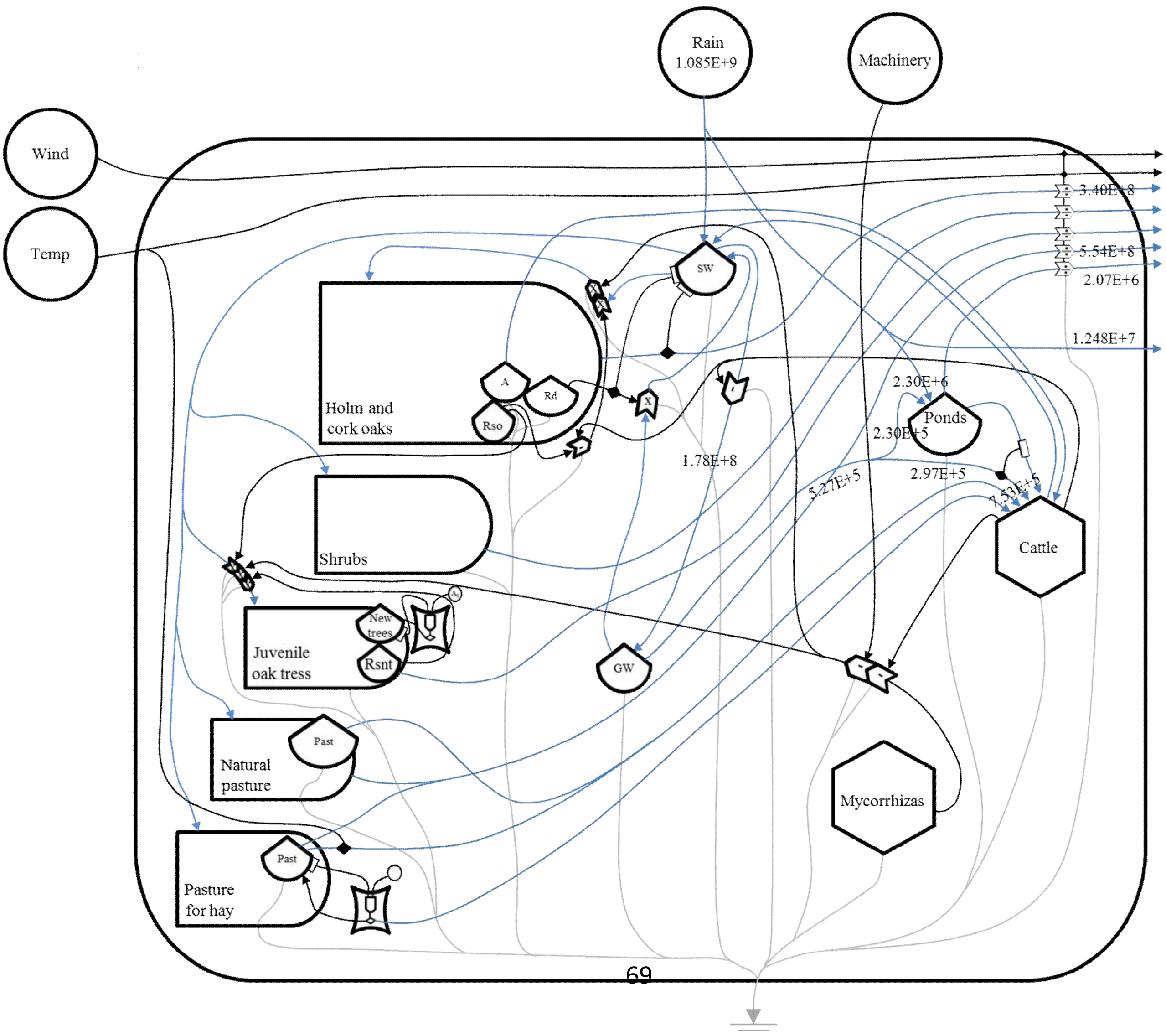


Figure 13 - Diagram representing the water flows (in liters per year) in the Holm Oaks Farm.

Data from Guerreiro *et al.* (1998) was used to find out the conductivity of water in springs and wells in the area of Montemor-o-Novo. According to these data and using the energy formulas to estimate the Gibbs free energy of the ground water and the energy formula to estimate the chemical potential of the ground water, an emergy corresponding to 6.94E+14sej y^{-1} was obtained.

Density of groundwater	1.00E+06	g m^3	
Conductivity of water in springs and wells in the area	500	µS cm^{-1}	(Guerreiro *et al.*, 1998)
Dry weight of dissolved substances in the water	350	ppm	(Custodio & Llamas, 1983)
Dry weight of dissolved substances in the seawater and plants interstitial fluids	35000	ppm	(Odum, 1970)
Average temperature of the air	289.01	K	Average of the values collected between 1971 and 2000 at the Évora Meteorological Station
Average temperature of the growing season	285.43	K	From October to April
Proportion between water in ground water and water in sea water (considered similar to plants interstitial fluids)	1.04E+00		
Universal gas constant (R)	8.3144	J $mole^{-1}$ K^{-1}	
Molecular weight of water vapor (m)	18	g $mole^{-1}$	
Gibbs free energy formula	[(universal gas constant)(avg. temp. of the growing season)/(molecular weight of water vapor)] x ln(proportion between water in ground water and water in sea water)		
Gibbs free energy	4.65E+00	J g^{-1}	
Groundwater supply from the ponds and pumped water	5.27E+05	L y^{-1}	
	5.27E+02	m^3 y^{-1}	
Energy formula	(ground water used)(pure water density)(Gibbs free energy of ground water)		
Energy	2.45E+09	J y^{-1}	
UEV	222671	sej J^{-1}	(Buenfil, 2001, in the 9.44E+24 baseline)
UEV (Baseline 2016)	283056.36	sej J^{-1}	
Emergy	6.94E+14	sej y^{-1}	

5. Rain, chemical potential

The rain has two kinds of actions over the system, its geo-potential energy acts through a physical effect related to its displacement from a higher point to a lower point in the system; and its chemical potential energy acts through a chemical action related to the ability to dissolve solutes and perform chemical work according to its prior level of solutes.

The rainfall in Montemor-o-Novo was found for an average year and for seven months corresponding to the growing season of the hay and the natural pasture (between October and April). The annual value of the chemical potential of rain was used in the formulas for tree growth, which is assumed to be more or less constant throughout the year, while the value of the chemical potential of the rain for seven months was included in the formulas associated with the hay and natural pasture growth.

According to these data and using the energy formulas to estimate the chemical potential of the rain for a year and for the growing season, an emergy corresponding to 1.21E+17 sej y^{-1} and 6.95E+16 sej y^{-1}, respectively, was obtained.

Area of the farm	1.68E+06	m^2	
Density of rain water	1.00E+06	$g\ m^3$	
Dry weight of dissolved substances in the rain water	1.2	ppm	(Odum, 1970)
Dry weight of dissolved substances in sea water and plant interstitial fluidsplants water	35000	ppm	(Odum, 1970)
Rainfall in Montemor-o-Novo	646.00	$mm\ y^{-1}$	(LNEC, 2002) using data between 1/10/1980 and 30/09/1990 for Montemor-o-Novo weather station with the pluviometer number 22H01.
	0.646	$m\ y^{-1}$	
Rainfall in seven months corresponding to the growing season (between October and April)	375.40	$mm\ y^{-1}$	Évora Meteorological Station - average rainfall data for the years 1971 to 2000 for the months of October to April
	0.38	$m\ y^{-1}$	
Average annual temperature	289.01	K	Average of the values collected

			between 1971 and 2000 at the Évora Meteorological Station
Average temperature in the months of October to April	285.43	K	Average of the values collected between 1971 and 2000 at the Évora Meteorological Station for the months of October to April (Hussain *et al.* 2009)
Proportion between water in rainwater and water in plant interstitial fluids	1.04E+00		
Universal gas constant (R)	8.3144	J mole^{-1} K^{-1}	
Molecular weight of water vapor (m)	18	g mole^{-1}	
Gibbs free energy formula	[(universal gas constant)(avg. temp. of the growing season or the year)/(molecular weight of water vapor)] x ln(proportion between water in rain water and water in plant interstitial fluids)		
Gibbs free energy in annual rainfall	4.76E+00	J g^{-1}	273.15
Gibbs free energy in rain from the growing season	4.70E+00	J g^{-1}	
Energy formula	(rain water amount)(pure water density)(Gibbs free energy in annual rainfall or for the growing season)		
Energy (annual)	5.16E+12	J y^{-1}	
Energy (growing season)	2.96E+12	J y^{-1}	
UEV	18100	sej J^{-1}	(Campbell, 2003, in the 9.26E+24 baseline)
UEV (Baseline 2016)	23456	sej J^{-1}	
Emergy (annual)	1.21E+17	sej y^{-1}	
Emergy (growing season)	6.95E+16	sej y^{-1}	

6. Evapotranspiration

The values linked to the evapotranspiration of the cork oaks and the holm oaks were difficult to find. The main problem was with values linked to evapotranspiration of the pasture for hay (natural pasture fertilized) and the natural pasture. These are values that vary greatly with the quality of soil, pasture productivity, the type of species that are present, the fact that it is or is not a fertilized area, has more or less water available, and is or is not under the canopy of trees. Once a measurement on the farm was impossible to get, evapotranspiration values had to be used from literature from similar areas close the farm. However, natural conditions will be slightly different. This is one of the most critical of all the estimates made in this work and would greatly benefit of the existence of more collected data, related to evapotranspiration, in natural pastures in the region in different, well defined, conditions.

After applying the energy equations for the chemical potential energy in evapotranspirationfor the different ocupations on the farm, emergy values were found for evapotranspitarion for the system, for the holm oaks, for the cork oaks, for the natural pastures and for the pastures for hay production.

Water density	1.00E+06	g m3	
Gibbs free energy of the water transpired by trees	4.76	J g-1	(considering that the evapotranspiration activity remains almost all the year)
Gibbs free energy for pastures	4.70	J g-1	(considering that the evapotranspiration activity is mainly from October to April)
Holm oak evapotranspiration	551.43	mm y-1	(David *et al.* 2002, David *et al.* 2007, Paço *et al.* 2009)
	0.55	m y-1	
Cork oak evapotranspiration	730	mm y-1	
	0.73	m y-1	
Natural pasture evapotranspiration	92.46	mmy-1	(Paço *et al*., 2009)
	0.09246	m y-1	
Pasture for hay evapotranspiration	517.50	mm y-1	(Ruivo, 2008)
	5.18E-01	m	
Area with holm oak canopy	5.90E+05	m2	
Area with cork oak canopy	2.00E+04	m2	
Area of pastures for hay	4.30E+05	m2	(The pastures' evapotranspiration understory was considered as insignificant)
Area of natural pastures	6.40E+05	m2	
Chemical potential energy in evapotranspiration of Montado with holm oak trees	1.55E+12	J y-1	
Chemical potential energy in evapotranspiration of Montado with cork oak trees	6.94E+10	J y-1	
Chemical potential energy in evapotranspiration of pastures and pastures	1.32E+12	J y-1	

for hay			
Chemical potential energy in evapotranspiration of natural pastures	2.78E+11	J y^{-1}	
Chemical potential energy in evapotranspiration of pastures for hay	1.05E+12	J y^{-1}	
Chemical potential energy in evapotranspiration of the system	2.94E+12	J y^{-1}	
Transformity of evapotranspiration	28100	sej J^{-1}	(Campbell, 2003, in the 9.26E+24 baseline)
Transformity of evapotranspiration (Baseline 2016)	36415	sej J^{-1}	
Emergy of the chemical potential energy in evapotranspiration for the system	1.07E+17	sej y^{-1}	
Emergy of evapotranspiration of holm oaks	5.63E+16	sej y^{-1}	
Emergy of evapotranspiration of cork oaks	2.53E+15	sej y^{-1}	
Emergy of evapotranspiration of the oaks	5.89E+16	sej y^{-1}	
Emergy of the evapotranspiration of the pastures	4.82E+16	sej y^{-1}	
Emergy of the evapotranspiration supporting hay production	3.81E+16	sej y^{-1}	

7. Trees biomass

The total biomass of holm oak and cork oak in the system was determined (Appendice A) through the application of the equations used in the National Forestry Inventory (AFN, 2010). First, an estimation based on seven field samples for seven different canopy typologies was undertaken to cover the different types of canopy identified on the farm by photo-interpretation (juvenile holm oak stands of low, medium and high density, adult holm oak stands with high density and in a heavily sloping area, cork oak stands, adult holm oak stands of medium density and, finally, adult holm oak stands with high density and poor soils). Trees were marked and the trees circumference measured at breast height within each sample unit of 1000 m^2. The biomass was estimated for each component of the tree using the above-mentioned biomass equations, and then all of the components were added to estimate the total biomass in each sample unit. The seven sampling areas where reduced to four typologies (juvenile holm oak, cork oak and holm oak stands with medium and high density) after merging areas which, on the ground, had similar typology (tree type, density and average age). Finally this data was used to estimate the biomass in larger areas with the same typology, obtaining a biomass value for the farm.

The annual growth in tree biomass was estimated by applying the growth equation for adult trees (Equation 1) (Tomé *et al.,* 2006) and for juvenile trees (Equation 2) (Paulo & Tomé, 2009). The first equation applies to adult trees (with diameter at chest height greater than 60 cm) whereas equation 2 is applied to juvenile trees (diameter at chest height lower than 60 cm). Although these equations were developed for cork oaks, they were also applied to estimate the growth of holm oaks, since the growth equations for this species considering the Portuguese edaphoclimatic constraints have not been developed yet. Growth equations have been developed for *Quercus ilex* spp*. balota* (Martin *et al*. manuscript draft) in Spain, but they were not used because of the ecological differences between the study sites.

Eq.1

$$d_{t+a} = 200\left(1-e^{-(-0.00173+0.000383\ Si)\ a}\left(1-\left(\frac{d_t}{200}\right)^{1.0819}\right)\right)^{\frac{1}{1.0819}}$$

Growth equation for adult trees. From (Tomé et al., 2006). Where dt and "dt + a" are the diameters at 1.30 m and at age t and at t + a, respectively; where a is one year and "Si" is a site index that typifies site productivity as a function of soil and climatic variables, such as precipitation, solar radiation, temperature, soil drainage or levels of soil organic matter.

Eq. 2

$$id = \frac{1}{3}\ (0.7356 + 0.0178\ d - 0.0475\ G + 0.0763\ Si)$$

Growth equation for juvenile trees. From (Paulo & Tomé, 2009). Where id is the annual growth in diameter (cm); d is diameter at 1.30 m (cm); G is basal area ($m^2\ ha^{-1}$);

A Si of 13 was assumed for the holm oak area and of 14 for the cork oak patches (Paulo *et al.*, 2014; Paulo & Tomé, 2009; Tomé *et al.*, 2006). For the holm oaks area, a lower Si was used corresponding to lower soil drainage and lower moisture content, conditions for which the holm oak is better adapted. G was defined as corresponding to one year, the year of the analysis, 2012, on which this evaluation focuses in this particular case.

Calculations were made considering the trees with and without roots. In general, in the emergy evaluation method, this calculation is simplified and made without considering the roots of the trees. However, the root system of oaks, in the Montado, has been considered fundamental for a set of ecosystem functions (Azul et al., 2010; Dinis et al., 2015), so the calculation was carried out considering also the emergy of the tree roots. In emergy terms the difference is not large, since the roots of the trees are a co-product of the growth of the tree itself, that is, the emergy which gives rise to the tree inevitably gives rise to its roots. What differs is its transformity, since the same emergy is distributed over a larger quantity of biomass and the corresponding energy, being the associated transformity, slightly lower.

Parcel with cork oak (biomass)				Total				
2.32	ha	**220156.95**	kg/ha	510962.25	kg	kg/ha	445771.7	kg
		100	tree/ha	232.09	trees			
Area with young trees				Total				
20.40	ha	47462.74	kg/ha	968486.64	kg	kg/ha	831211.1	kg
		100	tree/ha	2040.52	trees			
Holm oaks medium density				Total				
74.06	ha	48222.67	kg/ha	3571366.17	kg	kg/ha	2129930	kg
		73	tree/ha	5406.37	trees			
Holm oaks high density				Total				
17.77	ha	96359.12	kg/ha	1712792.95	kg	kg/ha	983931.2	kg
		110	tree/ha	1955.26	trees			
				6763608.02	kg	kg		
		Total with roots		6.76E+06	kg	**kg**	**Total without roots**	
					9402	holm oaks	465.51	kg average dry weight per holm oak
			9634	trees				
					232	cork oaks	1541.10	kg average dry weight per cork oak
				4.73E+06	kg	3.07E+06	kg	

16200000	J/kg	dry weight	dry weight
	Energy in biomass	7.67E+13	4.98E+13
	Energy in an average holm oak	7.54E+09	J
	Energy in an average cork oak	2.50E+10	J

Annual growth:

Parcel with cork oak				Total		Total without roots		
2.32	ha	**120.57**	kg/ha	279.82	Kg	116.00	kg/ha	269.22 kg
		100	tree/ha	232.09	Trees			
Area with young trees				Total		Total without roots		
20.40	ha	480.60	kg/ha	9806.71	Kg	456.72	kg/ha	9319.56 kg
		100	tree/ha	2040.52	Trees			
Holm oaks medium density				Total		Total without roots		
74.06	ha	239.07	kg/ha	17705.77	Kg	214.36	kg/ha	15875.26 kg
		73	tree/ha	5406.37	Trees			
Holm oaks high density				Total		Total without roots		
17.77	ha	265.27	kg/ha	4715.30	kg	230.90	kg/ha	4104.32 kg
		110	tree/ha	1955.26	trees			
				32507.61	kg	29568.37	kg	
		Total with roots		**3.25E+04**	**kg**	**2.96E+04**	**kg**	**Total without roots**

9634	9402	holm oaks	2.40	kg average dry weight of annual growth/holm oak			
trees	232	cork oaks	0.84	kg average dry weight of annual growth/cork oak			
			2.28E+04	kg	2.07E+04	kg	
			dry weight		dry weight		

Energy in biomass	3.69E+11	J	3.35E+11	J	16200000	J/kg	
Energy in an average holm oak	3.89E+07	J Total	3.65E+11	J		Total	3.32E+11
Energy in an average cork oak	1.37E+07	J Total	3.17E+09	J		Total	3.05E+09
			with roots			without roots	

Emergy to cork evaluation

Biomass growth in 9 years	2518.42	kg	2.34	%	279.82
Cork growth in 9 years	105000	kg	97.66	%	11666.67
					11946.49
	107518.4		100	%	
10 trees produce	610.98	kg	of cork in a year		

232.09	trees	produce	14180.36	kg	of cork in a year
			127623.2	kg	of corkin 9 years

After estimating the energy corresponding to the annual growth of the oak trees on the farm, the calculation of the emergy is the following.

7 Trees biomass			
Area with holm oaks	59	ha	
Area with cork oaks	2	ha	
Emergy of evapotranspiration of holm oaks	5.63E+16	sej y^{-1}	
Emergy of evapotranspiration of cork oaks	2.53E+15	sej y^{-1}	
Emergy of evapotranspiration of the oaks	5.89E+16	sej y^{-1}	
Annual growth of holm oaks	3.65E+11	J	Considering the roots
	3.32E+11	J	not considering the roots (used to compare with other evaluations)
Annual growth of cork oaks	3.17E+09	J	Considering the roots
	3.05E+09	J	not considering the roots (used to compare with other evaluations)
Total annual grouth	3.69E+11	J	
Transformity of annual growth of holm oaks biomass	154175	sej J^{-1}	considering the roots
	169586	sej J^{-1}	not considering the roots (used to compare with other evaluations)
Transformity of annual growth of cork oaks biomass	796835	sej J^{-1}	considering the roots
	828209	sej J^{-1}	not considering the roots (used to compare with other evaluations)
Transformity of the annual growth of the oaks	159707	sej J^{-1}	

8. Acorns

Acorns play various roles in the system, namely the function of tree regeneration, as food for wildlife, in addition to serving as feed for cattle raised on the farm (Focardi *et al.,* 2000; Pons & Pausas, 2007). Given the difficulty in estimating the proportion of acorns involved in each of these functions, it is assumed that cattle only consume half of acorn production. The emergy associated to these acorns is proportional to the amount of material in each flow, in this case half of the total emergy invested in producing acorns. Acorns consumed by cattle are a split of the same material so with the same transformity. The data for annual production of acorns was derived from the National Forestry Inventory (AFN, 2010).

Annual acorns production of an holm oak Montado		246.3	$g\ m^{-2}$	(IFN, 2010)	
Annual acorns production of a cork oak Montado		170.8	$g\ m^{-2}$	(IFN, 2010)	
Total annual production of acorns by holm oaks		1.45E+08	g		
Total annual production of acorns by cork oaks		3.42E+06	g		
Total annual production of acorns		1.49E+05	kg		7,44E+04
Energy in cork oak acorns		9.34	$MJ\ kg^{-1}$	(Kaya & Kamalak, 2012)	
The same content for holm oak acorns will be assumed		9.34E+06	$J\ kg^{-1}$		
Energy in acorns produced on the farm		1.39E+12	J		6.95E+11
Annual emergy of the acorns	HO	5.63E+16	sej		
	CO	2.53E+15	sej		
	Total	5.89E+16	sej		2.94E+16
Transformity of acorns		42381	$sej\ J^{-1}$		

9. Natural pasture (not including area for bales)

To estimate the emergy linked with the natural pasture the former calculation of evapotranspiration of natural pastures considering seven months of growing season was used. Due to the difficulty of accounting for the vegetative annual growth of the pasture in the different plots, data from literature was used to estimate the annual biomass production (dry weight) of natural pastures in open areas, in the understory, but also the above-ground biomass and roots in both situations. This is another source of uncertainty that would deserve more evaluations in the region focusing on natural pastures with different conditions and compositions.

Incident solar radiation	6.47E+13	$J\ ha^{-1}$
Area with natural pastures	125	ha
Natural pastures in open areas	64	ha

Natural pastures in the understory	61	ha	
Albedo	17%	SEARN, 1988	
Emergy of Incident solar radiation	(Incident) (1-albedo) (area)		
Emergy of Incident solar radiation	6.71E+15	seJ y^{-1}	
Soil loss each year in open pastures	15.6	kg $ha^{-1}y^{-1}$	Lopes *et al.* (1998)
Soil loss in the farm	9.98E+05	g y^{-1}	
Medium content in C of the farm soil	2.41%		
Energy content in organic matter	3.40E+04	J g^{-1}	Rovira & Henriques (2011)
Energy loss by erosion	8.17E+08	J y^{-1}	
Transformity of soil organic matter	1.12E+05	sej J^{-1}	(Cohen *et al.* 2006 multiplied by 0.585 to convert to the 9.26E+24 baseline)
Transformity of soil organic matter (Baseline 2016)	1.45E+05	sej J^{-1}	
Emergy of annual erosion	1.19E+14	sej y^{-1}	
Evapotranspiration of Montado natural pasture	92.46	mm y^{-1}	(Paço *et al.*, 2009)
Chemical potential energy in evapotranspiration of natural pasture	2.78E+11	J	
Transformity of evapotranspiration	28100	sej J^{-1}	(Campbell, 2003, in the 9.26E+24 baseline)
Transformity of evapotranspiration (Baseline 2016)	36415	sej J^{-1}	
Emergy of evapotranspiration	1.01E+16	sej y^{-1}	
Annual biomass production (dry weight) of natural pastures in open areas	642.5	g m^{-2}	(Hussain *et al.*, 2009)
Annual biomass production (dry weight) of natural pastures in the understory	368.8	g m^{-2}	(Hussain *et al.*, 2009)
Annual productivity of natural pasture in open areas (above-ground biomass and roots)	4.11E+08	g	
Annual productivity of natural pasture in the understory (above-ground biomass and roots)	2.25E+08	g	
Annual productivity of the natural pasture	6.36E+08	g	
Energy in natural pasture	1.60E+04	J g^{-1}	estimation based on Rosado (2009)
Energy annually available in natural pasture	1.02E+13	J y^{-1}	
Transformity of the natural pasture	1006	sej J^{-1}	(Only evapotranspiration and erosion were considered and not the incident solar radiation to avoid double counting)
Emergy of the natural pasture	1.02E+16	sej y^{-1}	

10. Bales

In this estimation of the emergy linked to bales, only the emergy necessary to the production of the hay that is used in bales is presented, once the corresponding fuels, machinery and labor necessary to transform this hay into bales were estimated in the corresponding sections. Later on, in sub-subsection 5.2.2, a calculation will be presented with the total emergy of the bales including the necessary machinery, fuels and labor. This procedure was carried out to avoid double counting the emergy in bales and because it is important for the conclusions of this study to distinguish the labor, the machinery and the fuels used in the different activities. Knowing, from the owner, the amount of bales produced in the 2012 year, the calculations were made to estimate the amount of hay used to make these bales.

Hay is cut at 25% moisture content	Guide to moisture content of hay (Australian Fodder Industry Association www.afia.org.au/index.php/fodder-care/hay-factshoots/making-quality-hay/144-guide-to-moisture-content-of-hay

If the farm produces 107500 kg of hay bales with 10% moisture, the hay that results in these bales was

	107500		10%	water	corresponds to		10750	kg of water
	107500		25%	water	corresponds to		26875	kg of water
To	107500	must add	15%	water	corresponding to		16125	Kg
	with a total weight of			1.24E+05	kg of hay			
	or			1.24E+08	g of hay			
	with			1.60E+04	Jg^{-1}	estimation based on Rosado (2009)		
	Energy in the hay			1.98E+12	J			
	Transformity in the hay before cutting is				19282	$seJ\ J^{-1}$		
	Emergy in the hay before cutting				3.81E+16	seJ		

11. Erosion, topsoil

The erosion of the topsoil is considered an input to the system because some practices lead inevitably to erosion. What matters to this study is the loss of organic matter because it is considered the soil component that plays the most important functions in the soil. To estimate the organic matter content, an assessment of the soil on the farm was carried out, as an analysis by the laboratory of the University of Évora. For this analysis 70 soil samples were taken from the farm unit, corresponding to 7 plots identified in order to cover all the variability of the farm situations, with regard to the soil quality. Different organic matter levels were detected in different plots, with the higher soil organic matter contents corresponding to the plots where cattle go more frequently. An average value for this soil organic matter was estimated for the entire farm from this calculation. The average soil loss of the natural pastures is a value that can not be determined for this farm. As the other data related to natural pastures (evapotranspiration and productivity) it was necessary to rely on data from literature. As in the former cases, better data will be obtained if more measures of soil loss were carried out and published for different conditions in Alentejo.

Organic Matter content	4.43%		
Energy in organic matter	34	J mg^{-1} C	Rovira & Henriques (2011)
	3.40E+07	J kg^{-1} C	
Medium content in C of the farm soil	2.41%		
Average soil loss in natural pastures in open spaces	15.6	kg ha^{-1} y^{-1}	Lopes *et al.* (1998)
Average soil loss under the trees	0	kg ha^{-1} y^{-1}	Cubera *et al*. (2009)
Area of natural pastures in open space	107	ha	
Total soil loss in open spaces in the farm	1669.2	kg y^{-1}	
Total organic matter loss in the farm	73.95	kg y^{-1}	
Total of organic carbon lost in the farm	40.18	kg y^{-1}	
Total of energy lost with this carbon	1.37E+09	J y^{-1}	
Transformity of soil organic matter	1.92E+05	sej J^{-1}	(Cohen *et al*., 2006 in 15.83E+24 sej baseline)
	1.12E+05	sej J^{-1}	in the 9.26E+24 baseline
Transformity of soil organic matter (Baseline 2016)	145555	sej J^{-1}	
Emergy of topsoil erosion	1.99E+14	sej y^{-1}	

12. Seeds

As explained previously, the sowing of *Trifolium subterraneum* was done in the poorer soil areas of the farm. However, the corresponding gains in pasture productivity are accessible for cattle in the same way as if it had been sown in a distributed mode by the farm, therefore it is assumed that the sowing has been done throughout the grazed area.

Lifetime of a sowed *Trifolium subterreneum* pasture	20	y	
Year of sowing	2002		
Amount applied	1.00E+03	kg	
Annual amortization	5.00E+01	kg	
Seeds cost	7	€ kg^{-1}	
	8.46	$	
Seeds total cost	8.46E+03	$	
Seeds annual cost	4.23E+02	$	
Unit emergy value for Portuguese money in 2012	4.08E+12	sej $\$^{-1}$	(adapted by Oliveira from Oliveira *et al*. 2013, in the 15.2E+24 baseline)
UEV for Portuguese money in 2012 (Baseline 2016)	3.22E+12	sej $\$^{-1}$	
Emergy of the seeds	1.36E+15	sej	as a service and not as material
Energy in seeds	1.44E+05	J g^{-1}	Schiere *et al.* (2006)
Total annual energy in seeds	7.19E+09	J	
UEV of forage seeds	6.89E+08	sej g^{-1}	in the 9.44E+24 sej y^{-1} baseline (Bastianoni, 2001)
UEV of forage seeds (Baseline 2016)	8.76E+08	sej g^{-1}	
Emergy of the seeds	4.38E+13	sej	as a material
Total emergy of the seeds with services	1.41E+15	sej	
Transformity of seeds with services	195546	sej J^{-1}	

13. Fuels

To discover the amount of fuels used on the farm it was necessary to know, beforehand, the activities carried out; with which kind of machinery and how much time was spend on them. For data organization Table 5 was built with the help of several interviews with the manager.

Table 5 - Activities developed in the Holm Oaks farm.

When	Activity	Equipment power cv	Hours y^{-1}	Fuels (L)	Lubricants (L)
Winter (before the maturation of shrubs' seeds)	Mobilize the soil where there are too many shrubs	70	16.00	123.2	14.784
Last half part of March	To fertilize the hay	70	15.00	115.5	13.86
First days of April and repeated in May or June	Make firebreaks	70	24.00	184.8	22.176
Last 15 days of May or 10 to 20 May	To cut the hay in 43 ha	80	27.00	237.6	28.512
2 days later	To rake the hay	120	8.00	105.6	20.064
10 days later the hay cut	To bale the hay	150	8.00	132	26.4
July	To store the bales	70	24.00	184.8	22.176
Summer and winter	To transport the bales to the fodder	70	183.00	1409.1	169.092
Summer	To give a bath to cattle	70	4.00	30.8	3.696
3 times a year	To sell cattle	70	30.00	231	27.72
Done at the same time he keeps the cattle	Water pump	163	46.00	184	16.008
Every day	Motion between the farm and manager's house	Van ISUZU 163 cv, spends 6.4L each 100 km on the road and 9.2 L each 100 km in the city.	182.50	2160	187.92
Sporadically	Making ponds	Caterpillar hydraulic drill 140 kW	21.15	846.12	211.53
Sporadically	In the fences	70	6.60	50,82	6.0984
Sporadically	Making fences	150	32.40	534.6	74.844
Note 1: 1 cv (cheval vapeur) = 7.350200E-1 kW (kJs^{-1}) has more or less the same meaning as horse power (hp) but hp = 7.456999E-1 kW (kJs^{-1}). Following this a tractor with 70 cv has 51.45 kW of power, with 80 cv has 58.8 kW of power, with 120 cv has 88.2 kW of power and finally a tractor with 150 cv has 110.25 kW (Santos, 1996). 1 hp = 1.013869 cv				6529.94	844.88

We used the average consumption of fuels and lubricants for different kinds of machines from Santos (1996) as well as from the catalogs of farming machinery with their characteristics.

On the other hand, there was the need, for the sake of evaluation, to separate the different activities carried out on the farm into activities linked to cattle (identified in table 5 with purple colour), to the bales (identified with pink colour), and general activities (identified with white colour). But the activities are not always easy to classify as some of these are mandatory for any exploration or relate to jobs that will benefit all the activities. Among these it is possible to identify the firebreaks maintenance, which is mandatory, even if the farm is not a source of any income, or the daily trips of the manager between his residence and the farm. This last activity was assigned to cattle because legislation about cattle rearing explicitly obliges a daily presence of the manager on the farm.

To discover the consumption of fuels in the activities it was assumed that the average consumption of petroleum per cv per hour to run a tractor is 0.11 L, acording to Santos (1996).

To discover the lubricants used in each activity Table 6 was used, which is an adaptation of a Santos (1996) table.

After accounting for all the fuels spent in the different activities, the associated energy was calculated and distinguished by fuels for bales, cattle, fences and other uses. With the transformity value for fuels estimated by Bastianoni *et al.* (2009) the corresponding emergy values were estimated.

Table 6 - Average consumption of lubricants for machines (Santos, 1996, p.25)

Kind of machine	Power kW	Power cv	Lubricants L h^{-1}
tractor	51 - 59	70 - 80	0.12
tractor	73.5	100	0.14
tractor	92	120	0.19
tractor	110	150	0.2
tractor	110	150	0.2
tractor	140	190	0.25
oil motor (not tractor)	120	163	0.087

Annual fuel consumption	7374.8	L of fuels
1 gal = 1,32E+8 J = 3,785412 L	Santos (1996)	
1 L = 1,32E+8 J/3,785412		
1L	3.49E+07	J
Total energy	2.57E+11	J
Energy in fuels for bales	3.09E+10	J
Energy in fuels for cattle	1.98E+11	J
Energy in fuels for fences	2.13E+10	J
Energy in fuels for other uses	7.22E+09	J

Transformity of fuels	65826	sej J^{-1}	(Bastianoni *et al.,* 2009)
Transformity of fuels (Baseline 2016)			85303.67 sej J^{-1}
Emergy in fuels for bales	2.64E+15	sej	
Emergy in fuels for cattle	1.69E+16	sej	
Emergy in fuels for fences	1.81E+15	sej	
Emergy in fuels for other uses	6.16E+14	sej	
Total emergy of fuels used in the farm	2.19E+16	sej	

14. Fertilizers

Fertilizers are apllied in a small area of the farm (40 hectares) from where hay will be cut to produce bales.

According to the manager he applies 150 kg of superphosphate 18% per hectare on 40 hectares of the farm. This corresponds to the application of 27 kg of P_2O_5 per hectare with a total amount of 1080 kg.

P_2O_5 annualy applied	1080 kg	1.08E+06 g		
Transformity of the Superphosphate 18% (Single Superphosphate – SSP - Granular)		3.32E+09	sej g^{-1}	(in the 15.80E+24 baseline, for DAP from Brandt-Williams, 2001)
Transformity for phosphate (Baseline 2016)		2.52E+09	sej g^{-1}	
Emergy of the fertilizer		2.72E+15	sej	

15. Mechanical equipment

The emergy assessment of the mechanical equipment is estimated by weight of steel of this machinery. The survey of the existing machinery in the farm and its power was made through various interviews and observation of the equipment itself. Its weight was estimated by reference to equipment manuals. These data are presented in Table 7 together with the useful life and other data from machinery and information about its use in the farm.

Table 7 – Machines used on the farm

Item	Brand	Weight	Year	Hours of utilization	Useful life	Mass	Type of use	Allocation to farm activity (kg)			
		(kg)			(y)	(kg y^{-1})		Cattle	Bales	Other uses	Fences
70 cv tractor	Ford	2960	1992	302.6	12	246.67	used only on the farm	181.78	31.79	19.56	5.38
Disc harrow	Galucho A2CP 1824H serie M91	800	2004	40	12	33.33	used half time on this farm	8.33	0.00	25.00	0
Mower machine a)	Krone Easy Cut	567	2012	8	12	0.19	rented	0	0.19	0	0
Hay rake	Landini	1460	2011	27	12	1.64	rented	0	1.64	0	0
Baler	New-Holland	1800	2009	8	12	0.60	rented	0	0.60	0	0
80 cv tractor	New-Holland	3780	2001	27	12	4.25	rented	0	4.25	0	0
120 cv tractor	New-Holland	3780	2001	8	12	1.26	rented	0	1.26	0	0
150 cv tractor	New-Holland	4360	2005	40.4	12	7.34	rented	0.00	1.45	0.00	5.89
Hydraulic driller	Caterpillar 325D 190 cv	28590	2009	21.15	12	25.19	rented	25.19	0.00	0.00	0
Pendulum sower	Aguirre	176	2003	15	10	5.87	used only 1/3 of the time on this farm	0.00	5.87	0.00	0
Water pump	Kubota KS 130	17	2006	46	12	1.42		1.42	0	0	0
Chainsaw	STIHL	5.6	2010	8	8	0.70		0	0	0.70	0
Van	ISUZU DMax30	1895	2007	182.5	10	94.75	half time on this farm	94.75	0	0	0
Trailer	Galucho	2185	1968	237	12	91.04	half time on this farm	81.82	9.22	0	0
Atomizer	Tomix	200	2010	21.2	10	10.00	half time on this farm	5.00	0	0	7.5
Pile driver	Rabaud Vibrescopic	1000		16.2	12	0.68	rented	0.00	0	0	0.68
Tightener		5		32.4	12	0.01	rented	0.01	0	0	0
Post pownder		0.5		32.4	12	0.00	rented	0.00	0	0	0
Total weight allocated to the farm						**519.28**		398.30	56.27	45.26	19.44
a) Mower machine – (567 kg x 8 h)/(12 y x 2000h y^{-1}) = 0.189 kg (same calculation for the other rented machines)									519.28		

To assign the emergy of the machinery to the different activities, the weight of the machines was affected to its depreciation rates and hours of work for each activity within the farm. The activities in which machinery is used are cattle, bales, other uses and fences.

Some machines belong to the manager, others are rented, some are used in many activities, and some activities are carried out together by the manager or another worker. As the manager owns another farm he can use some machines on both farms, and this proportion of utilization had also to be estimated.

After determining the machinery weight by activity the corresponding emergy was found through the transformity value found by Ulgiaty (1994) to steel.

Total machinery weight	5.19E+05	g	
Mechanical equipment for the bales	5.63E+04	g	
Mechanical equipment for cattle	3.98E+05	g	
Mechanical equipment for other uses	4.53E+04	g	
Mechanical equipment for fences	1.94E+04	g	
Transformity of steel	7.76E+09	sej g^{-1}	(Ulgiati *et al.*, 1994)
Transformity of steel (Baseline 2016)	1.01E+10	sej g^{-1}	
Emergy of mechanical equipment for the bales	5.66E+14	sej	
Emergy of mechanical equipment for cattle	4.01E+15	sej	
Emergy of mechanical equipment for other uses	4.55E+14	sej	
Emergy of mechanical equipment for fences	1.96E+14	sej	
Total emergy of machinery	5.22E+15	sej	

16. Plastic

Plastic is annualy used to cover and protect the bales made on the farm. It is a black plastic film of high density polyethylene purchased in rolls of 1890 square meters.

Material used to cover the bales	Black plastic film of high density polyethylene		
Amount of plastic annualy used	1890	m^2	
Plastic weight	116	g m^{-2}	
Total plastic weight	2.19E+05	g	
Plastic transformity (without services)	5.30E+09	sej g^{-1}	(Buranakarn, 1998; Odum, 2002)
Plastic transformity (Baseline 2016)	6.87E+09	sej g^{-1}	
Emergy of the plastic (material)	1.51E+15	sej	

17. Feeding troughs

The manager owns fithteen feeding troughs made of steel and iron. The emergy determination is slightly different because both emergy values must to be added. A new transformity value is then found for feeding troughs resulting from the conjugation of both emergy flows of steel and iron.

Feeding troughs number	15	units	
Feeding troughs weight	2.50E+05	g	
Feeding trough material	3.15E+06	g	iron
	6.00E+05	g	steel
Transformity of iron mesh	2.80E+09	sej g^{-1}	(Odum, 2002)
Transformity of iron mesh (Baseline 2016)	3.63E+09	sej g^{-1}	
Transformity of steel	7.76E+09	sej g^{-1}	(Ulgiati *et al.*, 1994)
Transformity of steel (Baseline 2016)	1.01E+10	sej g^{-1}	
Emergy of the iron	1.14E+16	sej	
Emergy of the steel	6.03E+15	sej	
Emergy of the feeding troughs	1.75E+16	sej	
Feeding trough lifetime	10	y	
Annual emergy of the feeding troughs	1.75E+15	sej	
Feeding trough weight	3.75E+06	g	
Transformity of feeding trough (without services)	4.66E+08	sej g^{-1}	

18. Fences

The determination of the emergy of the fences is more complex because it is a complex product composed of pine wood posts, and steel wire and iron mesh. The extension of the fences was determined using Quantum GIS and after establishing the fences location on the farm. It corresponds to 27 000 meters, half of which was built and is maintained by the manager.The fences' structure helped to estimate the quantity of the materials used on the farm. The fences on the farm are composed of posts of eight kilograms, each four meters long and two rows of galvanised steel wire, as well galvanised iron mesh. In addition to the material, working hours, machinery and fuel to build and maintain these fences was also required. Although they have been accounted for, in the final table, machinery, fuel and labor appear in the corresponding sections and so, only the emergy corresponding to the materials used in its construction appears individualized. The calculations for each component of fences were made separately to enable its accounting in the predefined groups (fuel, labor, machinery).

Fences extension	13500	m	
Distance between wood posts	4	m	
Total of wood posts in the farm	3375		
Posts material	pine wood		**Posts**
Posts weight	8.00E+03	g	
Total of posts weight in the farm	2.70E+07	g	
Total of posts weight in the farm (annual allocation)	2.70E+06	g	
Transformity of the posts	1.49E+09	sej g^{-1}	(Campbell *et al.*, 2005)
Transformity of the posts (Baseline 2016)	1.93E+09	sej g^{-1}	
Emergy in the posts	5.21E+15	sej	
Working hours to build the fences	324.00	h	
Lifetime of the fences	10	y	**Labor**
Corresponding metabolic energy	141210000	J	
Metabolic Energy per year	14121000	J	
Transformity of fence erectors	3.08E+08	sej ind^{-1}	(Campbell, 2013)
Transfromity of fence erectors (Baseline 2016)	3.99E+08	sej ind^{-1}	
Emergy of the service of puting fences	5.64E+15	sej	
Wire extension	27000	m	
Wire material	galvanized steel		Fregaze – Redes e Derivados de Arame, Lda. (2013)
Wire weight	80	g m^{-1}	Fregaze – Redes e Derivados de Arame, Lda. (2013)
Iron mesh weight	7900	g m^{-1}	Fregaze – Redes e Derivados de Arame, Lda. (2013)
Iron mesh extention	13500	m	
Lifetime of the wire	10	y	Fregaze – Redes e Derivados de Arame, Lda. (2013)
Galvanised steel wire weight	2.16E+06	g	
Galvanised iron mesh weight	1.07E+08	g	
Transformity of steel wire	7.76E+09	sej g^{-1}	(Ulgiati *et al.*, 1994)
Transformity of steel wire (Baseline 2016)	1.01E+10	sej g^{-1}	
Transformity of iron mesh	2.80E+09	sej g^{-1}	(Odum, 2002)
Transformity of iron mesh (Baseline 2016)	3.63E+09	sej g^{-1}	
Emergy of the steel wire	2.17E+16	sej	**Wire**
Emergy of the iron mesh	3.87E+17	sej	
Emergy in wire (steel wire + iron mesh) in fences	4.09E+17	sej	Transformity of wire in fences
Annual emergy in wire in fences	4.09E+16	sej	3.76E+09 sej g^{-1}
Fences wire weight	1.09E+08	g	

Fences wire weight (annual allocation)	1.09E+07	g	1.36E+07 g	
Annual machinery used to put the wire in the fence	7.43	g		
Transformity of steel	7.76E+09	sej g^{-1}	(Ulgiati *et al.*, 1994)	
Transformity of steel (Baseline 2016)	1.01E+10	sej g^{-1}		
Emergy of machinery annualy used to put the wire	7.47E+10	sej		
Emergy of machinery used to put the posts in the ground	1.96E+14	sej		**Machinery**
Emergy of fuels used to make fences	1.81E+15	sej		
Transformity of the fences (with services)	3.96E+09	sej g^{-1}		
Transformity of the fences (without services)	3.54E+09	sej g^{-1}		
Emergy of the fences (with services)	5.37E+16	sej		
Emergy of the fences (without services)	4.81E+16	sej		

Weight of the materials	1.36E+07	g	**Materials - Posts+Wire**
Transformity of fences' materials	3.39E+09	sej g^{-1}	
Emergy of fences'materials	4.61E+16	sej	

19 Medications

The veterinarian of the farm estimated an average annual spending of thirty grams of medication per animal per year. Besides the 80 suckler cows and the two bulls, 72 calves were estimated as annual production from the farm and all these animals need medication.

Nevertheless, the emergy value for medication is a small amount compared to other emergy flows in the farm.

Average weight of medications per animal	30	g y^{-1}	Local livestock veterinarian
Total number of animals in the farm	154		
Average weight of medications in the farm	4620	g y^{-1}	
UEV of medications	2.75E+09	sej g^{-1}	Campbell & Ohrt (2009)
UEV of medications (Baseline 2016)	3.56E+09	sej g^{-1}	
Emergy of medications	1.65E+13	sej	

20 Labor

The emergy in services was evaluated using the determination already carried out by Campbell *et al*. (2013) of the Emergy of the Occupations to the United States for the year 2008. To use this data it is assumed that the investment in education and training of a worker for a job in the United States operating in 2008 is similar to the education and training of a worker for the same job in Portugal operating in the year of 2012. Despite the uncertainty that this assumption may introduce in the analysis it allows an independent assessment in relation to the economic evaluation, enabling future comparisons between the two assessment methods. The transformity values for each occupation were indicated by Campbell (Campbell *et al.,* 2013).

Labor hours were distributed among the different activities, but some labor hours were assigned to various activities simultaneously, such as repairing machines or check-up for a tractor, because both the tractor and the machines are used in different activities. The allocation of these labor hours was made in proportion to the weight of the machines in the first case and the number of hours used in each activity, since the tractor works with these machines. The generic bureaucratic work was distributed similarly for all activities. Table 8 summarises all these data, where the purple color represents labor with cattle, the pink color represents labor with the bales, the white represents the labor for other work, and the light blue color represents labor for fences. The other work carried out on the farm includes opening firebreaks twice a year, repairing machines associated with this activity, some bureaucratic work, as well as the use of fuels and machinery associated with these activities. A distinction has also been made between the labor done by the manager and the purchased labor. In the rows corresponding to “Check-up for 70 cv tractor”, “respond to governmental bureaucracy” and “repairing machines”, it is possible to see the final distribution of the main activities: cattle, bales, other work and fences.

Table 8 – Working hours in the different activities.

Labor (h)	Activity	Done by	Transformity (Campbell *et al*,. 2013) (sej J^{-1})	Transformity (Baseline 2016) (sej J^{-1})	Energy of metabolic work spent (J)	Emergy (sej)
16	Mobilizing the soil	manager	3.93E+08	5.09E+08	6.97E+06	3.55E+15
15	Fertilizing the hay	manager	3.93E+08	5.09E+08	6.54E+06	3.33E+15
24	Making firebreaks	manager	3.93E+08	5.09E+08	1.05E+07	5.33E+15
27	Cutting the hay	purchased	3.93E+08	5.09E+08	1.18E+07	5.99E+15
8	Mowing the hay	purchased	3.93E+08	5.09E+08	3.49E+06	1.78E+15
8	Baling the hay	purchased	3.93E+08	5.09E+08	3.49E+06	1.78E+15
24	Storing the bales	manager	3.93E+08	5.09E+08	1.05E+07	5.33E+15
183	transporting the bales to the fodder	manager	3.93E+08	5.09E+08	7.98E+07	4.06E+16
4	giving baths to the cattle	manager	3.34E+08	4.33E+08	1.74E+06	7.55E+14
20	Supporting veterinary activity	manager	3.34E+08	4.33E+08	8.72E+06	3.77E+15
10	Veterinary activity	purchased	5.15E+08	6.67E+08	4.36E+06	2.91E+15
30	Selling cattle	manager	3.11E+08	4.03E+08	1.31E+07	5.27E+15
182.5	Travelling to the farm	manager	3.34E+08	4.33E+08	7.95E+07	3.44E+16
20	annual application to agro-environmental measures, keeping the field book, annual application to the single payment scheme and licenses	purchased	4.45E+08	5.77E+08	8.72E+06	5.03E+15
10	Integrated-production certification	purchased	4.45E+08	5.77E+08	4.36E+06	2.51E+15
21.153	Making ponds	purchased	3.11E+08	4.03E+08	9.22E+06	3.72E+15
3.07	Check-up for 70 cv tractor (see note 1)	manager	3.58E+08	4.64E+08	1.34E+06	6.21E+14
0.53			3.58E+08	4.64E+08	2.30E+05	1.07E+14
0.32			3.58E+08	4.64E+08	1.38E+05	6.39E+13
6.60			3.58E+08	4.64E+08	2.88E+06	1.33E+15
50	Respond to governmental bureaucracy	manager	4.45E+08	5.77E+08	2.18E+07	1.26E+16
50			4.45E+08	5.77E+08	2.18E+07	1.26E+16
50			4.45E+08	5.77E+08	2.18E+07	1.26E+16
30.68	Repairing machines	manager	3.58E+08	4.64E+08	1.34E+07	6.20E+15
4.33			3.58E+08	4.64E+08	1.89E+06	8.76E+14
3.49			3.58E+08	4.64E+08	1.52E+06	7.05E+14
1.50			3.58E+08	4.64E+08	6.53E+05	3.03E+14
32.4	Making fences	purchased	3.23E+08	4.19E+08	1.41E+07	5.91E+15
835.57	**Total**					

The activity of making ponds required a special procedure to find the annual number of hours dedicated to this activity. Knowing the amount of soil mobilized per hour by the caterpillar and the number of ponds made by the manager, an estimate was made of the soil mobilized to get the annual number of hours of work that is associated with this activity. The ponds' area was estimated with help of the Quantum GIS and it was considered on average three meters deep in order to estimate the amount of soil mobilized.

Making ponds by Cornacho & Filhos, an excavation company		
Average useful life for ponds	20	y
Machine model	Caterpillar D325	
Working capacity of the machine	25	m^3 h
Average deepth of the ponds	3	m
Total surface area	3525.5	m^2
Total volume of mobilized soil	10576.5	m^3
Total working hours in this work	423.06	h
Annual working hours spent making ponds	21.15	h

For the labor spent making the fences, the estimation was made using the indication by a fence buider that three workers in an eight hour day can make 1 kilometer of fence. Knowing that the manager made 13.5 kilometers of fences and assigning a lifetime of ten years to them, the value of 324 hours was obtained.

Making fences		
3 workers, during 8 hours to instal 1 km of fences		
324 h		
Lifetime of the fences	10	y

The hours of labor spent repairing machines were assigned to the different activities by the weight of the machinery, given that it will be an approximate measure of the need and time spent for repair. On the other hand the check-up for the tractor was assigned to the different activities using the number of hours spent on each of them.

Repairing machines				
for cattle	398.30	kg	30.68	h
for bales	56.27	kg	4.33	h
for other uses	45.26	kg	3.49	h
for fences	19.44	kg	1.50	h
Total	**519.28**	**kg**	**40.00**	**h**

Check-up for 70 cv tractor				
for cattle	233	H	3.07	h
for bales	40	h	0.53	h
for other uses	24	h	0.32	h
for fences	6.6	h	0.09	h
Total	**303.6**	**h**	**4.00**	**h**

After filling table 8 it was possible to determine the total number of labor hours spent on each activity and the total associated emergy. Once they were classified in relation to the main activity with which they were related, it was possible to find an emergy value for each main activity: bales, cattle, fences and other activities.

Total of hours	835.57	h
Total of metabolic energy	3.64E+08	J
Transformity	5.62E+08	sej J^{-1}
Emergy for the labor in bales	3.18E+16	sej
Emergy for the labor in cattle	1.22E+17	sej
Emergy for labor to make fences	7.55E+15	sej
Emergy for labor in other activities	1.87E+16	sej
Emergy of the labor of harvesting firewood	4.60E+15	sej
Emergy of the labor in cork harvesting	2.01E+16	sej
Total emergy in labor on the farm	2.05E+17	sej

21 Subsidies

The subsidies received correspond to values indicated by the bookkeeper. The bookkeeping indications about the subsidies are in Appendix B.

A request for clarification from the IFAP – the Financing Institute of Agriculture and Fisheries, I.P. - Strategic Planning Office, helped to get a clearer idea of these subsidies

In the year of 2012 the support measures in the First pillar of the Common Agricultural Policy (CAP) – Direct payments to farmers were: RPU (Regime de Pagamento Único) which is the Single Payment Scheme (SPS), a support system for farmers, the basic principle of which is the total or partial detachment of production from farm productivity; VAL (Pémio às Vacas Aleitantes) is the Suckler Cow Premium which is granted provided that the stocking density on the holding is not more than 2 livestock units per unit of forage area used for these animals; and the POC (Prémio aos Ovinos e Caprinos) is the Sheep and Goat Premium. These had a European Community contribution of 100%. In 2012 the Slaughter Premium (Prémio ao Abate de Bovinos) was integrated into the RPU.

The support measures in the Second pillar of the Common Agricultural Policy (CAP) - rural development policy were: the ASA (Medidas Agro-Silvo Ambientais) that correspond to the Agri-environment measures. These are a key element for the integration of environmental concerns into the Common Agricultural Policy; and MZD (Medidas de Apoio às Zonas Desfavorecidas) is an aid to farmers in Less Favoured Areas (LFA) that provides a mechanism for maintaining the countryside in areas where agricultural production or activity is more difficult because of natural handicaps. These two measures benefited from a European Community contribution of 85%.

The SEC measure was a support for cattle farms with especially dry conditions and it was supported 100% by national funds.

Monetary support from the government to cattle	23669.63	€	
	27054	$	
Unit Emergy Value for Portuguese money in 2012 sej/$	4.08E+12	sej $\$^{-1}$	(adapted by Oliveira from Oliveira *et al*., 2013)
UEV for Portuguese money in 2012 (Baseline 2016)	3.22E+12	sej $\$^{-1}$	
Emergy of governmental support to cattle rearing	8.71E+16	sej y^{-1}	
Subsidies to the farm in general	15054.74	€	
	17207.57	$	
Emergy of governmental support to the farm in general	5.54E+16	sej y^{-1}	
Total	1.43E+17	sej y^{-1}	

22 Taxes paid to the government

As the manager owns another farm and taxes are payed including the activity of this other farm, the values indicated by the bookkeeping are not likely to be used in this evaluation. In an attempt to determin the amount of taxes paid to the government due to the cattle rearing activity, a simplification was made in order to deal with this question as if the owner had a system of simplified taxation. In fact he has the general system of taxation, but this includes other activities that are not of interest to this study, namely heritage, education expenses and expenses associated with his other holdings. On a simplified taxation system this deals with the volume of sales of the commercial activity, that which is of interest to this study. In this regime sales are taxed at 4% and subsidies at 13%.

		number	weight	price per kg								
Sells:	female calves	35	220	2.2	€ kg-1	7700	kg	16940	€	19362.42	$
	male calves	35	220	2.4	€ kg-1	7700	kg	18480	€	21122.64	$
	old cows	10	500	1	€ kg-1	5000	kg	5000	€	5715.00	$
	Totals					**20400**	**kg**	**40420**	**€**	**46200.06**	**$**
								4%		1848.00	$

Subsidies:		55437	$
	13%	7206.81	$

Value of taxes paid to the Government	9054.08	$
Unit Emergy Value for Portuguese money in 2012	4.08E+12	sej $\$^{-1}$
UEV for Portuguese money (Baseline 2016)	3.22E+12	sej $\$^{-1}$
Emergy in the taxes paid to the Government	2.92E+16	sej

23 Land use permit (rent to the owner)

This value is clearly indicated in the bookkeeping of the farm.

Annual rent to the owner	6616.82	€
	7563.03	$
Unit Emergy Value for Portuguese money in 2012	4.08E+12	sej $\$^{-1}$
UEV for Portuguese money (Baseline 2016)	3.22E+12	sej $\$^{-1}$
Emergy in the annual rent to the owner	2.44E+16	Sej

24 Hunting

To estimate the hunting on the farm we used the VAT registration number of the enterprise that manages the farm to know the number of hunted animals in the last seven years (2008-2014) in the hunting reserve. An average value of kilograms of hunting animals was found for the year of 2012. Once the hunting reserve is bigger than the Holm Oaks Farm, an estimation was made, in proportion to the farms area. The energy in these animals was estimated using the energy in raw deer meat from USDA nutrient lab (http://ndb.nal.usda.gov/ndb/foods/show/5263?manu=&fgcd).

= 120 kcal per 100 grams = 1200 cal g^{-1}* 4.186 J cal^{-1} = 5023 J g^{-1}

In order to have more accurate values for the emergy of the outputs of the farm, a solution had to be found for activities that were carried out on the farm without being assigned to a specific activity but without which the other activities could not continue. The way to solve this question was to assigne the emergy of the labor for other activities, of the fuels for other uses, mechanical equipment for other uses and subsidies received for the farm in general, to the outputs, in proportion of their emergy in an iteractive way. That is is to say that, in a first account, these emergy values were not included. The percentage of the emergy of each output was estimated and then the unassigned emergy flows were distributed among the outputs in proportions of their emergy share. New values of emergy were then found for the outputs.

		%	Labor in other activities (sej)	Fuels for other uses (sej)	Mechanical eq. for other uses (sej)	Subsidies to the farm in general (sej)
Hunting	1.77E+15	0.49	9.07E+13	2.99E+12	2.21E+12	2.69E+14
Firewood	6.35E+16	17.41	3.25E+15	1.07E+14	7.93E+13	9.65E+15
Cork	2.86E+16	7.84	1.46E+15	4.83E+13	3.57E+13	4.35E+15
Calves	2.71E+17	74.26	1.39E+16	4.57E+14	3.38E+14	4.12E+16
	3.65E+17	sej	1.87E+16	6.16E+14	4.55E+14	5.54E+16

Average weight of the hunting products	138820	g y^{-1}	(DGRF - Direcção Geral dos Recursos Florestais, process nº 4533)
UEV for hunting products in general	2.00E+06	sej J^{-1}	in 9.44E+24 sej y^{-1} baseline Brown & Arding (1991) with labor
	1.96E+06	sej J^{-1}	in 9.26E+24 sej y^{-1} baseline
UEV for hunting products in this farm (Baseline 2016)	2.54E+06	sej J^{-1}	
Energy in game meat	5023	J g^{-1}	
Energy in game meat in the farm	6.97E+08	J	
UEV for hunting products in this farm by weight unit	1.28E+10	sej g^{-1}	
Emergy of the hunting products	1.77E+15	sej y^{-1}	
Emergy of labor for other activities	9.07E+13	sej y^{-1}	
Emergy of fuels for other uses	2.99E+12	sej y^{-1}	
Emergy of mechanical equipment for other uses	2.21E+12	sej y^{-1}	
Emergy of the subsidies received	2.69E+14	sej y^{-1}	

for the farm in general			
UEV for hunting products in this farm (with services)	3.06E+06	sej J^{-1}	
Emergy of hunting products in this farm (with services)	2.14E+15	sej y^{-1}	
Annual value of the hunting products	1470	€	
	1680.21	$	Here it is not possible to have the value without services because the UEV value for hunting products in general is with services
Unit Emergy Value for Portuguese money in 2012	4.08E+12	sej $\$^{-1}$	
UEV for Portuguese money (Baseline 2016)	3.22E+12	sej $\$^{-1}$	

25 Firewood

The quantity of firewood extracted from the montado areas of the region was indicated by a specialized worker, as were the number of hours required to do the job, and the price charged for it. There exists some difference between the price of holm oak firewook and that of the cork oak firewood, due to the fact that the latter requires that the cork is removed in order for it to be burned as firewood. Anyway this output of the farm is from the owner and not from the manager.

The price of the work was used to estimate the emergy in the service of harvesting the firewood.

Average firewood harvested per year	0.2	Ton $ha^{-1}y^{-1}$	12.2	Ton y^{-1}
	2.00E+05	g $ha^{-1}y^{-1}$	1.22E+07	g y^{-1}
Energy in firewood	1.62E+04	J g^{-1}	(Francescato *et al.*, 2009)	
Energy in the firewood collected in the farm	1.98E+11	J		
Price of holm oak firewood	114.3	\$ Ton^{-1} ha^{-1}	24.4	Working hours
Price of the cork oak firewood	80.0	\$ Ton^{-1} ha^{-1}		
Holm oak area	59.0	ha		
Cork oak area	2.0	ha		
Working hours	24.40	h		

	10634333.3		
Metabolic energy to make this work	3	J	
Transformity of the service of harvesting firewood	3.34E+08	sej J^{-1}	
Transformity of the service of harvesting firewood (Baseline 2016)	4.33E+08	sej J^{-1}	
Emergy of the service of harvesting firewood	4.60E+15	sej y^{-1}	
Emergy of labor for other activities	3.25E+15	sej y^{-1}	
Emergy of fuels for other uses	1.07E+14	sej y^{-1}	
Emergy of mechanical equipment for other uses	7.93E+13	sej y^{-1}	
Emergy of the subsidies received for the farm in general	9.65E+15	sej y^{-1}	
Emergy of firewood (material)	5.63E+16	sej y^{-1}	Holm oaks
	2.53E+15	sej y^{-1}	Cork Oaks
Total emergy of the firewood (material)	5.89E+16	sej	
UEV (with services)	387386	sej J^{-1}	
UEV (without services)	298827	sej J^{-1}	
Emergy of the firewood (with services)	7.66E+16	sej	
Emergy of the firewood (without services)	5.91E+16	sej	

26 Cork

The amount of cork extracted each nine years was known directly from the farm owner. The hours of labor required to harvest this cork and the corresponding price was indicated by a specialized worker.

Value of the @ of cork	15	kg $@^{-1}$	
Average value of this low quality cork	15	€ $@^{-1}$ (regional prices by a farmer worker)	
	17.145	\$ $@^{-1}$	
Average cork production in the farm	7000	@	each 9 years
Production of cork	1.05E+05	kg	each 9 years
Production of cork in a year	1.17E+04	kg	
Total value of the cork	13335	\$ y^{-1}	
Working hours	1.38E+02	h y^{-1}	
Transformity of the cork harvester	3.34E+08	sej J^{-1}	
Trasformity of cork harvester (Baseline 2016)	4.33E+08	sej J^{-1}	
Emergy of the labor associated to cork	2.61E+16	sej y^{-1}	
Emergy of the cork oaks	2.53E+15	sej y^{-1}	
Emergy of cork in the tree	2.53E+15	sej y^{-1}	

Emergy of labor for other activities	1.46E+15	sej y^{-1}	
Emergy of fuels for other uses	4.83E+13	sej y^{-1}	
Emergy of mechanical equipment for other uses	3.57E+13	sej y^{-1}	
Emergy of the subsidies received for the farm in general	4.35E+15	sej y^{-1}	
The energy in the cork	26.2	kJ kg^{-1}	(according Mário Caetano from a cork enterprise)
Total annual energy in cork	3.06E+08	J	
Transformity of the cork (with services)	1.13E+08	sej J^{-1}	
Transformity of the cork (without services)	8.55E+06	sej J^{-1}	
Emergy of cork (with services)	3.45E+16	sej	
Emergy of cork (without services)	2.61E+15	sej	

27 Calves

Calves are the main output of this farm and represent a source of income to the manager. The number of animals sold in the auction was estimated with the help of the manager. 80 cows give birth to 72 calves from which 70 are sold in the market with 220 kg, plus some old cows with an average weight of 500 kg. This results in an average sale on auction of 2.04E+07 g y^{-1}.

	number	weight		
female calves	35	220	7700	kg
male calves	35	220	7700	kg
old cows	10	500	5000	kg
Total			**20400**	**kg**
Total		2.04E+07	g y^{-1}	

From this liveweight, and according Syrstad (1993), 7.5 % is fat and 9% protein. Greenfield and Southgate (2003) defined that the protein has 17 kJ g^{-1}, and the fat has 37 kJ g^{-1}, resulting in a total value of 8.78E+10 J of energy exported on sales in the auction.

		energy	
1.53E+06	g fat	5.66E+10	J
1.84E+06	g protein	3.12E+10	J
Total		**8.78E+10**	**J**

All the emergy values found up to this point of the work come together to produce this important output of the farm.

Emergy of the natural pasture	1.02E+16	sej
Emergy in bales	3.81E+16	sej
Emergy of the acorns	2.94E+16	sej
Emergy of fences (annual contribution)	4.61E+16	sej
Emergy for the labor in cattle	1.22E+17	sej
Emergy of the plastic used in the farm	1.51E+15	sej
Emergy of the seeds	4.38E+13	sej
Emergy of the feeding trough	1.75E+15	sej
Emergy of medication	1.65E+13	sej
Emergy of labor for other activities	1.39E+16	sej
Emergy of fuels for other uses	4.57E+14	sej
Emergy of mecanical equipment for other uses	3.38E+14	sej
Emergy of the subsidies received for the farm in general	4.12E+16	sej
Emergy of mechanical equipment for cattle	4.01E+15	sej
Emergy of the fertilizers for bales	2.72E+15	sej
Emergy in fuels for cattle	1.69E+16	sej
Emergy of groundwater	6.94E+14	sej
Emergy in the annual rent to the owner	2.44E+16	sej
Emergy of governmental support to cattle rearing	8.71E+16	sej
Emergy of the taxes	2.92E+16	sej
Energy in the calves	8.78E+10	J
Transformity of the calves (with services)	4.13E+06	sej J^{-1}
Transformity of the calves (without services)	1.73E+06	sej J^{-1}
Transformity of the calves (without taxes, subsidies and rent but with labor)	3.28E+06	sej J^{-1}
Emergy of the calves (with services)	3.63E+17	sej
Emergy of the calves (without services)	1.52E+17	sej
Emergy of the calves (without taxes, subsidies and rent but with)	2.88E+17	sej

All the values of energy, emergy and transformity found for each farm item will allow the construction of the emergy accounting table found below (Table 13).

4.2.2 Determination of renewability factors for the farm items

For this determination we used data from Oliveira *et al.* (2013) to estimate the renewability of the Portuguese economy (used in the Portuguese component of the subsidies) and data from NEAD, the National Environmental Accounting Database, that compiles detailed information for over 150 countries for the full array of resources that underlie economies, for the years 2000, 2004 and 2008. Data from Eurostat (http://ec.europa.eu/dgs/budget/index_en.htm, http://europa.eu/about-eu/basic-information/money/revenue-income/index_pt.htm, http://ec.europa.eu/budget/biblio/documents/2012/2012_en.cfm) was used to estimate the renewability of European Union countries in 2012 (used in the European component of the subsidies), and finally data from Panzieri *et al.* (2002) to estimate the renewability in Portuguese services. The renewability of Portuguese services was considered similar to Italy, as having 10% renewability. For other items, data origin is indicated with the item evaluated.

The calculation of renewability factors was only carried out for the items considered as provided from the economic system and that are usualy considered as non-renewable items. This is the reason why the renewability calculations are only presented from item "10 Bales". The other items are considered as 100% renewable.

These calculations, as well as all the assumptions made for their determination are described below.

10 Bales

This is the first item that has human intervention in their manufacture, and items that have a lower number are considered as 100% renewable.

	Emergy (sej)	Renewability	References	Renewable emergy (sej)	Nonrenewable emergy (sej)
Emergy of Incident solar radiation	2.31E+15	1.00		2.31E+15	0.00E+00
Emergy of the energy lost in erosion	7.99E+13	1.00		7.99E+13	0.00E+00

Emergy of the evapotranspiration	3.81E+16	1.00		3.81E+16	0.00E+00
Emergy of the labor in bales	3.17E+16	0.10	Panzieri *et al.,* 2002	3.17E+15	2.85E+16
Emergy of mechanical equipment for bales	1.03E+15	0.00137	Odum *et al.*, 1987	1.41E+12	1.03E+15
Emergy of the fuels for the bales	2.64E+15	0.00128	Odum, 1996	3.38E+12	2.63E+15
Emergy of the fertilizers	2.72E+15	0.06	Odum, 1996	1.63E+14	2.56E+15
Total	7.62E+16			4.15E+16	3.48E+16
	100%			54.41%	45.59%

12 Seeds

Purchased seeds have a significant amount of emergy linked with human labor in activities like selection, multiplication, evaluation of genetic stability, marketing and distribution. In the emergy evaluation method it is considered that the price of the seeds reflects all this work.

	Emergy (sej)	Renewability	References	Renewable emergy (sej)	Nonrenewable emergy (sej)
Emergy of the seeds as a service	1.36E+15	0.1	Panzieri *et al.,* 2002	1.36E+14	1.23E+15
Emergy of the seeds as material	4.38E+13	1		4.38E+13	0.00E+00
Total	1.41E+15			1.80E+14	1.23E+15
	100%			13%	87%

18 Fences

Here is evaluated the renewability of the material. The renewability of the other components required to construct a fence, such as machinery, labor and fuels is evaluated in the respective items.

	Emergy (sej)	Renew ability	References	Renewable emergy (sej)	Nonrenewable emergy (sej)
Emergy in the posts	5.21E+15	0.3285	Odum, 1996	1.71E+15	3.50E+15
Annual emergy in wire in fences	4.09E+16	0.0137	Zhang *et al.,* 2009	5.60E+14	4.03E+16
Total	4.61E+16			2.27E+15	4.38E+16
	100%			5%	95%

21 Subsidies

To find the renewability of the subsidies the renewability of the countries from where the money is coming had to be found. The renewability of Portugal was given by Oliveira *et al*. (2013). The renewability of the European component of these subsidies had to be estimated through the renewability of each country contributing to the European budget. Table 9 presents the contribution to the European budget of each country and its renewability, in order to estimate the renewability of the European component.

Table 9 – Determination of the renewability of the European subsidies

Country	BE	BG	CZ	DK	DE	EE	IE	EL	ES	FR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	UK
M€ of contribution to european budget	3.64	371	1.39	2.39	22.82	154	1.24	1.68	9.66	19.79	14.98	165	205	294	265	832	59	4.17	2.76	3.52	1.65	1.33	334	646	1.86	3.29	13.46
% of this contribution	3.22	0.33	1.24	2.12	20.20	0.14	1.09	1.49	8.55	17.52	13.26	0.15	0.18	0.26	0.23	0.74	0.05	3.69	2.45	3.12	1.46	1.17	0.30	0.57	1.65	2.91	11.91
Renewable fraction	0.20	0.90	0.10	2.00	0.20	0.70	25.50	0.60	0.40	6.30	0.30	0.20	1.90	0.50	no data	0.20	no data	1.00	0.40	0.30	1.30	1.30	0.90	0.20	0.60	0.80	13.20
Corresponding amount from the european budget	7.29	3.34	1.40	47.82	45.64	1.07	315.08	10.09	38.65	1247.20	44.94	0.33	3.89	1.47	147.62	1.66	147.62	41.73	11.06	10.58	21.40	17.24	3.00	1.29	11.17	26.31	1776.87

Total renewable in european subsidies	3985.76	3.53%	Total renewable in Portuguese subsidies	4.60%	
Average	147.62	Used to estimate the renewable componente for the two contries for which there is no data			

	Farm		Cattle					
	15054.74	€	23669.63	€				
	17207.57	$	27054.39	$				
	1st pillar		1st pillar		2nd pillar			
€	15054.70		14574.10	€	9095.60	€		
$	17207.52	Renewability	16658.20	$	10396.27	$	Renewability	$

European participation ($)	100%	17207.52	3.53%	607.43	100%	16658.20	85%	8836.83		3.53%	899.97
Portugese participation ($)	0%	0	4.60%	0	0%	0	15%	1559.44		4.60%	71.73

Renewable component of subsidies 607.43 $ Renewable component of subsidies 971.71

Nonrenewable componet 16600.10 $ Nonrenewable componet 26082.68

0.037 %

In emergy terms it would be:

Renewable component of subsidies for the farm	1.96E+15	sej $\$^{-1}$
Nonrenewable componet if subsidies for the farm	5.35E+16	sej $\$^{-1}$
Renewable component of subsidies for the cattle	3.13E+15	sej $\$^{-1}$
Nonrenewable componet if subsidies for the cattle	8.40E+16	sej $\$^{-1}$

In relation to the outputs of the farm these include part of the mechanical equipment, fuels and labor for other uses as well as part of the subsidies received for the farm in general, and in this case, the corresponding renewabilities.

24 Hunting

	Emergy (sej)	Renewability	References	Renewable emergy (sej)	Nonrenewable emergy (sej)
Emergy of the hunting products	1.77E+15	1.0000		1.77E+15	0.00E+00
Emergy of labor for other activities	8.95E+13	0.1000	Pazieri *et al.*, 2002	8.95E+12	8.06E+13
Emergy of fuels for other uses	2.96E+12	0.0128	Odum, 1996	3.79E+10	2.92E+12
Emergy of mechanical equipment for other uses	3.97E+12	0.0137	Odum *et al.*, 1987	5.44E+10	3.92E+12
Emergy of the subsidies received for the farm in general	2.66E+14	0.0353	This study	9.40E+12	2.57E+14
	2.13E+15			1.79E+15	3.44E+14

	100%			83.86%	16%

25 Firewood

	Emergy (sej)	Renew ability	References	Renewable emergy (sej)	Nonrenewable emergy (sej)
Emergy of the service of harvesting firewood	4.60E+15	0.1000	Pazieri *et al.*, 2002	4.60E+14	4.14E+15
Emergy of labor for other activities	3.21E+15	0.1000	Pazieri *et al.*, 2002	3.21E+14	2.89E+15
Emergy of fuels for other uses	1.06E+14	0.0128	Odum, 1996	1.36E+12	1.05E+14
Emergy of mechanical equipment for other uses	1.42E+14	0.0137	Odum *et al.*, 1987	1.95E+12	1.40E+14
Emergy of the subsidies received for the farm in general	9.55E+15	0.0353	This study	3.37E+14	9.21E+15
Total emergy of the firewood (material)	5.89E+16	1.0000		5.89E+16	0.00E+00
	7.65E+16			6.00E+16	1.65E+16
	100%			78.45%	21.55%

26 Cork

	Emergy (sej)	Renewability	References	Renewable emergy (sej)	Nonrenewable emergy (sej)
Emergy of the labor associated to cork	2.61E+16	0.1000	Pazieri *et al.*, 2002	2.61E+15	2.35E+16
Emergy of cork in the tree	2.53E+15	1.0000		2.53E+15	0.00E+00
Emergy of labor for other activities	1.44E+15	0.1000	Pazieri *et al.*, 2002	1.44E+14	1.30E+15
Emergy of fuels for other uses	4.78E+13	0.0128	Odum, 1996	6.11E+11	4.71E+13
Emergy of mechanical equipment for other uses	6.41E+13	0.0137	Odum *et al.*, 1987	8.79E+11	6.33E+13
Emergy of the subsidies received for the farm in general	4.30E+15	0.0353	This study	1.52E+14	4.15E+15
	3.44E+16			5.43E+15	2.90E+16
	100%			15.77%	84.23%

27 Calves (services in colored line)

	Emergy (sej)	Renewability	References	Renewable emergy (sej)	Nonrenewable emergy (sej)
Emergy of the natural pasture	1.02E+16	1.0000		1.02E+16	0.00E+00
Emergy in bales	3.81E+16	0.4500	This study	1.72E+16	2.10E+16
Emergy of the acorns	2.94E+16	1.0000		2.94E+16	0.00E+00
Emergy of fences	4.61E+16	0.0500	This study	2.30E+15	4.38E+16
Emergy for the labor in cattle	1.22E+17	0.1000	Pazieri *et al.*, 2002	1.22E+16	1.10E+17
Emergy of the plastic used in the farm	1.51E+15	0.0204	Buranakarn, 1998	3.07E+13	1.48E+15
Emergy of the seeds	4.38E+13	0.1300	This study	5.69E+12	3.81E+13
Emergy of the feeding trough	1.75E+15	0.0137	Odum *et al.*, 1987	2.39E+13	1.72E+15
Emergy of medication	1.65E+13	0.0598	Brandt-Williams, 2002	9.85E+11	1.55E+13
Emergy of labor for other activities	1.39E+16	0.1000	Pazieri *et al.*, 2002	1.39E+15	1.25E+16
Emergy of fuels for other uses	4.59E+14	0.0128	Odum, 1996	5.87E+12	4.53E+14
Emergy of mecanical equipment for other uses	6.16E+14	0.0137	Odum *et al.*, 1987	8.44E+12	6.08E+14
Emergy of the subsidies received for the farm in general	4.13E+16	0.0353	This study	1.46E+15	3.99E+16
Emergy of mechanical equipment for cattle	7.85E+15	0.0137	Odum *et al.*, 1987	1.08E+14	7.74E+15
Emergy in fuels for cattle	1.69E+16	0.0128	Odum, 1996	2.16E+14	1.67E+16
Emergy of the fertilizers for bales	2.72E+15	0.0598	Odum, 1996	1.63E+14	2.56E+15
Emergy of groundwater	6.94E+14	1.0000		6.94E+14	0.00E+00
Emergy in the annual rent to the owner	2.44E+16	0.3806	This study	9.27E+15	1.51E+16
Emergy of governmental support to cattle rearing	8.71E+16	0.0359	This study	3.13E+15	8.40E+16
Emergy of the taxes	2.92E+16	0.0460	This study	1.34E+15	2.78E+16
	4.16E+17			8.65E+16	3.30E+17
	100%			20.79%	79.21%

These renewability values, estimated in this section, as well as others given directly from other studies, are used to fill table 19.

4.2.3 Co-products

It is common to find situations where a transformation process gives origin to two or more flows. This process can result in an output that splits into two distinct flows (Figure 14 a)) e.g. bales can be given to cattle or can be sold. The material is the same and therefore its transformity remains the same while the emergy associated with each new flow is proportional to the amount of material following each separate channel. The same happens with other flows such as the acorns. In the case of Holm Oaks Farm we considered that cattle consume half of the acorns produced by trees and that the rest of the acorns play other functions such as regeneration of new trees (Pulido & Dias, 2005), with high mortality rates of young shoots, some are hidden by dispersing animals or consumed by wild animals (Focardi *et al.,* 2000; Pons & Pausas, 2007). Once the material (the acorns) remains the same as well as its transformity, half of the emergy of the total acorns produced on the farm was considered for the evaluation.

It is also common, in farming systems, to find co-products. This is a different situation where the same process would inevitably result in two emergy flows with distinct qualities (Figure 14 b)).

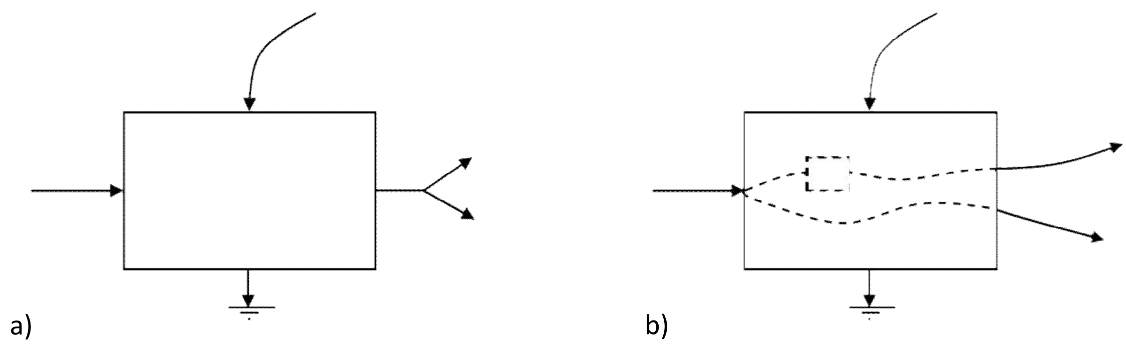


Figure 14 – Distinction between output splits (a)) and co-products (b)).

In the case of the system under study, the biomass of trees and acorns are co-products of the same emergy flow. This means that it is not possible for trees to gain biomass without producing, at the same time, acorns. The emergy required by the tree to produce new biomass is the same as that which is required for the tree to produce acorns. In this case, if the emergy required for the annual growth of the tree is added to the emergy necessary for the production of acorns, there will exist a double counting problem.

To avoid double counting, the emergy required for acorn production was not added to the renewable inputs of the system when considered globally, since the trees biomass growth was already considered. However the emergy of the acorns was added to the calves since, in this case, there is no double counting because the biomass of the trees is not an input to calf production in any other way.

Cork is also a co-product of cork oaks. In years where biogeophysical conditions are less suitable for the trees growth and support, the emergy available for the tree is less and the growth rate of the tree will be lower as will be the growth rate of the cork (Aranda *et al*., 2005).

In this analysis, it was considered that cork emergy is equal to the emergy of the annual growth of cork oak biomass.

4.2.4 Accounting for fuels, machinery and labor in a farm

The emergy assessment of a farm with different activities requires the accounting of a set of equipment (by weight), fuel and working hours as well as knowing their distribution among the different activities.

Some machines are from the manager, others are rented, some are used in many activities, and some activities are carried out together by the manager or other worker. As it can be seen in item 15 - Mechanical equipment, the weight of the machines was affected by its depreciation rates and hours of work for each activity within the farm. For the calculation of the money involved in farm operation the same accounting was made but with machinery prices.

The same operation was made for fuels and lubricants (Item 13) using the average consumption of fuels and lubricants for machines from Santos (1996). All the assumptions and data about machinery were heavily supported in the notebooks about farm equipment from Santos (1996) as well as the catalogs of farming machinery with their characteristics and prices.

Labor hours were distributed by the different activities as well as their prices (Item 20 - Labor), but some activities were assigned to various activities simultaneously, such as repairing machines or check-up for tractor. This allocation was made in proportion to the weight of the machines used in each activity since the tractor works with these machines and the hours spent repairing machines are also dependent on the distribution of the machines weight by the different activities. The generic bureaucratic work was distributed similarly for all activities.

4.3 The economic evaluation

In economic terms, agricultural farming systems and activities are evaluated 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 organized lists of quantities used, unit prices and total values of all tradable outputs and inputs of agricultural systems or activities.

There are different formats to organize groups of outputs and inputs according to the type of analysis that there is interest in and that allows the calculation of selected results from different perspectives, for instance, gross and net, social and private, family and entrepreneurial (Marques, 2012). However, all of these perspectives include benefits and costs to the systems that are under evaluation (Fisher & Kinnard, 2003). Benefits are the value of outputs produced and 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 (Cools & Emmanuel, 2007).

Outputs or products sold are valued at their selling prices or the monetary value that the farmer receives from selling them at the market place. Purchased inputs or resources used in agricultural systems are valued at market prices, because they represent in monetary terms the value that the farmer has to pay to use those resources (Baumol, 1977). These might be goods, such as fertilizer, or services, like the technical operation of a machine, including machine time and operator labor costs.

Production that is not sold and owned resources such as the stocks used in production (e.g., land, labor and capital of the farmer) are valued at allocated benefits and costs (Tietenberg & Lewis, 2012). Their value can be estimated in different ways, namely at the average, substitution or opportunity cost (Tietenberg & Lewis, 2012). The opportunity cost relates the production or resource with its return in alternative allocation possibilities, i.e., the return from an alternative economic use. Hence they are 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. Notice that by saying ownership resources, these returns are being associated with property rights over resources, including land (Deininger, 2003; Feder & Feeny, 1991; Tietenberg & Lewis, 2012).

Alternatively, to compute returns to these ownership resources, which may not be considered in farm budgets and records and to evaluate their global return, approaches like the residual method are used (Marques, 2012). Entrepreneurial net income is obtained by deducting all tradable factors from total income costs and constitutes the return for these resources.

In farm accounting budgets and records no value is allocated or attributed to the natural resources such solar radiation, wind, evapotranspiration, ground water. However, they are critical to agricultural production. These natural resources are not tradable. Hence, their value cannot be “priced” by the market. Notice that these are common goods that have specific consumption characteristics that cause problems of property rights (Tietenberg & Lewis, 2012). The bio-geophysical system can be used by everyone; however natural resources are appropriated and their value captured through property rights (Deinenger, 2003). The owner of the land uses these resources in farming systems and gets a return from them, or alternatively, he leases land and receives a rent for them. Since it is an economic rent with no cost to the owner, this resource value ends up being given according to the buyers' willingness to pay, i.e., tenants that pay land rent and consumers that pay for the products produced (Phipps, 1984).

4.3.1 Determination of the economic values

To determine the economic values of the diferent items of the farm, the farm balance sheet for the year 2012 was used and the accounts required to proceed with this evaluation were identified. However, it should be noted that monetary values specified in the farm balance sheet and accounts do not always correspond to the activities developed in this farm. As the manager owns another farm where he develops the same kind of activity, often, discriminated values in the accounts and in the corresponding invoices are related to goods or services acquired for both farms. The only exception refers to the manager's remuneration where the value in balance sheet account accurately represents the amount received by the manager. 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 to discriminate, with the manager and the accountant, the amounts related to the Holm Oaks Farm.

Anyway, all balance sheet and accounts used, the reasoning underlying the estimation of some of the values relative to Holm Oaks Farm operation, and also the item codes and description, when available, are shown in Table 10.

Once again all the money values were collected in euros (€) and converted to United States dollars ($) relative to the year 2005 through applying a conversion factor of 1.143 (http://www.x-rates.com/calculator/ and http://www.usinflationcalculator.com/).

Table 10 – Balance sheet accounts used on the estimation of monetary values for some goods and services used in Holm Oaks Farm and reasoning underlying the estimation of the corresponding amount used in this farm.

Note [a]	Item	Farm balance sheet account	Reasoning underlying the estimation for the value used in Holm Oaks Farm. Item codes are indicated when available.	Value considered ($)
1	Solar radiation	-		-

2	Wind, kinetic	-		-
3	Rain, geo-potential absorbed	-		-
4	Ground water, chemical potential	-		-
5	Rain, chemical potential	-		-
6	Evapotranspiration	-		-
7	Trees biomass	-		-
8	Acorns	-		-
19	Natural pasture	-		-
10	Bales	62.1.1.1	Only labor	3657.60
11	Erosion, topsoil	-		-
12	Fuels	62.4.2.1.1.1 62.4.2.1.1.3 62.4.2.1.2	For the van, only 3500 € were used in this farm corresponding to 2160 L For the tractor For the water pump	4000.0 4131.93 936.59
13	Fertilizers	31.2.1.1.1.1.4		8628.11
14	Mechanical equipment	6423	Item code 00950006 corresponding to the pendulum sower Item code 01100001 corresponding to a water pump Item code 00950005 corresponding to the trailer Item code 00950003 corresponding to a disc arrow Item code 00750001 corresponding to a 70 cv tractor	53.58 47.23 71.44 85.73 190.42
		6424	Item code 23750001 corresponding to the van used to daily motion	354.24
		6425	Item code 24300001 corresponding to a chainsaw	45.72
15	Fences	6422	Item code 01500001 Item code 01500002 Item code 01500003	93.73 100.58 822.96
16	Plastic	626811	Indicated by the farmer	571.50
17	Feeding trough	6422	Item code 00350001 Item code 00350002	308.61
18	Medication	31.2.1.1.1.1.2 31.2.1.1.1.2.1	Medication Product to give bath to cattle	927.73 191.78
19	Labor	63	Only includes manager's labor	9302.18
20	Subsidies	75		55428.16
21	Taxes paid to the government	81.2.1	Includes corn yield in another farm	9045.16
22	Land use permit (rent to the owner)	62.6.1.1.3.1		7563.03
23	Hunting	-		-
24	Firewood	-		-
26	Cork	-		13335.00
27	Calves	71.2.1.1.1.1	Corresponding to 39 female calf with 220 Kg weight each sold at 2.51 $ Kg^{-1}, 37 male calf with 240 Kg weight each sold at 2.74 $ Kg^{-1} and 11 old cows with 500 Kg weight each sol at 1.14 $ Kg^{-1}	52209.92

[a] From the Emergy Accounting Table.

Given the limitations presented previously, the calculations to estimate the economic value of the majority of the items used in this work will be shown above.

10 Hay for bales

This does not correspond exactly to the bales price, which varies according to whether the year was more or less rainy. It is rather the price indicated by the farm manager for the year of 2012.

The hay for bales presented does not include the work and machinery leasing required to make the bale. These both will be included in labor prices and machinery prices, to avoid double counting.

Economic evaluation			1	€
	2580	€ ha^{-1} y^{-1}	1.143	$
	2948.94	$ y^{-1}		

12 Seeds

Seeds are currently sold in the market. However it values only the service of reproduction of the seeds to get a sufficient amount to sell. Usually the selection work of nature is not accounted. The price was found from the company that sells the seeds.

Seeds cost	7	€ kg^{-1}
	8.46	$
Seeds total cost	8.46E+03	$
Seeds annual cost	4.23E+02	$

13 Fuels

The average monthly price for the fuels in 2012, helped to estimate the corresponding value for this year.

Fuels price on 2012	
Jan	1.247
Fev	1.288
Mar	1.325
Abr	1.325
Mai	1.305

				Jun	1.305		
				Jul	1.278		
Economic evaluation							
				Average	1.30	€ L^{-1}	
1313	$	Total			1.48	$ L^{-1}	
8319	$		10841	$			
903	$						
307	$						
				Total spent on fuels in 2012			
				9558.8	€		

14 Fertilizers

The price of the fertilizer was provided by the company that sells it.

1080	kg	18%		1	€
6000	Kg	100%		1.143	$
500	kg	147.34	€		
6000	kg	1768.08	€		
		2020.92	$		

15 Mechanical Equipment

The process of distribution of the value of each machine for the different activities (Table 11) was the same used previously to assign the weight of machinery, by the number of hours of work in each activity.

The prices for these machines in 2012 were obtained with the help of a machinery salesman, together with machinery catalogs.

Table 11 – Distribution of the price of machinery by the different activities of the farm.

Item	Prices €	Prices $	Year acquired	Hours of annual utilization	Useful life (y)	Allocation to farm work ($ y^{-1})	Type of use	Allocation to farm activity ($)			
								Cattle	Bales	Other uses	Fences
70 cv tractor	32300	36918.9	1992	302.6	6	6153.15	used only on the farm	4534.54	793.04	488.02	134.21
Disc harrow	6291	7190.6	2004	40	8	449.41	used half time on this farm	112.35	0.00	337.06	0
Mower machine	16000	18288.0	2012	8	8	9.14	rented	0	9.14	0	0
Hay rake	16000	18288.0	2011	27	8	30.86	rented	0	30.86	0	0
Baler	85000	97155.0	2009	8	8	48.58	rented	0	48.58	0	0
80 cv tractor	37900	43319.7	2001	27	6	97.47	rented	0	97.47	0	0
120 cv tractor	64800	74066.4	2001	8	6	49.38	rented	0	49.38	0	0
150 cv tractor	94700	108242.1	2005	40.4	6	364.42	rented	0.00	72.16	0.00	292.25
Hydraulic driller	140000	160020.0	2009	21.15	8	211.53	rented	211.53	0.00	0.00	0
Pendulum sower	1810	2068.8	2003	15	8	86.20	used only 1/3 of the time on the farm	0.00	86.20	0.00	0
Water pump	300	342.9	2006	46	8	42.86		42.86	0	0	0
Chainsaw	180	205.7	2010	8	1	205.74		0	0	205.74	0
Van	24850	28403.5	2007	182.5	4	3 550.44	half time on this farm	3 550.44	0	0	0
Trailer	7316	8362.2	1968	237	8	522.64	half time on this farm	469.71	52.93	0	0
Atomizer	2000	2286.0	2010	21.2	8	142.88	half time on this farm	5.00	0	0	7.5
Pile driver	24000	27432.0		16.2	8	27.77	rented	0.00	0	0	27.77
Tightener	300	342.9		0	8	0.00	rented	0.00	0	0	0
Post pounder	3000	3429.0		0	8	0.00	rented	0.00	0	0	0
						11 658.75	$	8 926.44	1239.75	1 030.82	461.73

16 Plastic

The value of the plastic was established with the seller of the plastic to the farm. These are plastic rollers suitable to cover bales and sold as a roll.

Price of the plastic annualy used 500 € 571.5 $

17 Feeding troughs

The price of the feeding troughs was established with a seller of this equipment.

Feeding troughs price 733.62 $ $unit^{-1}$
Total value of the feeding troughs 11004.3 $

18 Fences

The cost of the fences was obtained from a local fence buider.

Fences cost 4000 € km^{-1}

20 Labor

To estimate labor prices several techniques were used. Care was taken to make a clear distinction between the labor carried out by the manager and the rented labor. To evaluate the first, the monthly salary was used. Then, a value per hour and per day was determined, since these are the periods used to define the duration of farm activities. The same distribution of the number of hours "repairing machines" and "Check-up for 70 cv tractor" for the different activities to which they contribute, was made, but this time with money values and not hours.

To evaluate the purchased labor known values were used for the services on the farm about the hours or the remuneration paid in the region for the same job, and indicated by the workers who undertake these activities.

After finding both values of labor, from the manager and purchased, Table 12 was filled and the total value of the labor required for each activity was found.

Average days in a month	30.44					
678.20	€ $month^{-1}$					
22.28	€ day^{-1}					
					25.47	\$ day^{-1}
Labor in bales	136.64	h	4410.09	\$	3.18	\$ hr^{-1}
Labor in cattle	581.07	h	7518.05	\$		
Labor to make fences	40.25	h	4633.40	\$		
Other labor in the farm	77.62	h	247.10	\$		

Making fences		
3 workers, during 8 hours to instal 1 km of fences		
324 h		
Lifetime of the fences	10	y

Annual work 32.4 h

3000	€ km^{-1}	3429	\$ km^{-1}	13.5	km
		46291.5	\$		
		4629.15	\$ y^{-1}		

Repairing machines							Check-up for 70 cv tractor							
for cattle	780.60	kg	99.78	\$	31.34	h	for cattle	233	h	3.07	h	9.77	\$
for bales	102.32	kg	13.08	\$	4.11	h	for bales	40	h	0.53	h	1.68	\$
for other uses	82.23	kg	10.51	\$	3.30	h	for other uses	24	h	0.32	h	1.01	\$
for fences	31.04	kg	3.97	\$	1.25	h	for fences	6.6	h	0.09	h	0.28	\$
Total	**996.19**	**kg**	**127.34**	**\$**	**40.00**	**h**	**Total**	**303.6**	**h**	**4.00**	**h**	**12.73**	**\$**

21 Subsidies

These values were found previously, when determining the emergy associated with subsidies.

Monetary support from the government for cattle	23669.63	€
	27054.39	\$
Subsidies to the farm in general	15054.74	€
	17207.57	\$

22 Taxes paid to the governmet

This value has been explained previously, as once having the emergy value for taxes, the amount of money paid in taxes was accounted.

		number	weght	price per kg							
Sells:	female calves	35	220	2.2	€ kg^{-1}	7700	kg	16940	€	19362.42	\$
	male calves	35	220	2.4	€ kg^{-1}	7700	kg	18480	€	21122.64	\$
	old cows	10	500	1	€ kg^{-1}	5000	kg	5000	€	5715.00	\$
	Totals					**20400**	**kg**	**40420**	**€**	**46200.06**	**\$**

	7921.33	€
Value of taxes paid to the Government	9054.08	\$

Table 12 – Hours assigned to each activity and corresponding market prices ($) from the manager and purchased labor. Purple color lines corresponds to labor to cattle, pink color lines corresponds to labor linked to hay, white color lines correspond to labor for other work, and light blue color lines correspond to labor to fences.

Working hours	Activity	Done by	Market prices $
16	Mobilizing the soil	manager	50.94
15	Fertilizing the hay	manager	47.75
24	Making firebreaks	manager	76.40
27	Cutting the hay	purchased	2704.00
8	Mowing the hay	purchased	
8	Baling the hay	purchased	1408.00
24	Storing the bales	manager	76.40
183	transporting the bales to the fodder	manager	582.58
4	giving baths to the cattle	manager	12.73
20	Supporting veterinary activity	manager	63.67
10	Veterinary activity	purchased	3167.00
30	Selling cattle	manager	95.50
182.5	Travelling to the farm	manager	580.99
20	annual application to agro-environmental measures, keeping the field book, annual application to the single payment scheme and licenses	purchased	685.00
10	Integrated-production certification	purchased	318.88
21.15	Making ponds	purchased	1692.03
3.07	Check-up for 70 cv tractor (see note 1)	manager	9.77
0.53			1.68
0.32			1.01
6.60			0.28
50	Respond to governmental bureaucracy	manager	159.17
50			159.17
50			159.17
31.34	Repairing machines	manager	99.78
4.11			13.08
3.30			10.51
1.25			3.97
32.4	Making fences	purchased	4629.15
835.57	**Total**		16808.63

23 Land use permit

Land use permit is an annual rent that is paid to the owner and that is indicated in the farm accounting balance.

Annual rent to the owner	6616.82	€
	7563.03	$

24 Hunting

The hunting is not sold, so a price is difficult to find for this output. The value indicated is the value of the licence given to the manager allowing him to hunt on the farm.

Annual value of the hunting products	1470	€	1680.21	$

25 Firewood

Firewood value was estimated using the indications for the region about quantities produced by hectare and the corresponding values of the cork oak and the holm oak firewood.

Price of holm oak firewood	114.3	$ Ton^{-1}
Price of the cork oak firewood	80.0	$ Ton^{-1} ha^{-1}
Holm oak area	59.0	ha
Cork oak area	2.0	ha
Income resulting from holm oak firewood	1 348.7	$ y^{-1}
Income resulting from cork oak firewood	32.00	$ y^{-1}
Total	1380.74	$ y^{-1}

26 Cork

The estimated value of the cork is the price given to the cork in the region in the year of 2012, according to the indication of a specialized worker in this activity area.

Value of the @ of cork	15	kg $@^{-1}$	
Average value of this low quality cork	15	€ $@^{-1}$	
	17.14	\$ $@^{-1}$	
Average cork production in the farm	7000	@	each 9 years
Production of cork	1.05E+05	kg	each 9 years
Production of cork in a year	1.17E+04	kg	
Total value of the cork	13335	\$ y^{-1}	

27 Calves

The number of calves sold in the local auction was given directly by the manager.

		number	weight	price per kg		Total weight		Total price			
Sells:	female calves	35	220	2.2	€ kg^{-1}	7700	kg	16940	€	19362.42	\$
	male calves	35	220	2.4	€ kg^{-1}	7700	kg	18480	€	21122.64	\$
	old cows	10	500	1	€ kg^{-1}	5000	kg	5000	€	5715.00	\$
	Totals					**20400**	**kg**	**40420**	**€**	**46200.06**	**\$**

These money values will be used in the subsection “5.2 Comparing economic and emergy evaluations”.

5. Results & Discussion

5.1 The emergy evaluation of the Holm Oaks Farm

After estimating all the energy, emergy and UEV data corresponding to the items identified on the farm, these were collected in an emergy accounting table (Table 13). This table provides a first overview of the Holm Oaks Farm. It is possible to see, for instance, that the major free input provided from nature, is the chemical potential of the rain, followed by the evapotranspiration from the oaks and the pastures. It is possible to see also that erosion is a minor emergy flow. The free inputs from nature correspond to 25.29% of all the inputs, while purchased materials correspond to 18.95%. Labor represents the major purchased input with 47.94% of the emergy inputs to the system while subsidies represent 20.42% of these emergy inputs. The emergy that is fed back from the economy to the Montado system in order to produce outputs is 74.77%.

The renewable energy base for the farm, R, corresponds to the sum of the energy corresponding to the trees and pastures' evapotranspiration (Item 6) plus the chemical potential energy of the ground water used by cattle (Item 4). Other smaller emergy inflows are not included in the farm's renewable emergy base, to avoid double counting the inputs (Odum 1996; Lefroy and Rydberg 2003).

According to the termodinamics laws, the emergy invested in the system should correspond to the emergy of the outputs. In fact this is not what we see in Table 13. The emergy of the outputs (4.76E+17 sej) is higher than the emergy of the inputs (4.27E+17 sej). The reason behind this difference is that we are accounting as an output the hunting, whose inputs to the system were not estimated and correspond to shrubby hedgerows, shrubs and shelter provided by old trees, between others.

Table 13 – Emergy accounting table for the Holm Oaks Farm.

Notes	Items	Raw data (Unit y^{-1})	Units (b)	UEV (sej $unit^{-1}$) (c)	Emergy (sej y^{-1})	%	UEV (sej $unit^{-1}$)	Emergy (sej y^{-1})	Reference for UEV
Farm resources				(with services included)			(without services)		
1	Solar radiation (a)	9.02E+15	J	1	9.02E+15	2.11	1	9.02E+15	By definition
2	Wind, kinetic (a)	5.11E+12	J	1240	6.33E+15	1.48	1240	6.33E+15	Campbell & Erban 2016
3	Rain, geo-potential absorbed (a)	5.82E+09	J	35435	2.06E+14	0.05	35435	2.06E+14	Odum, 1996, p. 309
4	Ground water, chemical potential	2.45E+09	J	283056	6.94E+14	0.16	283056	6.94E+14	Buenfil (2001)
5	Rain, chemical potential (a)	5.16E+12	J	23456	1.21E+17	28.36	23456	1.21E+17	Campbell, 2003
6	Evapotranspiration	2.94E+12	J	36415	1.07E+17	25.08	36415	1.07E+17	Campbell, 2003
Sum renewable (4+6)					1.08E+17	25.24			
Nutrients mobilized by native plants									
7	Trees biomass	3.69E+11	J	159707	5.89E+16	13.79	159707	5.89E+16	This study
8	Acorns (a)	1.39E+12	J	42381	5.89E+16	13.79	42381	5.89E+16	This study
9	Natural pasture	1.02E+13	J	1006	1.02E+16	2.40	1006	1.02E+16	This study
10	Hay for bales	1.98E+12	J	19282	3.81E+16	8.94	19282	3.81E+16	This study
Sum addicional renewable (7+9+10)					1.07E+17	25.13			
Sum all renewable resources (4+6))					1.08E+17	25.24			
Nonrenewable resources from within the system (N)									
11	Erosion, topsoil	1.37E+09	J	145555	1.99E+14	0.05	145555	1.99E+14	Cohen *et al.*, 2006
	Sum free inputs (R+N)		J		1.08E+17	25.29			
Purchased Inputs (M)									
12	Seeds	7.19E+09	J	195546	1.41E+15	0.39	8.76E+08	4.38E+13	Bastianoni 2001
13	Fuels	2.57E+11	J	85304	2.19E+16	5.14	85304	2.19E+16	Bastianoni *et al.* 2009
14	Fertilizers	1.08E+06	g	2.52E+09	2.72E+15	0.64	2.52E+09	2.72E+15	Brandt-Williams 2001
15	Mechanical equipment	5.19E+05	g	1.01E+10	5.22E+15	1.22	1.01E+10	5.22E+15	Ulgiati *et al.* 1994
16	Plastic	2.19E+05	g	6.87E+09	1.51E+15	0.35	6.87E+09	1.51E+15	Buranakarn 1998
17	Feeding trough	3.75E+06	g	4.66E+08	1.75E+15	0.41	4.66E+08	1.75E+15	This study
18	Fences (material)	1.36E+07	g	3.39E+09	4.61E+16	10.80	3.39E+09	4.61E+16	Campbell *et al.* 2004
19	Medication	4620	g	3.56E+09	1.65E+13	0.00	3.56E+09	1.65E+13	Campbell & Ohrt 2009
Total purchased materials from economy (M)					8.06E+16	18.95		3.32E+16	
Labor and services (S)									
20	Labor	3.64E+08	J	5.62E+08	2.05E+17	47.94			This study
21	Subsidies	27054	$	3.22E+12	8.71E+16	20.42			This study
22	Taxes paid to the government	9054.08	$	3.22E+12	2.92E+16	6.83			This study
Diference between subsidies and taxes (21-22)					5.80E+16	13.58			
23	Land use permit (rent to the owner)	7563.03	$	3.22E+12	2.44E+16	5.71			This study
Net flow of services					2.38E+17	55.82			
Feed back from Economy (F)					3.19E+17	74.77			
	Y = R+N+M+S				4.27E+17	100.00			
Output (Y)									
24	Hunting	6.97E+08	J	3.06E+06	2.14E+15	0.45			Brown & Arding 1991
25	Firewood	1.98E+11	J	387386	7.66E+16	16.08	298827	5.91E+16	This study
26	Cork	3.06E+08	J	1.13E+08	3.45E+16	7.24	8.55E+06	2.61E+15	This study
27	Calves	8.78E+10	J	3.28E+06	2.88E+17	60.52	1.73E+06	1.52E+17	This study
28	Calves (labor, taxes, subsidies and rent)	8.78E+10	J	4.13E+06	3.63E+17	76.23			
Total of outputs		2.86E+11	J	1.66E+06	4.76E+17	100.00			

a Values not considered to avoid double counting; b $ refers to 2005 values; c Transformities are relative to the 1.2E+25 sej y^{-1} planetary baseline (Campbell 2016).

The transformity values for cork (8.55E+06 sej y^{-1}) without services and (1.13E+08 sej y^{-1}) with services can be used for other calculations, taking into account the fact that it varies according to the "Si" which define the site conditions for the growth of the cork oak and its cork.

In Table 14 it is possible to find the emergy indices used to evaluate the processes in the farm and their overall impact on the system.

Table 14 - Emergy indices for Montado farm.

Emergy Indices	Values
Renewability (%R)	27%
Emergy Yield Ratio (EYR)	1.38
Emergy Investment Ratio (EIR)	2.64
Environmental Loading Ratio (ELR)	2.65
Emergy Sustainability Index (ESI)	0.52

The emergy yield ratio (EYR) of 1.38 is how much output the system is able to produce in proportion to purchased inputs. This agricultural system can produce 1.38 times the emergy input from non-local resources.

The emergy investment ratio (EIR) is 2.64, indicating that the Montado farm system relies more on outside resources than on natural local resources. However, this ratio is low compared to an average ratio for a developed economic activity, thus pressure for further use of local resources may arise in the future.

The emergy loading ratio (ELR) of the Montado farm system is 2.65, indicating that a relatively low impact is expected from silvo-pastoral activities.

Finally, the emergy sustainability index (ESI) is 0.52, which is an average value for an agricultural system, showing that the system provides an average value of emergy output in relation to the amount of potential stress on the environment.

5.1.1 The different activities of the Holm Oaks Farm

After collecting data to fill Table 13 these emergy flows were aggregated in Table 15 to create a first view of the farm as a whole and to have an idea about the role of each activity in the system. For the construction of Table 15 were used different values of Table 13 but also values of fuels and mechanical equipment used specifically in each activity and which can be found in the sub-subsection 4.2.1, items “13 Fuels”, “15 Mechanical equipment”, and “20 Labor”. To each activity was added the component of "Labor", "Fuel", "Mechanical Equipment" and "Subsidies" used to carry out joint actions across the whole farm, called "other activities", and were allocated to each activity in proportion to the emergy shown before this allocation being done in Item “24 Hunting”.

Thus, for cattle, the same free components of nature which were used to characterize all the farm activity were added, but the following materials (M): "13 Fertilizers", "15 Plastic", "17 Feeding trough", "19 Medication" and fuels for direct work with cattle, to make fences, bales and a part of the fuels used in "other uses".

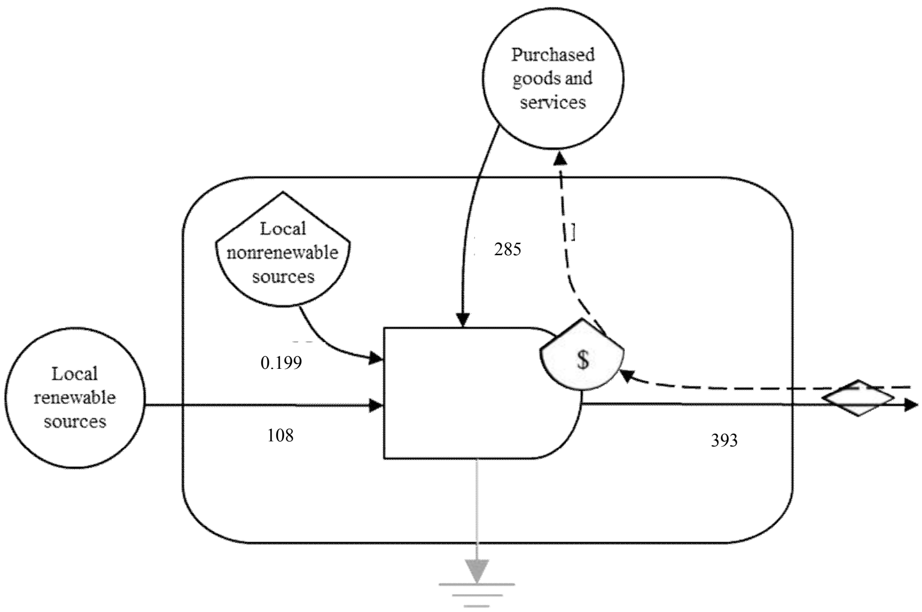
Table 15 - Aggregated emergy flows of the Holm Oaks Farm (excluding subsidies, rent and taxes but including labor), by activity

Aggregated Emergy Flows (sej)	Holm Oaks farm		Cattle rearing		Cork harvesting		Firewood harvesting	
Renewable local resources (R)	1.08E+17	27.40%	1.77E+17	45.96%	1.66E+17	88%	1.66E+17	90%
Nonrenewable local resources (N)	1.99E+14	0.05%	1.99E+14	0.05%	0.00E+00	0%	0.00E+00	0%
Nature contribution (I=R+N)	1.08E+17	27.45%	1.77E+17	46.01%	1.66E+17	88%	1.66E+17	90%
Materials (M)	8.06E+16	20.51%	3.29E+16	8.53%	8.40E+13	0%	1.86E+14	0%
Labor (S)	2.05E+17	52.04%	1.75E+17	45.45%	2.16E+16	11%	7.85E+15	4%
Feedback from economy (F=M+S)	2.85E+17	72.55%	2.08E+17	53.99%	2.17E+16	12%	1.77E+16	10%
Total Emergy Yield (Y)	3.93E+17	100.00%	3.85E+17	100.00%	1.88E+17	100%	1.84E+17	100%

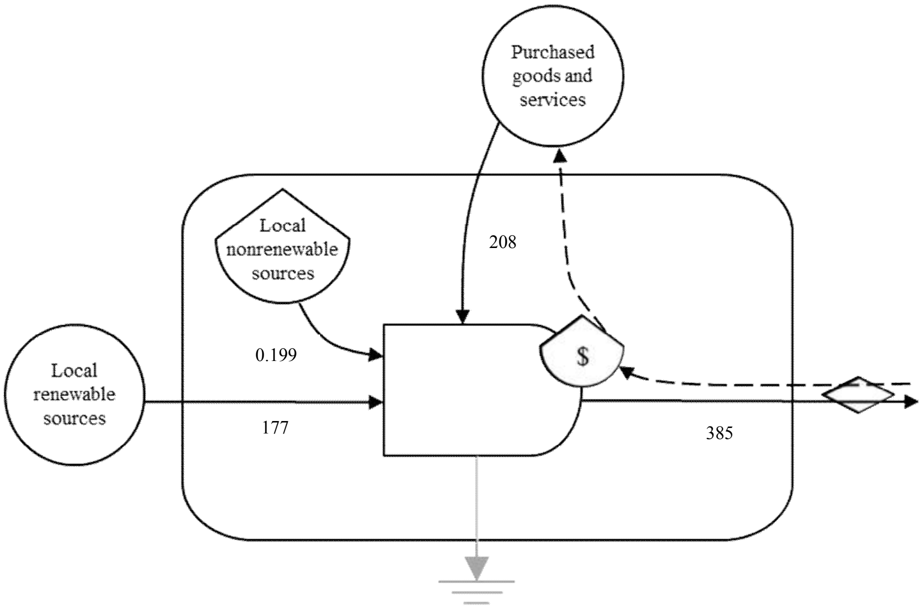
The mechanical equipment necessary to direct work with cattle, to make bales, fences and part of the mechanical equipment used in “other uses” was also added. To estimate the labor invested the “labor to do direct work with cattle”, and the “labor to make bales”, “labor to make fences” and a part of the “labor invested in other services in the farm” was also considered.

The cork and firewood, were considered as renewable resources used in these activities "3 Rain geo-potential absorbed", "6 Evapotranspiration", "7 Trees biomass". For both activities there is no nonrenewable energy input. With regard to materials, only the respective “fuels and mechanical equipment to other uses” components were accounted. In relation to the labor the direct labor input was accounted in each of the activities as well as the corresponding proportion of “labor for other activities”.

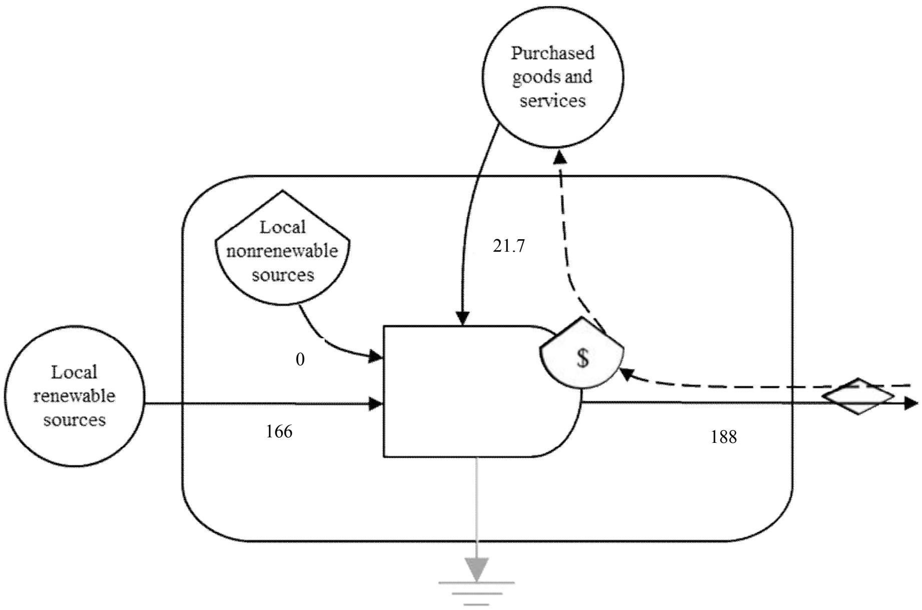
Simplified ESL diagrams for the Holm Oaks Farm are presented for the integrated production system (Figure 15 a), and for the different farm activities individually: cattle production (Figure 15 b), cork (Figure 15 c) and firewood (Figure 15 d).



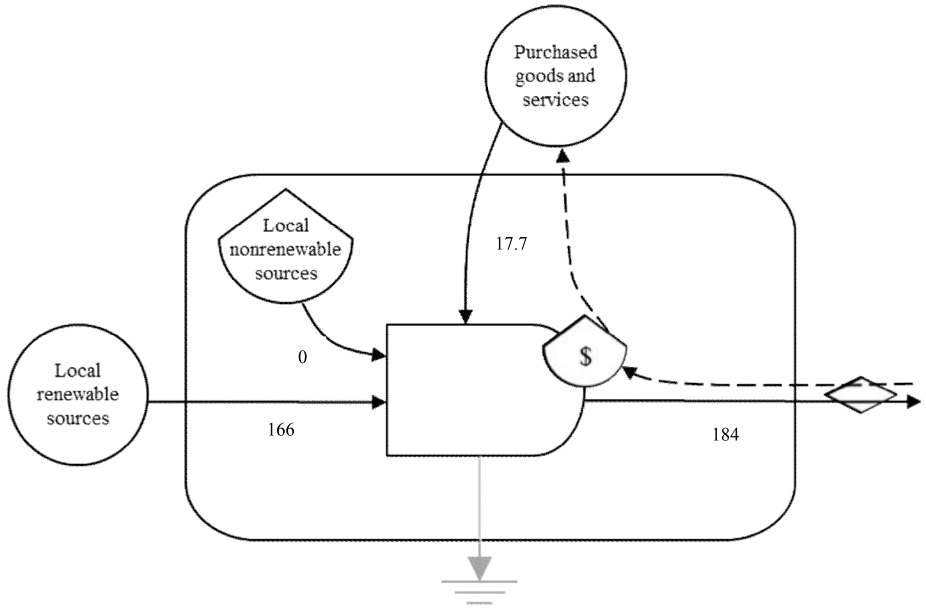
a) Integrated production system. Emergy flow x E+15 sej y^{-1}



b) Cattle production. Emergy flow x E+15 sej y^{-1}



c) Cork. Emergy flow x E+15 sej y^{-1}



d) Firewood. Emergy flow x E+15 sej y^{-1}

Figure 15 - Simplified diagrams of the emergy flows in Holm Oaks Farm for the whole system as a) an integrated production system, b) for cattle production, c) cork and d) firewood.

These aggregated emergy flows were used to estimate the emergy indices of the farm (Table 16) for the whole system and for the different activities (cattle rearing, cork and firewood), with and without subsidies, taxes and the land use permit, but considering the labor in both cases. This makes it possible to obtain an assessment of the farm based on the actual costs of its operation to allow a comparison with other agricultural systems, where the value of subsidies may be different or not come into the evaluation at all.

After this evaluation, a comparison of the Holm Oaks Farm (not considering subsidies, taxes and the land use permit) with other emergy evaluations previously done in other regions of the world (Table 17) was made.

With this objective the values of the other evaluations were previously converted to the 1.2E+25 sej y^{-1} planetary baseline.

Table 16 – Emergy indices of the Holm Oaks Farm by activity.

Emergy indices	complete system	cattle rearing	cork harvesting	firewood harvesting	complete system	cattle rearing	cork harvesting	firewood harvest
					without taxes, subsidies or land use permit			
Transformity (sej/J)	1.58E+06	4.13E+06	1.13E+08	3.87E+05	1.49E+06	3.28E+06	1.13E+08	3.87E+05
Renewability (%R)	**24%**	**38%**	**86%**	**90%**	**27%**	**46%**	**88%**	**90%**
Emergy Yield Ratio (EYR)	1.31	1.61	7.39	10.39	1.38	1.85	8.67	10.39
Emergy Investment Ratio (EIR)	3.18	1.64	0.16	0.11	2.64	1.17	0.13	0.11
Environmental Loading Ratio (ELR)	3.19	1.64	0.16	0.11	2.65	1.18	0.13	0.11
Emergy Sustainability Index (ESI)	0.41	0.98	47.21	97.60	0.52	1.58	66.52	97.60

The following studies of agricultural production were considered: beef production in Florida (Brandt-Williams, 2001), the organic farming system of Duas Cachoeiras in Brazil (Agostinho *et al*., 2004), a forest in China (Lu *et al.,* 2006), the Yancheng Biosphere Reserve in China (Lu *et al.,* 2007), indigenous agro-forestry in Mexico (Diemont *et al.,* 2006) and cattle rearing in Argentina's Pampas (Rótolo *et al.,* 2007).

Table 17 – Comparison of the Holm Oaks Farm with other systems of the world.

Emergy indices	Holm Oaks Farm (integrated production)	Holm Oak Farm (cattle rearing)	Florida[a] (for beef)	Duas Cachoeiras Farm in Brazil[b]	Forest in China[c]	Yancheng Reserve in China[d]	Indigenous agro-forestry in Mexico[e]	Cattle in Argentine Pampas[f]
Solar transformity of outputs (sej/J)	1.49E+06	3.28E+06	6.52E+05	1.10E+06				8.94E+05
Empower density (sej/ha)	2.34E+15	1.71E+15	4.02E+15					
Renewability (%R)	27	46	77	83			97	65
Emergy Yield Ratio (EYR)	1.38	1.85	2.49	26.10	2.15	2.86	50.72	3.73
Emergy Investment Ratio (EIR)	2.64	1.17	1.18	0.04				0.37
Environmental Loading Ratio (ELR)	2.65	1.18	1.18	0.69	0.01	0.48	0.03	0.55
Emergy Sustainability Index (ESI)	0.52	1.58	2.11		191	5.96	1739.85	6.80

a - Brandt-Williams (2001); b - Agostinho *et al.* (2004); c - Lu *et al.* (2006); d - Lu *et al.* (2007); e - Diemont *et al.* (2006); f - Rótolo *et al.* (2007)

The transformity for the calves produced on the Holm Oaks Farm is 3.28E+06 sej J^{-1} (Table 17) and this value is higher than the transformity for beef production in Florida (6.52E+05 sej J^{-1}) and for calf production in Argentine Pampas (8.94E+05 sej J^{-1}), indicating a lower efficiency of the Holm Oaks Farm in the production of this item. On the other hand, a higher Transformity is associated with an increased quality of product, resulting from a larger investment of the ecosystem in their preparation. Looking at these values in more detail (Table 18) and comparing the emergy fluxes by hectare for each production system, it can be seen that the renewable emergy base is quite similar presenting slightly higher values for ground water and rain chemical potential in the Argentine Pampas and for evapotranspiration in Florida.

The higher value for erosion emergy flow in the pampas of Argentina is a consequence of the quantity of rain that feeds this system. The overall emergy invested per hectare to produce calves corresponds to 1.71E+15 sej $ha^{-1}y^{-1}$ in our system, a lower value compared to 2.79E+15 sej $ha^{-1}y^{-1}$ in the Argentine Pampas and the 6.05E+15 sej $ha^{-1}y^{-1}$ in Florida. The lower emergy investment in Holm Oaks Farm for calves' production corresponds to a lower value of the production of the final product reflecting the extensivity of this system and the lower efficiency of the cattle breed. Transformity, that includes emergy investment in the numerator and the corresponding available energy produced, in denominator, reflects this lower efficiency through a higher value for Holm Oaks Farm. However, as has been said before, a higher Transformity is associated with a higher quality of the product, resulting from a larger investment of the ecosystem by energy of the product.

This system corresponds to the presence of a characteristic and unique landscape that provides multiple goods and services to society (Pinto-Correia *et al.,* 2011b; Surová *et al.,* 2011; 2014; Sá-Sousa, 2014; Godinho *et al.,* 2011; Plieninger, 2007; Pulido *et al.,* 2001), such as leisure or hunting, cultural identity of the region, carbon sequestration, soil conservation, hydrological regulation, among them. Nevertheless it would be important to measure the emergy investment of using more productive species, to increase the efficiency of the calves' production system, the manager's income and the viability of the system.

Table 18 - Comparison between emergy inputs to the Holm Oaks Farm, Argentine Pampas and Florida production systems (sej ha-1 y-1).

	Holm Oaks Farm (cattle rearing)	Argentine Pampas[a]	Florida[b]
Farm renewable resources			
1 Solar radiation	5.37E+13	5.93E+13	4.55E+13
2 Wind, kinetic	3.77E+13	5.08E+10	c
3 Rain, geo-potential absorbed	1.23E+12	c	c
4 Ground water, chemical potential	4.13E+12	5.68E+13	c
5 Rain, chemical potential	7.20E+14	9.14E+14	c
6 Evapotranspiration	4.63E+14	c	2.25E+15
Sum Renewable (for cattle rearing is 4+6)	4.66E+14	9.90E+14	2.31E+15
Nonrenewable sources from within the system (N)			
11 Erosion, topsoil	1.18E+12	1.10E+15	7.58E+12
Sum free inputs (R+N)	**4.67E+14**	**2.11E+15**	**2.31E+15**
Purchased Inputs (M)			
12 Seeds	2.61E+11	c	c
13 Fuels	1.03E+14	3.59E+13	1.01E+15
14 Fertilizers	1.62E+13	1.03E+14	1.16E+15
15 Mechanical equipment	2.59E+13	1.03E+13	c
16 Plastic	8.99E+12	c	c
17 Feeding trough	1.04E+13	c	c
18 Fences (material)	2.74E+14	c	c
19 Medication	9.80E+10	c	c
Potash	c	c	9.86E+13
Lime	c	c	7.05E+14
Pesticides	c	c	2.05E+14
Total purchased	**4.39E+14**	**3.03E+14**	**2.44E+15**
18 Labor	8.08E+14	4.03E+14	1.31E+15
Total emergy input in the system	**1.71E+15**	**2.79E+15**	**6.05E+15**
Emergy output	1.71E+15	3.01E+15	6.75E+15
Calves energy	5.23E+08	4.35E+09	1.35E+10
Transformity	3.28E+06	8.94E+05	6.52E+05
Production (g $ha^{-1}y^{-1}$)	121429	252000	c
Average weight of each animal (kg)	255	400	c
Estimation of energy in calves (J g^{-1})	4.31E+03	1.33E+04	c
a - Rótolo *et al.* (2007); b - Brandt-Williams (2001); c – without data			

Looking at Renewability (%R) (Diemont *et al.,* 2005) of the farm, as an integrated production system (Table 17), it can be concluded that it has low renewability (27%) for an agricultural system and it is highly dependent on labor. However, considering only the cattle rearing on the Holm Oaks Farm, the renewability shows a higher value (46%). The work developed on this farm is family-based but, similar to that which happens in many other farms in the region, the manager doesn't live there, so he has to travel several kilometers every day, lowering the renewability index for the system.

Cork and firewood harvesting have higher renewability values, 88% and 90% respectively (Table 16). This can be explained by the low investment in maintenance required for their production and thus a correspondingly lower amount of nonrenewable inputs are needed. It is usual, in a farm with cork oaks to control the shrubs regularly to get better cork quality, but the labor associated with cork in Holm Oaks Farm is limited, almost exclusively, to that required for harvesting. The reason for this is that the cattle rearing activities carried out by the manager, significantly delay the growth of shrubs. If there were no cattle on this farm, the renewability of cork and firewood production activities would be lower, because the landowner would have to carry out regular shrub control to reduce fire risk and maintain cork quality. The same happens with the "labor for other uses" performed by the farm manager, which includes opening firebreaks twice a year, repairing machines associated with this activity, some bureaucratic work, as well as the use of fuels and machinery associated with these activities. The emergy linked to these activities was distributed among them in proportion to their previous emergy, but if this emergy was not distributed by the several activities, they had to be done at same. This means that the best way to take advantage of the range of activities necessary for maintaining a farm in Montado is to diversify the activities carried out there, taking better advantage of the investment made.

Higher values of renewability can be found in other systems (Table 17), as in the organic integrated farm of Duas Cachoeiras (83%), indigenous agro-forestry in Mexico (97%). These are all multifunctional systems such as Holm Oaks Farm but they are less fuel-intensive. The rearing production systems of Florida and the Argentine Pampas also have higher values of renewability

(77% and 65%, respectively) relying more on renewable local resources for their production as shown by Table 18.

As presented in Table 16, the Emergy Yield Ratio (EYR) (Odum, 1996) has a lower value for the integrated system (1.38) and higher values for cattle rearing (1.85), cork (8.67) and firewood (10.39) production. This means that the integrated system has a lower efficiency in concentrating dispersed local inputs into the production of yield per unit of emergy invested from outside. This may be related to required system-wide activities, like making firebreaks twice a year to avoid fire risk, repairing machines associated with this activity, some bureaucratic work, as well as the use of fuels and machinery associated with these activities which demand extra investment (3.65E+17 sej y^{-1}) without any direct and immediate benefit to increase production of individual products.

Higher values for EYR could be obtained if the renewable emergy component of the system is improved by reinforcing productivity of natural pastures or allowing the natural regeneration of the trees. This can be achieved by raising livestock species that have less impact on the natural regeneration of trees (e.g., pigs or sheep) (Bilotta *et al.,* 2007; Dobarro *et al.,* 2013) or by adopting soil conservation practices that improve the content of organic matter in the soil or the productivity of natural pastures (Lopes *et al.,* 1998) Cork and firewood activities have higher EYR values showing more use of dispersed local inputs per unit of external investment in the production of cork and firewood. The efficiency of these activities means that their development is a common option chosen by absent land owners in Alentejo region. The owner of Holm Oaks Farm opted to exploit these resources herself, choosing to rent the more labor demanding activity – cattle rearing. Systems with higher EYRs (Table 17) can be found such as the Duas Cachoeiras farm (26.1) or indigenous agro-forestry in Mexico (50.72); however, these are relatively undeveloped systems that rely mainly on local free inputs to produce their outputs. Compared with cattle rearing in Holm Oaks Farm, the EYR for cattle rearing in Florida or on the Argentine Pampas present higher values corresponding to higher efficiency in concentrating dispersed local inputs into the production of yield per unit of emergy invested from outside.

The Emergy Investment Ratio (EIR) (Odum, 1996; Brown & Ulgiati, 2004) in Table 16, excluding subsidies, rent and taxes, follows the tendency revealed by the previous indexes examined for Holm Oaks Farm that, as an integrated system, it has a higher value of the EIR (2.64) while activities considered separately have lower values of 1.17 for cattle, 0.13 for cork and 0.11 for firewood. This confirms, once again, that Holm Oaks Farm activities, when considered separately, have a more favorable relation between the free emergy invested by nature in relation to the emergy invested from the economy, i.e., the activities considered individually are more economically attractive for investment. It is important to remember, however that this happens because the different activities are carried out together. If each of these activities were implemented exclusively in the farm without the implementation of any of the other activities, each of them would require labor for shrub control, firebreak maintenance and other management practices, which would make the individual activities less advantageous. This means that the owner of the farm takes advantage of leasing the farm for cattle rearing as, besides receiving an income, she has an amount of work done for free, saving this investment.

Looking at Table 17 a lower value of the EIR for the other systems is found, revealing that in these systems there is a high free environmental contribution to the activities gained from relatively low investments from the economy. Compared to the other systems, Holm Oaks Farm reveals a less favorable relation between the free emergy providing from nature in relation to the emergy providing from the economy, and because of this, less economically attractive for investment. This is because the Montado, as many other Mediterranean system, are systems found where human land use had to adapt to limiting natural conditions, with strong scarcity of water, very long and dry summers and often low soil fertility. It is a situation where investment by the man is not as favorable in relation to other systems and hence the fragile balance between the two trends, reflecting what occurs in this farm: an intensification over a certain threshold that quickly leads to degradation, or abandonment.

In relation to the Environmental Loading Ratio (ELR), thresholds have already been set. When the ELR is lower than two, the process has a relatively low impact on the environment (Brown & Ulgiati, 1997). When the ELR values lie between three and ten the environmental impacts are considered to be moderate. Impacts are expected to be high, if the ELR value exceeds ten. It can be seen, in Table 16, that the ELR value for the integrated system is 2.65 indicating a low impact on the environment of the joint productions carried out on the farm. The ELR values of 1.18 for cattle, 0.13 for cork and 0.11 for firewood harvesting show also a low potential impact of these activities on the environment. Looking at Table 17 it is possible to find systems with lower impact on the environment compared to the Montado system: e.g., a forest in China (0.011) and an integrated farming, such as the indigenous agro-forestry system in Mexico (0.03) or cattle rearing in the Argentine Pampas (0.55). The cattle rearing system of Florida presents a similar value for this ratio (1.18) comparative to cattle rearing in the Holm Oaks Farm corresponding to a similar impact on their environment.

The Emergy Sustainability Index (ESI) (Ulgiati & Brown, 1998) is lower for the Holm Oaks Farm when integrating different activities (0.52) (Table 16) and higher for separated activities (1.58 for cattle, 66.52 for cork and 97.60 for firewood). The last ones are relatively high values of this index for agricultural systems showing that the system provides a good value of emergy output in relation to the amount of stress on the environment. However the figures presented by the overall system, for this index, are lower than for the other systems considered.

5.1.2 The renewability of the purchased inputs

After finding values for the renewability factors of the items whose emergy was estimated in this work and using other emergy factors already estimated in the past by Panzieri *et al.* (2002), Sharlynn (NEAD) and Rugani (SED) table 19 was filled giving a first idea about a new, more accurate renewability of the farm. We can see that the percentage of renewable emergy of farm outputs (28.82%) is greater than the percentage of renewable emergy of the inputs (23.91%). This is related to the fact that a number of outputs have been calculated without the corresponding inputs having been completely accounted. An example is hunting, renewable inputs of which were not accounted and correspond, between others, to the shelter provided by the treetop and the bushes which that are both 100% renewable. This shows that the inputs more difficult to quantify are the natural ones. For its full accounting it would be necessary to have a better understanding of the roles played by different natural components of the system. In this case we would need to know how much less energy, in the form of game, we would have in a situation with no bushes and treetops on the farm.

Table 19 – Renewable and nonrenewable emergy component for each farm item.

	Inputs	%Renewable	Renewable componente (sej y^{-1})	Nomrenewable component (sej y^{-1})
1	Solar radiation	100.00	9.02E+15	0.00E+00
2	Wind, kinetic	100.00	6.33E+15	0.00E+00
3	Rain, geo-potential absorbed	100.00	2.06E+14	0.00E+00
4	Ground water, chemical potential	100.00	6.94E+14	0.00E+00
5	Rain, chemical potential	100.00	1.21E+17	0.00E+00
6	Evapotranspiration	100.00	1.07E+17	0.00E+00
7	Trees biomass	100.00	5.89E+16	0.00E+00
8	Acorns	100.00	5.89E+16	0.00E+00
9	Natural pasture	100.00	1.02E+16	0.00E+00
10	Hay for bales	100.00	3.81E+16	0.00E+00
11	Erosion, topsoil	100.00	1.99E+14	0.00E+00
12	Seeds	12.80	1.80E+14	1.23E+15
13	Fuels	1.28	2.81E+14	2.17E+16
14	Fertilizers	5.98	1.63E+14	2.56E+15
15	Mechanical equipment	1.37	1.37E+14	9.88E+15
16	Plastic	2.04	3.07E+13	1.48E+15
17	Feeding trough	2.81	4.91E+13	1.70E+15
18	Fences (material)	4.93	2.27E+15	4.38E+16
19	Medication	5.98	9.85E+11	1.55E+13
20	Labor	10.00	2.05E+16	1.84E+17
21	Subsidies to the farm	3.53	1.96E+15	5.35E+16
21	Subsidies to cattle	3.59	3.13E+15	8.40E+16
22	Taxes paid to the government	37.61	1.10E+16	1.82E+16
23	Land use permit (rent to the owner)	37.61	9.16E+15	1.52E+16
	Y = R+N+M+S		1.16E+17	3.37E+17
			23.91%	76.09%
	Outputs			
24	Hunting	83.86	1.79E+15	3.44E+14
25	Firewood	78.45	6.00E+16	1.65E+16
26	Cork	15.77	5.43E+15	2.90E+16
27	Calves	18.50	7.12E+16	3.14E+17
Total of outputs			1.38E+17	3.42E+17
			28.82%	71.18%

5.2 Comparing economic and emergy evaluations

Despite the influence of man on the natural systems being increasingly widespread, the emergy assessment applies both to the study of more naturalized systems such as biogeochemical cycles or a forest or bay, but also to more humanized systems such as a library or a city. This includes the economic system of money flows in counter-cycle of energy, information and materials flows. The emergy perspective of the integration of the economic system in the global system is described in figure 16.

In this chapter, the goal is to compare the emergy evaluation with a traditional economic evaluation of the Holm Oaks Farm.

To enable a comparison between the economic and the emergy assessment of the farm some adjustments had to be made to the initial evaluation (Fonseca *et al*., 2016). A main difference is related to the depreciation rates attributed to the 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 20.

In the first evaluation, the equipment useful life periods indicated in the manuals of agricultural machinery (Santos, 1996), were considered. In the second evaluation, the equipment useful life periods used by the financial accounting of the farm, and established by what is defined in taxes rules, were assumed.

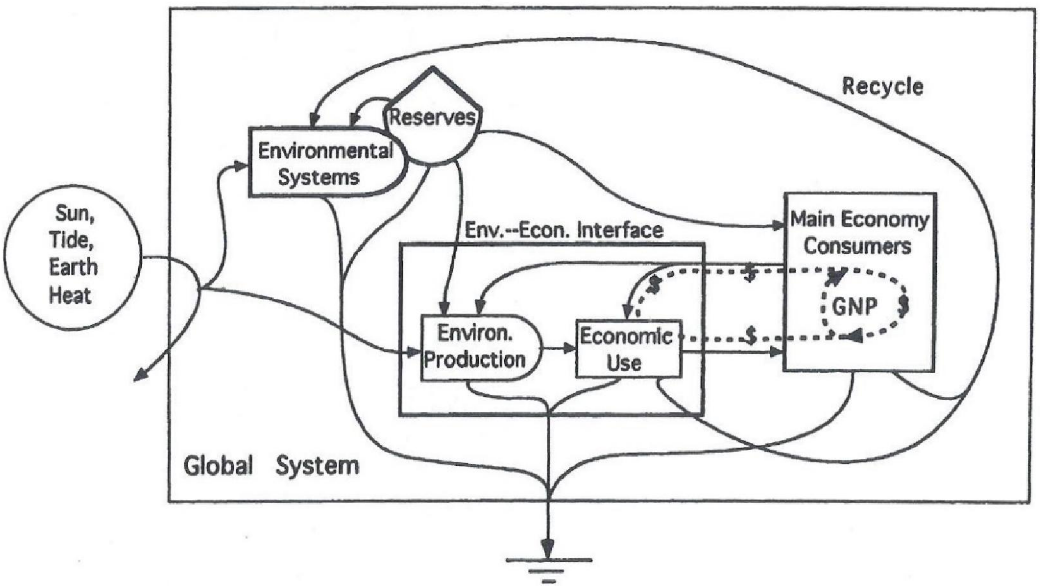


Figure 16 – ESL representation of the emergy perspective about the integration of the economic system in the global system. Adapted from Odum (1996).

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 rather rapid amortization of the expenses in accounting terms.

Table 20 - 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
Atomizer	10	8
Other mechanical equipment	12	8
Feeding trough	10	10
Ponds	20	20
Fences	10	10

Table 21 – Emergy accounting table for the Holm Oaks Farm with larger depreciation rates for the equipment.

Notes		Raw data (Unit y^{-1})	Units (b)	UEV (sej $unit^{-1}$) (c)	Emergy (sej y^{-1})	%	UEV (sej $unit^{-1}$)	Emergy (sej y^{-1})	Reference for UEV
Farm resources				(with services included)			(without services)		
1	Solar radiation (a)	9.02E+15	J	1	9.2E+15	1.98	1	9.02E+15	By definition
2	Wind, kinetic (a)	5.11E+12	J	1240	6.33E+15	1.39	1240	6.33E+15	Campbell & Erban 2016
3	Rain, geo-potential absorbed (a)	5.82E+09	J	35435	2.06E+14	0.05	35435	2.06E+14	Odum, 1996, p. 309
4	Ground water, chemical potential	2.45E+09	J	283056	6.94E+14	0.15	283056	6.94E+14	Buenfil (2001)
5	Rain, chemical potential (a)	5.16E+12	J	23456	1.21E+17	26.55	23456	1.21E+17	Campbell, 2003
6	Evapotranspiration	2.94E+12	J	36415	1.07E+17	23.48	36415	1.07E+17	Campbell, 2003
Sum renewable (4+6)					1.08E+17	23.63			
Nutrients mobilized by native plants									
7	Trees biomass	3.69E+11	J	159707	5.89E+16	12.91	159707	5.89E+16	This study
8	Acorns (a)	1.39E+12	J	42381	5.89E+16	12.91	42381	5.89E+16	This study
9	Natural pasture	1.02E+13	J	1006	1.02E+16	2.25	1006	1.02E+16	This study
10	Hay for bales	1.98E+12	J	19282	3.81E+16	8.36	19282	3.81E+16	This study
Sum addicional renewable (7+9+10)					1.07E+17	23.52			
Sum all renewable resources (R)					1.08E+17	23.63			
Nonrenewable resources from within the system (N)									
11	Erosion, topsoil	1.37E+09	J	145555	1.99E+14	0.04	145555	1.99E+14	Cohen *et al.*, 2006
	Sum free inputs (R+N)		J		1.08E+17	23.67			
Purchased Inputs (M)									
12	Seeds	7.19E+09	J	195546	1.41E+15	0.32	8.76E+08	4.38E+13	Bastianoni 2001
13	Fuels	2.57E+11	J	85304	2.19E+16	4.81	85304	2.19E+16	Bastianoni *et al.* 2009
14	Fertilizers	1.08E+06	g	2.52E+09	2.72E+15	0.60	2.52E+09	2.72E+15	Brandt-Williams 2001
15	Mechanical equipment	9.96E+05	g	1.01E+10	1.00E+16	2.20	1.01E+10	1.00E+16	Ulgiati *et al.* 1994
16	Plastic	2.19E+05	g	6.87E+09	1.51E+15	0.33	6.87E+09	1.51E+15	Buranakarn 1998
17	Feeding trough	3.75E+06	g	4.66E+08	1.75E+15	0.38	4.66E+08	1.75E+15	This study
18	Fences (material)	1.36E+07	g	3.39E+09	4.61E+16	10.11	3.39E+09	4.61E+16	Campbell *et al.* 2004
19	Medication	4620	g	3.56E+09	1.65E+13	0.00	3.56E+09	1.65E+13	Campbell & Ohrt 2009
Total purchased materials from economy (M)					8.54E+16	18.74		3.80E+16	
Labor and services (S)									
20	Labor	3.64E+08	J	5.62E+08	2.05E+17	44.88			This study
21	Subsidies	27054	$	3.22E+12	8.71E+16	19.11			This study
22	Taxes paid to the government	9054.08	$	3.22E+12	2.92E+16	6.40			This study
Diference between subsidies and taxes (21-22)					5.80E+16	12.72			
23	Land use permit (rent to the owner)	7563.03	$	3.22E+12	2.44E+16	5.34			This study
Net flow of services					2.63E+17	57.59			
Feed back 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			Brown & Arding 1991
25	Firewood	1.98E+11	J	386962	7.65E+16	13.70	299141	5.91E+16	This study
26	Cork	3.06E+08	J	1.13E+08	3.44E+16	6.17	8.64E+06	2.64E+15	This study
27	Calves	8.78E+10	J	4.39E+06	3.85E+17	68.99	2.84E+06	2.49E+17	This study
28	Calves (labor, 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 Transformities are relative to the 1.2E+25 sej y^{-1} planetary baseline (Campbell 2016).

The impact of changing the depreciation rates of the equipments of the farm is higher on cattle rearing since this is the productive activity most demanding in materials and equipment. Anyway the second evaluation, with faster depreciation rates, was used just for comparison with the economic assessment. Table 21 presents the emergy accounting table for the Holm Oaks Farm used to carry out the comparison with the economic evaluation.

An important concept that allows the comparison between economic and emergy evauations 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 3.22E+12 sej (adapted by Oliveira from Oliveira *et al.,* 2013). If the value of 13335.00 $ was paid for the cork in the year of 2012, it will correspond to a value of 4.29E+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.

Table 22 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.

Table 22 – Determination of the Emergy Exchange Ratio (EER) for the different outputs of the farm

Output (Y)	Emergy (sej y^{-1})	Emergy 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

As can be seen in table 22, the manager is losing emergy when selling calves in the auction because the EER is lower than 1 (0.44). Each year that he sells cattle he loses 2.17E+17 sej of emergy. It is in order to compensate this value that the manager receives a support of 29787.30 $ each year, but to completely compensate the emergy exported from the system he should receive a total support in the value of 67393.38 $, or sell the calves for 119 565 $. This means that he should sell calves in the auction at an average price of 5.13€ kg^{-1}.

With an EER of 2.54, the emergy in the hunting license is much higher than the emergy invested by the system in the production of game animals. It would be, therefore, a good investment for the manager to sell his hunting license to others who would like to benefit from it.

The owner gets a reasonable profit with the sale of cork with an EER of 1.25, getting more emergy in the money it receives for cork than that which is exported by the system.

By dividing the emergy value found for each output of the farm by the EMR of a country in a certain year, a money equivalent is obtained which, in the emergy evaluation method, is called Emdollars (Em$) (Table 23). These Emdollars are a measure of the money that circulates in an economy as a result of a flow of emergy.

In table 23 the emergy values corresponding to each item (column 3) are presented as the money values, when available (column 4). Column 5 presents the Em$ values corresponding to the emergy of each item and column 6 presents the emergy in the prices at which items are valued.

Table 23 – Comparison between the emergy of farms inputs, its prices, the corresponding Emdollars and the emergy in the money

Notes	Resources	Emergy (a) values (sej y^{-1})	Economy (c) values ($ y^{-1})	Em $ Values ($ y^{-1})	Emergy in the money (sej y^{-1})
(1)	(2)	(3)	(4)	(5)	(6)
1	Solar radiation (b)	9.02E+15		2801.79	
2	Wind, kinetic (b)	6.33E+15		1966.02	
3	Rain, geo-potential absorbed (b)	2.06E+14		64.10	
4	Ground water, chemical potential	6.94E+14		215.46	
5	Rain, chemical potential (b)	1.21E+17		37598.70	
6	Evapotranspiration	1.07E+17		33247.14	
7	Trees biomass (b)	5.89E+16		18283.77	
8	Acorns (b)	5.89E+16		18283.77	
9	Natural pasture (b)	1.02E+16		3180.07	
10	Hay for bales (b)	3.81E+16		11844.94	
11	Erosion, topsoil	1.99E+14		61.75	
12	Seeds	1.41E+15	422.90	436.64	1.32E+17
13	Fuels	2.19E+16	9558.82	6812.78	1.36E+15
14	Fertilizers	2.72E+15	2020.92	844.12	3.08E+16
15	Mechanical equipment	1.00E+16	11658.75	3111.14	6.51E+15
16	Plastic	1.51E+15	571.50	467.64	3.75E+16
17	Feeding trough	1.75E+15	11004.30	542.34	1.84E+15
18	Fences (material)	4.61E+16	5058.98	14311.67	3.54E+16
19	Medication	1.65E+13	1119.51	5.11	1.63E+16
20	Labor	2.05E+17	16808.63	63548.02	5.41E+16
21	Subsidies		44261.95		8.71E+16
22	Taxes paid to the government		- 9054.08		- 2.92E+16
23	Land use permit		- 7563.03		- 2.44E+16
24	Hunting	2.13E+15	1680.21	662.70	5.41E+15
25	Firewood	7.65E+16	1380.74	23757.76	4.45E+15
26	Cork	3.44E+16	13335.00	10683.23	4.29E+16
27	Calves	3.67E+17	52209.92	113975.15	1.68E+17

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.

In Figure 17 can be seen a bar chart with the comparison between the real prices and the Emdollar equivalents for each of the inputs in the Holm Oaks Farm.

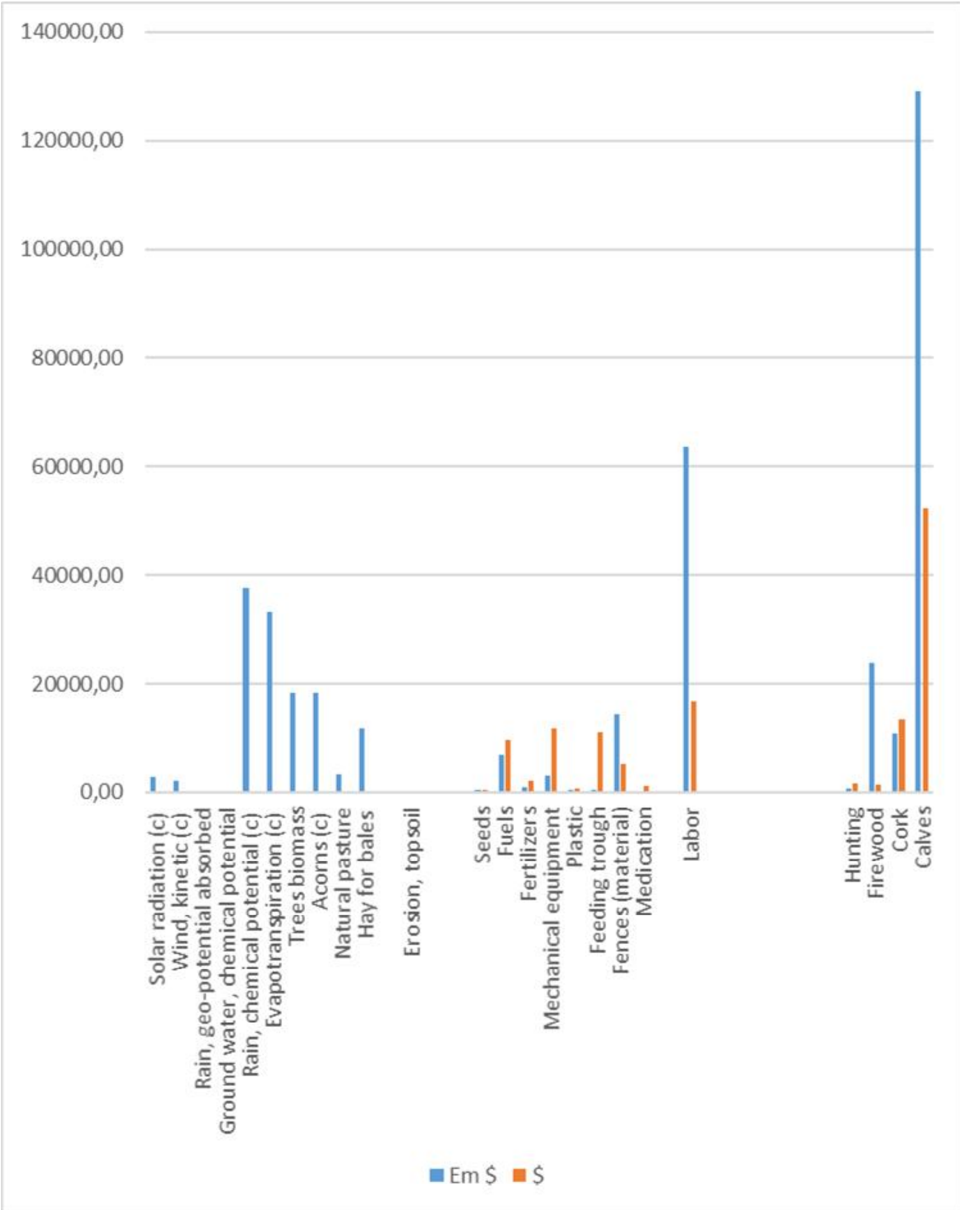


Figure 17 – Bar chart with the comparison between the real prices ($) and the Emdollar equivalents (Em$) for each input of the Holm Oaks Farm.

What first can be seen is that there are a number of inputs for which there is no monetary value assigned. These correspond to the free emergy inputs available on the farm that usually are not measured in economic terms. Two inputs for which there is a large discrepancy between the Em $ value and the price given by the market, are "Labor" and "Calves" sold at the auction. The Em $ value is 26 % higher than the economic value for "Labor" and 40 % higher than the economic value assigned to “Calves”. This means that the market is not properly valuing these inputs and that the price paid for them should be re-adjusted in order to fully pay the investment of the overall system to provide them. The same difference happens with “Fences” and “Firewood”. For other inputs we observe the opposite situation, (e.g. Mechanical equipment and Feeding trough) the prices assigned by the market being higher than the Em $ values. One reason for this situation may be not properly accounting for all emergy invested in the production of these items. In the case of agricultural machinery and transport vehicles, its emergy is accounted by its weight in steel, but we know that there is factory work required to make any kind of equipment, besides the transportation of the equipment and raw materials. Such emergy evaluations are being made gradually in different studies allowing for these assessments to be increasingly accurate.

The Em$ values and the emergy in the money paid for a product (Table 23) are only translations that allow the comparison between the emergy values and the monetary values assigned to the resources. If the first measure unit represents an approximation from the emergy side to money values, using, as conversion factor, the EMR for Portugal; the emergy in the money paid for a product represents an approximation from the economic evaluation to the emergy values using the same conversion factor. In this way, when comparing the calves’ emergy with the emergy in the money received for them, we must be aware that we are comparing the emergy of this process, of producing calves on this farm, in relation to an average value for the emergy in Portuguese money.

A comparison table similar to Table 22 but where only the emergy values corresponding to each item (column 3) and the corresponding percentage in relation to the total of inputs (column 4) are presented was built (Table 24). In this table money values, when available (column 5) and the percentage in relation to the total of inputs (column 6), are also presented.

Table 24 - Emergy versus budget accounting for the Montado farm.

Notes	Resources	Emergy (a)		Economy	
		Values (sej y^{-1})	%	Values $ (c)	%
(1)	(2)	(3)	(4)	(5)	(6)
Farm renewable resources (R)		**1.08E+17**	**27.53**		
1	Solar radiation (b)	9.02E+15	2.27		
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	23 Land use permit	(rent)
6	Evapotranspiration	1.07E+17	26.90		
7	Trees biomass (b)	5.89E+16	14.79	7563.03	13.08
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 nonrenewable 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	70.92
12	Seeds	1.41E+15	0.35	422.90	
13	Fuels	2.19E+16	5.51	9558.82	16.54
14	Fertilizers	2.72E+15	0.68	2020.92	3.50
15	Mechanical equipment	1.00E+16	2.52	11658.75	20.17
16	Plastic	1.51E+15	0.38	571.50	0.99
17	Feeding trough	1.75E+15	0.44	11004.30	19.04
18	Fences (material)	4.61E+16	11.58	5058.98	8.75
19	Medication	1.65E+13	0.00	1119.51	1.94
Services (S)		**2.05E+17**	**51.41**		
20	Labor	2.05E+17	51.41	16808.63	29.08
Total Social Cost = R+N+M+S		**3.98E+17**	**100.00**	57801.40	100.00
Transfers		-5.80E+16	-14.57	-35207.87	-60.91
21	Subsidies	-8.71E+16	-21.90	-44261.95	-76.58
22	Taxes paid to the government	2.92E+16	7.33	9054.08	15.66
Total Private Cost		**3.40E+17**	85.43	22593.53	39.09
Output (Y)					
24	Hunting	2.13E+15	0.40	1680.21	2.45
25	Firewood	7.65E+16	15.92	1380.74	2.01
26	Cork	3.44E+16	7.17	13335.00	19.44
27	Calves	3.67E+17	76.46	52209.92	76.10
Total		**4.80E+17**	**100.00**	**68605.87**	100.00
Returns					
Social Net Return		8.24E+17	20.70	10804.47	18.69
Private Net Return		**1.40E+17**	35.27	91199.40	157.78

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.

Basically these estimates provide an income statement or real budget accounting organized in an emergy format table. Emergy and economic evaluations can be easily compared by looking at the relative values allocated to each item and group of items indicated above.

Social and private costs and returns are also computed and included in Table 24. Total inputs were considered first without government transfers, subsidies and taxes deriving, in economic terminology, in social results. Transfers are wealth or work that does 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.

A specific procedure was adopted, in this comparison, to allow for rigorous evaluation of emergy that was previously emphasized. The property rights of landowners allow them to decide on the use of the work of the bio-geophysical system on their farms.They benefit for example from rainwater 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 allows for the tenant farmer to have access to natural resources of the farm. Hence, land rent was considered to be a payment by the tenant, who manages cattle rearing, for the availability of a set of local natural renewable and nonrenewable resources, including sun, rain and top soil use, although the landowner and not the bio-geophysical system receives the payment for that work. Since the rent is a payment in money for the local resources the monetary value was included in the budget accounting for the farm.

Total social costs of the Holm Oaks Farm are estimated to be 57.8 thousand dollars. Production benefits are estimated to be 68.6 thousand dollars. Hence, net social return of the farm is estimated to be 10.8 thousand dollars which is 18.7% of total costs. Labor costs represent 29.08% of the total costs followed by renewable and nonrenewable local resources with 13.08%. Purchased resources makeup most of the remaining 70.9% of total costs. Calves' sales represent 76.1% of the total benefits of the system, followed by cork, a benefit received by landowner, 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.

Agricultural policies through subsidies and payment transfers are very important to economic results. The montado farm receives the equivalent to 44.3 thousand dollars per year. This governmental transfer (net of taxes) is estimated to be 35.2 thousand dollars per year, which represents 60.9% of the total costs, and results in an increase in the net private income return of the farm to 91.2 thousand dollars or 157.8% of total costs.

Comparing emergy and economic evaluations in Table 24, one can immediately visualize which resources are not accounted for when budget accounting is used. Empty slots in the economic evaluation that have a value in the emergy evaluation indicate the bio-geophysical system's renewable and nonrenewable resources that are not accounted for in monetary terms. Rent that globally relates to the cost paid for these resources represents in economic terms 13.1% of total costs of the system. Note that in the case of an owner-managed farm this money value would be zero. However, these resources represent 27.1% of total value in emergy terms. Hence, local natural resources of the system are undervalued in economic terms relative to emergy. Markets are not socially valuing in monetary terms the bio-geophysical's contribution to the Montado silvo-pastoral system as they should to ensure an economic activity that is sustainable over the long term.

The services required by the system only include labor. Relative values allocated to labor are also far apart in the two evaluations. Labor costs represent 29.1% percent of the total monetary costs. The estimated contribution of labor using emergy is 51.4%, considerably higher. Therefore, in monetary terms, markets seem to be socially valuing human labor 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 70.9% of total costs. The emergy of purchased factors relative to total emergy of the system is only 21.5%. In terms of different purchased factors the mechanical equipment, the feeding trough and fuels, are the main components of economic costs with shares of 20.2, 19.0 and 16.5%, respectively. However, emergy evaluation values their work contribution for the system only at 2.5, 0.4 and 5.5% shares, respectively. Hence, 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 that there is 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 of the system are overvalued relative to other factors, namely local natural renewable and nonrenewable resources as well as labor services, and vice-versa, in emergy versus economic evaluation local natural renewable and nonrenewable resources are overvalued relative to purchased factors.

Comparing the importance of agricultural policy in money and emergy terms is also possible. As referred to earlier, government net transfers end up having an effect equivalent to decreasing private costs by 76.6%, i.e., to private costs of only 39.1% of total costs. In emergy terms transfers have a lower impact representing a net decrease of 21.9% and resulting in private costs that are 85.4% of total costs. In economic terms, net transfers derived from agricultural policy increase the social net return of the system from 18.7% of total costs to a private net return of 157.8% 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. Hence, agricultural policy evaluation varies depending upon the evaluation method, economic or emergy, used to estimate its impact.

5.2.1 The share of emergy investment and return between the owner and the manager of the Holm Oaks Farm

A lot of work, measured through emergy and, in some cases, money, is annually invested in the Holm Oaks Farm by different actors in order to get distinct outputs. The manager invests in fences, ponds, fertilizer, machinery and fuels to produce extra feed for cattle, a water-pump and fuels to have water in the summer, as well as labor, machinery and fuels that he uses when visiting the farm every day to prune trees or make firebreaks among other works. Nature participates in this process by concentrating dispersed nutrients in the soils in the form of natural pastures and acorns and by providing conditions for the natural regeneration of the trees and their growth, by the actions of birds and other animals in dispersing acorns through open areas; thus seeding new Montado areas. Nature also contributes with work by developing seeds and plants with different forms of resistance to the adverse weather conditions of the Mediterranean region and by maintaining soil life and the necessary biodiversity to ensure balance in the ecosystem and to protect plants and trees from pest attacks (da Clara & Ribeiro, 2013). The farm owner invests in the farm by providing the conditions for cork and firewood harvesting and by paying the corresponding taxes to the state.

The diagram presented in figure 18 describes the investments of each actor in this farm, including the emergy and money fluxes in functional groups.

Flows of money and emergy were kept separate in the diagram, but in fact they are coupled. Some emergy flows have associated money flows and some are alone. Most money flows are associated with emergy flows in exchange, but some are not. Money flows that enter the system alone will be associated with emergy flows when spent. So major money flows are money received for products sold on the market, money spent for goods and services purchased, money received as subsidies or investment and money paid in taxes. Money paid for rent to the landowner makes the “free” flows of nature associated with the land available for use by the farmer. Subsidies received by the farmer from the government and the European Union are used by the farmer to supplement his profit and to make-up for shortfalls in revenues to purchase needed inputs.

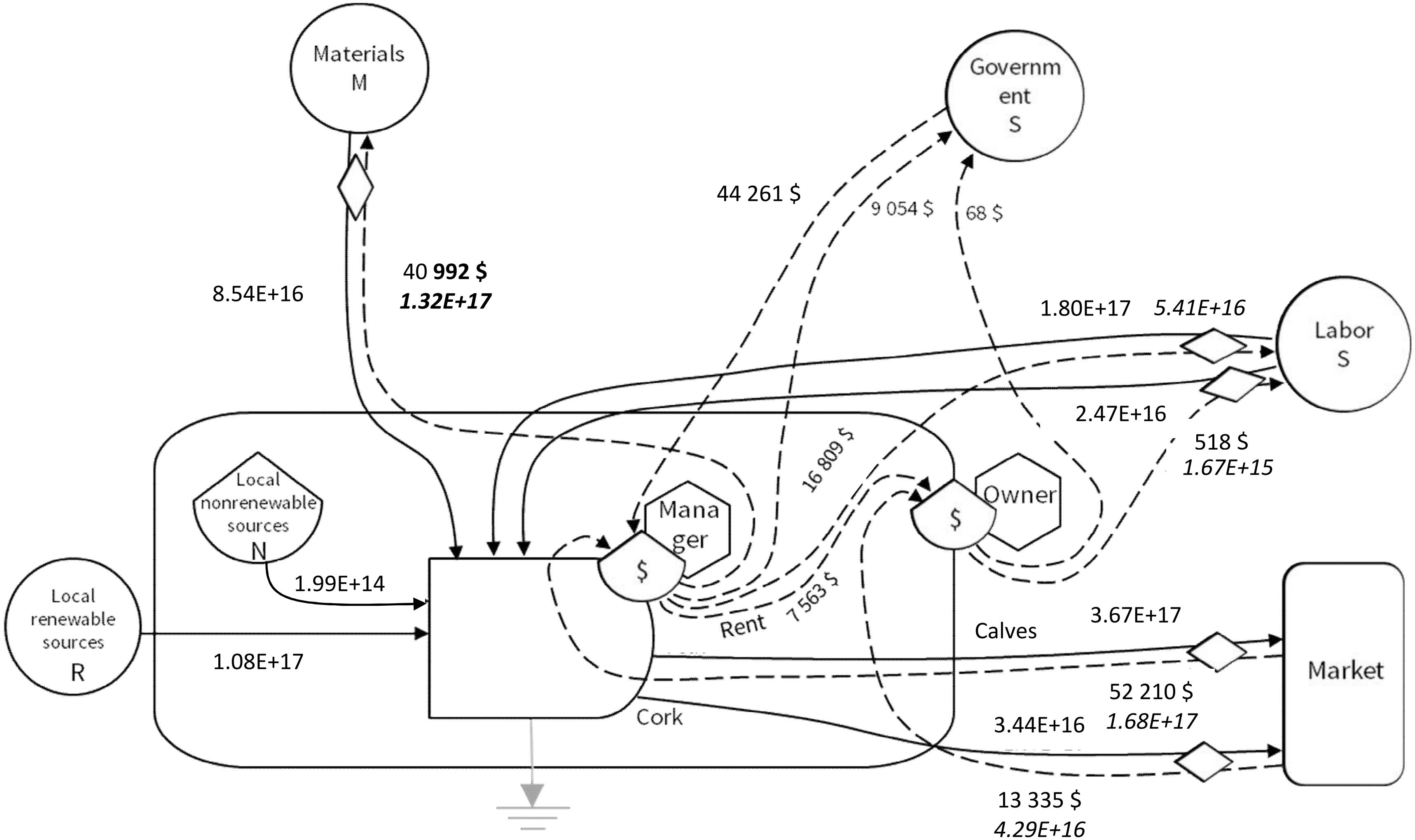


Figure 18 - Aggregate ESL diagram representing the emergy and money fluxes aggregated by function. Emergy fluxes are in sej and normal lettering, money fluxes are presented in $ and by the emergy that is possible to buy with this money (in italic) below.

The money balance for expenses and revenues on the farm is presented in equation 4:

Eq. 4 $ manager profit + $ purchased inputs + $ rent + $ taxes = $ products sold + $ subsidies

To analyze the distribution of expenses and revenues between the manager and the owner, who leases the farm, Table 25 is presented. The income statement shows how much money the manager or the landowner generated (revenue), how much was spent (expenses) and the difference between the two (profit) over the year of 2012.

Table 25 – Distribution of expenses and revenues ($) between the owner and the manager of Holm Oaks Farm.

Profit ($) +	Purchased inputs ($) +	Rent($) +	Taxes ($) +	=	Products sold ($) +	Subsidies ($)
Manager (system)						
Profit ($) +	40 992.77 + 16 808.63 +	7563.03 +	9054.08	=	52 209.92 +	44 261.00
Profit ($) =	22 052.41					
Owner						
Profit ($) +	518.22 +		68.00	=	13 335.00	
Profit ($) =	12 748.78					

Analyzing Table 25 it can be concluded that, in 2012, the manager made a profit of 22 052 $, almost the double of the owner (12 749 $), reflecting the higher intensity of investment in the system from the manager. Here, firewood is not being accounted because there is no payment for the service of pruning the trees. This is, instead, exchanged for the firewood. That means that an emergy of 7.65E+16 sej in firewood is annualy exchanged for a service of pruning corresponding to 2.95E+14 sej, which some forestry engineers consider unnecessary and even harmful to the trees. The landowner is thus exporting emergy from the system without receiving a corresponding service or product in return.

Doing the same exercise with the emergy flows (Table 26) and using the emergy in the money for money flows, the manager will present a result of 1.06E+17 sej and the owner will present a result of - 2.09E+15 sej of emergy.

Table 26 – Distribution of expenses and revenues (sej) between the owner and the manager of Holm Oaks Farm.

Profit (sej) +	Purchased inputs (sej) +	Flows of nature (sej) +	Taxes (sej)	=	Products sold (sej) +	Subsidies (sej)
(1)	(2)	(3)	(4)		(5)	(6)
Manager						
Profit (sej) +	8.54E+16 + 1.80E+17 +	1.08E+17 +	2.91E+16	=	3.67E+17 +	1.42E+17
Profit (sej) =	1.06E+17					
Owner						
Profit (sej) +	1.67E+15 +	5.89E+16 +	2.19E+14	=	3.44E+16	+ 2.43E+16 (rent)
Profit (sej) =	- 2.09E+15					

In this case the emergy provided from the free inputs from nature is accounted, this being responsible for the emergy profit of both the farmer and owner. For the manager, purchased materials and services were included in column 2 and all the free flows of nature used by calves were accounted in column 3. For the landowner, the labor in cork was accounted (column 2) and the free flow corresponding to the annual growth of the trees (column 3). The taxes of the landowner is the property tax (column 4) and the rent was considered as a subsidy to his activity (column 5).

While the manager is a net importer of emergy to the system, corresponding to 1.06E+17 sej, the landowner is a net exporter with the sale of cork and rent not compensating the investment from nature and the labor in the creation of cork. This is only less visible because the emergy exploited is renewable, but the activity carried out by the landowner is clearly extractive.

5.2.2 The bales

In addition to the emergy determination for each farm item, the emergy of bales, an intermediate product in the system, was also estimated. Bales are produced on the farm but their total emergy value was not added to the emergy accounting table because it is an intermediate product and its addition would correspond to a double accounting. What was added, to the emergy accounting table, were the fuels, machinery and hours of labor required for its production and the pasture for hay, and fertilizers' emergy. Even in the calculation of renewability of bales this indicator was calculated separately for each item and never for the bales as a product. The farm produces about 1.08E+5 kg of bales corresponding to a total of 7.62E+16 sej of emergy. The average price of the bales is 0.07 to 0.18 € kg^{-1} depending on the time of the year, the quality and quantity of hay on the market, which in turn is dependent on the precipitation. The average value of 0.125 € kg^{-1} was used corresponding to 0.143 \$ kg^{-1} and a total of 15 430.5 \$ that the manager would gain if he sold all his production of bales in the market. But multiplying this value by the EMR for Portuguese money in 2012 (Oliveira *et al*. 2013) corresponds to 4.97E+16 sej for the emergy in the money that is paid for the bales. This means that if the manager chooses to sell the bales he will lose on emergy terms, because the emergy that he can buy with this money in the Portuguese economy is, in general, lower than the emergy in the bales.

In fact it is uncommon for the manager to choose to sell the bales, preferring to keep the excess production for the coming years.

The renewability of these bales corresponds to 54.41%. This value could be increased if the productivity per emergy invested was higher, if instead of using a chemical fertilizer an organic fertilizer was applied, or if the baling process was less dependent on heavy farm machinery and fuels.

5.2.3 The renewability of purchased inputs and their prices

In Figure 17 it was seen that the prices assigned by the markets do not always cover the emergy investment made by man and nature in production. In the case of calves, firewood, labor or fences, a significant part of this investment is not being paid. Once the renewable and nonrenewable components of these items were identified, it will be assessed below to what extent the prices allocated by the market cover, at least, its nonrenewable component.

In Figure 19 is discriminated the amount of emergy of each farm item provided from renewable sources and nonrenewable sources.

In this figure it is possible to see, as suggested by the traditional classification of the emergy evaluation method, that most of the free inputs provided from nature are renewable and that most of the purchased inputs provided from the economic system are non-renewable. The renewability of the outputs are a consequence of the renewability of the corresponding inputs. Therefore, only the firewood has an emergy maily renewable, the emergy of the other outputs being mainly nonrenewable.

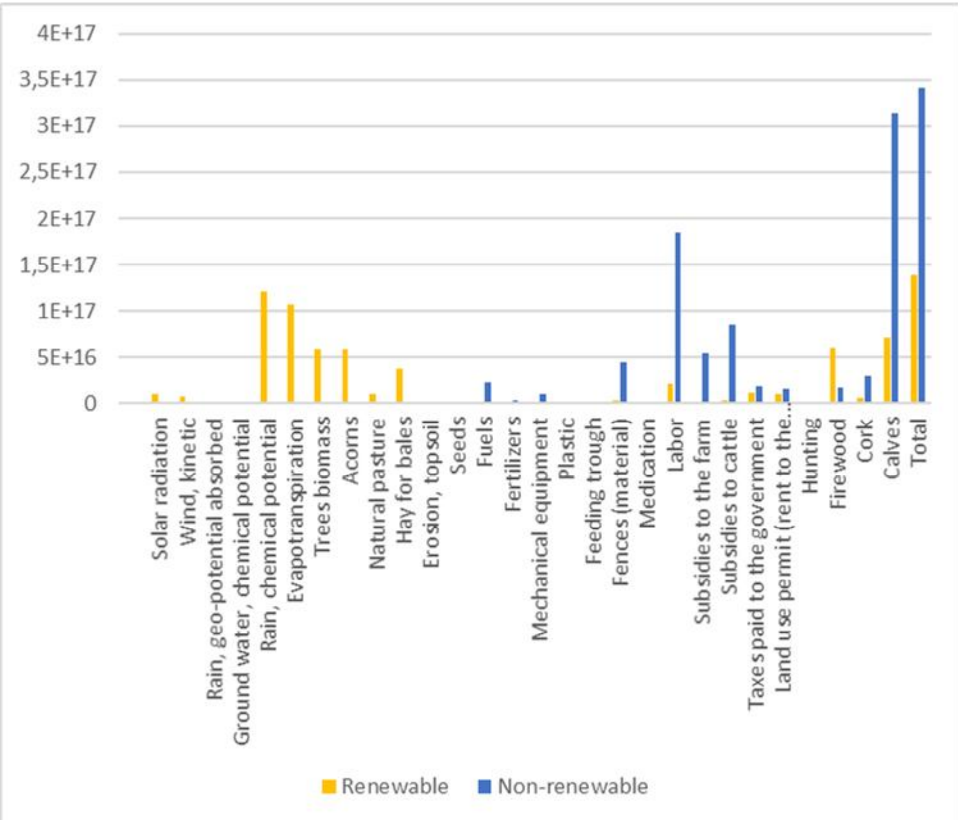


Figure 19 – Bar chart with the renewable and nonrenewable emergy component of each input and output of the Holm Oaks Farm.

The "labor", that in this farm represents the most important emergy flux with 47% of the emergy share (2.05E + 17 sej y^{-1}), has a major impact on this distribution. Since “labor” is considered only as 10% renewable (Panzieri *et al.,* 2002), the effect on outputs is to lower significantly their renewability. A more accurate determination of the level of renewability of labor for Portugal would allow more accurate values for the renewability of each item. In countries less dependent on non-renewable flows to support its working class (traditionally in developing countries), the renewability of the “labor” is higher and all the products derived therefrom have a higher renewability.

Recreating 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 nonrenewable emergy that the system invested in the creation of this product (Table 27) it is possible to get a new ratio that was called Nonrenewable Emergy Exchange Ratio (EER_N) (Equation 5).

Eq. 5 $$EER_N = Y_M/Y_N$$

Table 27 – Determination of the Nonrenewable Emergy Exchange Ratio (EER_N) for the different outputs of the farm

Output (Y)	Nonrenewable 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

After new determination of this ratio to farm outputs (cork and calves), values for EER_N of 1.48 for cork and 0.53 for calves were obtained against the values obtained previously (Table 22) (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 nonrenewable 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 nonrenewable emergy investment in the production of calves, would be to sell the calves at the auction at least at 4.78 $ kg^{-1} instead the 2.26 $ kg^{-1} actually charged. And this money should be used to compensate the nonrenewable emergy spent in calves' production, in order to avoid farm degradation and the degradation of the system from which the other nonrenewable 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 made, based on the nonrenewable emergy invested in calves' production (Table 28) indicates the type of investment that should be made in the system in order to avoid deterioration.

With this money the manager should 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 should be done to compensate for the extraction of ores used in the manufacture of machines and equipment. The investment in a more sustainable lifestyle should 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 could 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.

Table 28 – Determination of the annual investment, and corresponding area, in order to compensate the impacts of calves' production

	Nonrenewable emergy	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 mecanical 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

According to the same reasoning, the farmer's income should correspond to the renewable emergy invested in calves' production, that is 21 118 $. As the nonrenewable sources of emergy 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 emergy available to obtain resources would increase, thus increasing the managers' income.

6. CONCLUSIONS

6.1 The Montado

Resulting from the human intervention on the primitive Mediterranean oaks forest, the Montado maintains a set of natural mechanisms or emergy fluxes from which farmers take advantage, as cork and acorn production, natural pastures or game production which benefits hunting. This means that the manager of a farm in Montado can take advantage of a larger set of free energies of nature than in other more industrialized agricultural systems. In this evaluation it was estimated that as much as 27% of the inputs to the production is derived from renewable resources if the subsidies, the rent and the taxes are not taken in account. The common economic evaluation of montado system neglects this natural component and although some managers attempt to manage this component so that the balance of the natural resources is maintained, and a few rules established by the government aim to guarantee the balance of these resources, if management startegies do not take consciousely in account the role fo natural resources, management oriented for short term profit ends up being at the expenses of its long-term continuity (Godinho et al., 2016c).

Emergy evaluation makes these free inputs to the system visible, facilitating or at least providing the complete information and knowledge for their full account in decisions by managers, as well as in policy design by decision-makers and the consequent policy measures. Besides the integrated and long term information it provides to the land owner, emergy evaluation is a practical approach to fully integrate the full range of factors intervening in a production system, and thus it also supports the integration of different sector policies for a systemic view and an integrated public sector strategy for the Montado. Thus it supports the integrative and adaptative management pathway which so often has been defended as required for the sustainability of the Montado (Pinto-Correia *et al.,* 2011; Pinto-Correia *et al.,* 2013; Ferraz de Oliveira *et al.,* 2016). Some questions, related to the application of the emergy evaluation method, which were not considered when applying this method to other systems, were clarified during the present work. Just to list a few of them: a) the way to deal with the co-products that are generated in the Montado (eg. cork, acorns and trees annual growth), and b) how to deal with the complexity of the set of activities, performed by the same machines, with a proposal to address this issue in Table 7; or c) the difference between machines that are from the owner and machines which are rented, (same Table 7); and d) the same labor being linked to different activities and resulting in different outputs at the same time, from which Table 8 is a proposal of solution. These are usual questions concerning complex systems like the Montado and deserve a systematic approach – finding a functional way to integrate them in the analysis has been a challenge during the present work, but adequate solutions were found and thus progress was made in the sense of an increased capacity for integration, in this type of complex system analysis. The accounting of the renewability of the purchased materials, machinery, services and labor, as used in the present work, is a proposal for a different evaluation and accounting for the usually considered non-renewable inputs to the system. In promoting sustainability it is important that this non-renewable component of the items, contributing to the lack of sustainability of the system, can be progressively replaced by a renewable component in more sustainable inputs.

6.2 Economic versus Emergy evaluations

One of the central concepts of economic evaluation is that money plays the significant role of valuing goods and services as a common denominator providing an absolute and a relative scale for their evaluation and allowing for exchange (Hicks, 1989; Napoleoni, 1977; Smith, 1776). Prices establish values of contracts agreed between buyers and sellers of goods or receivers and providers of services in their respective markets. Hence, the first assumption underlying the economic evaluation of goods and services is that they are tradable or exchangeable in a market. In addition, prices result from market supply and demand or from the cost of goods and services to producers or providers and the willingness of consumers or receivers to pay for them and from differences in the market power of these economic players (Baumol, 1977). Moving from individual to aggregate demand the value of those goods or resources depends on the individuals' values or, in other words, on society's values because values are determined by collective choices. They are anthropocentric because they express exclusively human views and values. In this way the neoclassical economy describes the economic process as an isolated circular flow diagram from firms to households and back again with no inlets or outlets. Despite the utility of this diagram in analyzing exchange, it fails when studying production and consumption (Daly, 1995). Both the resources used, the marketed products resulting from industrial activity, and this industrial activity, are integrated into the wider bio-geophysical system and are subject to the same laws, including the second law of thermodynamics. This law states that reversible processes are a convenient theoretical fiction and do not occur in nature. This is the same as saying that every system is subject to entropy or degradation of its structure and order, and to maintain it, there must exist a continuous input of high-quality energy and materials and the corresponding output of low-quality energy and materials in the form of heat and waste (Ayres, 1998; Daly, 1995; Georgescu-Roegen, 1993). Instead of an isolated circular flow diagram representing the processes between firms and households, the emergy evaluation method proposes a vision of open systems, always taking into account the next larger level (Odum, 1996) at a lower scale, and the inputs provided from it to the system under evaluation and the outputs to the next larger level, with lower entropy, such as calves or cork, or with higher entropy, such as metabolic heat, dung or eroded soil. This perspective of the emergy evaluation is well illustrated through one of its main concepts, the nested systems, (Morandi *et al*., 2013, 2015) exchanging with each other products with successively lower levels of entropy, but in reverse, also products or energy with a lower capacity to do work.

Many classical economists, biologists and physicists thought about biophysics as a source of wealth (Christensen, 1989; Cleveland & Ruth, 1997; Hall *et al*., 2001; Martinez-Alier, 1987; Marx, 1906; Ricardo, 1891; Smith, 1937). Georgescu (in Daly, 1995) noticed that nature is also a source of value added in the form of low entropy and the emergy evaluation method evaluates equally "natural" or "human" value added. In this way emergy accounting can be viewed as the added solar equivalent energy value as economic accounting views added monetary value (Bowman &

Ambrosini, 2000). Indeed the emergy, just as the money incorporated in a product, 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. It is this possibility of comparison of different qualities of the energy and its ability to perform work against the same baseline, provided by the emergy evaluation method that allows us to compare products and services from the geo-biophysical and the economic system on a common basis (Odum, 2001; 2002). In this context it can be considered that the emergy measures real wealth and that the emergy per person measures the standard of living. The emergy per money unit will indicate the real wealth buying power, being used to calculate the economic equivalent, the *emdollars* (Odum, 2002). The emergy balance in a country in a certain year corresponds to the real wealth responsible for the Gross Domestic Product (GDP) of this year (Huang & Odum, 1991; Oliveira *et al*., 2013), and the same estimation can be carried out for the world (Brown & Ulgiati, 1999).

According to Hirschberg (2012) "externalities are defined as changes in welfare generated by a given activity that are not reflected in market prices". These are out-flowing non-commodity outputs resulting from economic activity and can be positive or negative. Determining the value of externalities is a way to determine the full benefits or costs of an economic activity. This can be done through other pricing schemes such as travel cost (Hanley, 1995), hedonic pricing (Sander & Haight, 2012; Sunak & Madlener, 2012) and contingent valuation (Saz-Salazar & Guaita-Pradas, 2013; Stigka *et al*., 2014) depending on the specific characteristics of the resource and the components of use or non-use value that need to be evaluated (Campbell *et al.,* 2014; Tietenberg & Lewis, 2012). The methodologies and techniques mentioned above are available as a way to internalize, in market prices, those externalities, to the extent that this is possible, as a framework to account for the full benefit or the costs of decision-making. However, willingness to pay (Hanemann, 1991) and associated preference structure of the individual or the collective receivers (Srinivasan & Park, 1997) is the base pricing mechanism underlying these evaluation procedures. In all these methods the approach is based on a value judgment of the benefit gained from the good or resource that the user receives or expects from its use or conservation. Hence, resource evaluations with these methods depend on receiver values. In economics these are said to be individual preferences (Pillet, 2004; Tietenberg & Lewis, 2012).

The emergy evaluation considers that even when the non-commodity outputs (as pollution) are accounted, the standard economic picture is incomplete because the corresponding positive environmental non-commodity inputs (as environmental goods and services) were not accounted. It is in this context, and within a deliberate attempt to make a bridge between the emergy evaluation and the conceptual framework used by economics, that emternalities concept was proposed (Pillet, 2004). Unlike externalities that correspond to unaccounted out-flowing impacts of the economic process, internalized in economic decision-making through valuing in monetary terms benefits and costs based on the preference structure of receivers; emternalities correspond to the unaccounted inflowing environmental contributions, evaluated in terms of the emergy received from the donors (Pillet, 2004; Pillet *et al*., 2001). Hence, their value is not established on the basis of exchange or contract between parties because it occurs independent of actions and thoughts and also because the bio-geophysical system has no juridical individual or collective person existence. This leads to the input of natural values into economic accounting, enlarging economic analysis and the total value of resources (Campbell, 2013). Some cases of emternalities are rain, sunlight or organic content of the soil for farming activities. They have specific consumption characteristics and cannot be managed through regular property rights. However, in agriculture, access to land through property or lease contracts allows for the appropriation of that environmental value.

Unlike economic methods, through emergy evaluation one can evaluate natural resources and their contribution to the production of goods or to provide services particularly the non-tradable ones. Emergy evaluation is therefore a framework that, in addition to tradable factors of production, can be used to evaluate the bio-geophysical system´s work and its relative contribution, to fully value products and services at universal values. Emergy evaluation of benefits and costs of the bio-geophysical system's resources is not based on the buyers' values expressed by their willingness to pay. The approach is a donor rather than a receiver based evaluation that can also be described as ecocentric. Hence, it is a universal valued-based estimation. Therefore, the proponents of emergy argue that this evaluation method provides a basis for economic, social and ecological systems' evaluation (Campbell, 2013; Odum, 2007).

Still comparing the emergy and the economic evaluations regarding the use of renewable and nonrenewable resources, the former takes special care identifying the renewability of the resources used by the system in question (Brown & Buranakarn, 2003; Brown & Ulgiati, 1997, 1999; Ulgiati *et al*., 1995) and even among the resources that have already been transformed by man (e.g. medication, agricultural machinery, fuels) there is a concern in determining the amount of renewable and nonrenewable resources that were used. This is done by studying the production processes and estimating renewability factors associated with each product that comes from a certain well-defined production process (Odum, 1996). The aim is to make an impact assessment of the processes in the surrounding system and propose alternative processes that produce less negative impact (Wright & Østergård, 2015).

In the case of the Holm Oaks farm its renewability of 24% is low, due mainly to cattle production and some activities of general management of the farm. This means that, for the long term survival of this system, the manager should carry out management changes in order to increase renewability values of the purchased and transformed inputs and increase the renewable inputs. In opposition to emergy evaluation, neoclassical economics does not make a proper distinction between renewable and nonrenewable inputs since it only focuses on the value assigned by the consumer and their insufficiently informed willingness to pay, leading to an insufficient appreciation of the renewability of resources such as the almost nonrenewable fossil fuels (Hall *et al*., 2001) or soil. Making use of their common sense, farmers, commonly, carry out crop rotation in order to not deplete the soil, but these activities do not result directly from the economic evaluation of the farm. They result, instead, of farmer concerns about soil fertility, not common to many other farmers (Gucci *et al*., 2012).

As Hall & Klitgaard (2006) observed, the low effective collaboration between economists and ecologists leads to the latter developing their "nature-based thing" while ecological-economists, using the economic-derived techniques, end up giving a value to the world's ecosystem services (Costanza *et al*., 1997). Effectively, emergy accounting provides an indication of the proportion of the value of resources that standard farm budgeting fails to take into account in cases where no markets exist, or do not function adequately, or where no market prices are available or they fail to incorporate the full value of those resources. However, the emergy evaluation method is not intended to replace the economic evaluation, but just inform it better and, when necessary, provide the economy with credible and appropriate values on prices to allocate the goods and services of nature that are usually not valued by markets (Campbell & Tilley, 2014b). Complementing budget accounting with emergy accounting allows the possibility of evaluating the *emternalities* of farming systems thereby bringing to economic analysis a full evaluation of resources. In this way, it enlarges the total economic value of resources with a donor perspective that enriches economic analysis and allows better informed, fully accounted and sustainable economic decisions.

6.3 Knowledge gaps and future research paths

Several issues would benefit from a closer look, or more targeted research and a deepening of the existing knowledge. These are issues which were raised during the present work, but could not be fully solved. Some deserve to be referred to:

a) The Montado silvo-pastoral system is quite complex with several situations where co-products result from the same process. Part of the acorns produced by trees is used to feed wild animals and for natural regeneration of the holm and cork oaks (Focardi *et al.,* 2000; Pons & Pausas, 2007), and these processes were not accounted in this evaluation. For this determination it would be necessary to estimate the population of wild animals and know their corresponding rate of acorn consumption and also estimate the proportion of acorns that result in new regeneration. It was only estimated and assumed that half of acorns produced by the trees are consumed by cattle. The trees themselves serve as shelter to a rich wildlife population that, again, was not accounted, although this biodiversity is highly valued in the context of ecosystem services by European Union (Almeida *et al*., 2013; Godinho *et al*., 2011).

b) Soil and soil mycorrhizae are sensitive system components which may be subject to degradation. This can be estimated by determining the average weight of the livestock, the surface of the hoof and the period of time they spend in each area of the farm. Future evaluations can incorporate these and other interdependent aspects of the Montado system.

c) There are also few studies on the productivity of natural pastures in different soil and weather conditions, and therefore most often average values were used, which do not correspond to the productivity of each soil, slope and climate context. More accurate values for natural pastures productivity would make it possible to obtain more reliable values for the farm, or for any other case studied in this system.

d) The work of acorn dispersion, carried out by jays, wild pigeons, wild boar and other animals, leads to the creation of new areas of Montado. This work takes place on the farm. It is free work from nature avoiding the financial burden of installing new stands, but was not assessed due to the difficulty in accounting it with the required precision.

e) Erosion could be determined using more detailed data relating specifically to the farm.

f) The development of a method for measuring trees and shrubs biomass using aerial photography would also be a great improvement for future evaluations, since the biomass production is a determinant of the production of the system.

These are questions that can be improved, in the future, when evaluation farming systems in Montado, if the aim is to achieve a more accurate evaluation of the system with all its components – and particularly, if comparisons between different farms are required. Only a sound and accurate evaluation would make it possible to assess the long term impact of management strategies and practices, both in what concerns each single farm and in what concerns the effect of public policies and related tools.

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Appendices

A. Estimation of the biomass and annual growth of the holm and cork oaks.

B. Extended ESL diagram of the Holm Oaks Farm.

C. Legend to the extended ESL diagram of the Holm Oaks Farm.

D. Simplified movements statement with the subsidies received in 2012 for the farm.

A. Estimation of the biomass and annual growth of the holm and cork oaks.

Tree	area 1 Holm oak			Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 1		Total without roots A1	Total (kg) in area 1	
	circumference at 1.30 m (cm)	diameter	branches / trunks											
1	160	50.93	B	444.69	123.84	213.70	617.61	1399.84	4199.51	**5311.95 in 1000 m²**	**53119.5 a hectare**	3581.90	**4565.99 in 1000 m²**	**45659.9 a hectare**
2	16	5.09	B	4.34	5.46	13.47	10.03	33.30	99.89			89.86		
3	27	8.59	B	12.42	11.09	25.25	25.59	74.35	223.04		60 tree/ha	197.45		
4	29	9.23	B	14.34	12.22	27.51	29.08	83.14	249.43			220.36		
5	31	9.87	B	16.39	13.38	29.80	32.76	92.34	277.01			244.25		
6	30	9.55	B	15.35	12.80	28.65	30.90	87.69	263.07			232.18		
	area 2 Holm oak			Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 2		Total without roots A2	Total (kg) in area 2	
	circumference at 1.30 m (cm)	diameter	branches / trunks											
7	25	7.96	B	10.64	9.99	23.02	22.30	65.95	197.84	**1827.52 in 1000 m²**	**18275.2 a hectare**	175.54	**1491.01 in 1000 m²**	**14910.1 a hectare**
8	26	8.28	B	11.51	10.54	24.13	23.92	70.10	210.29			186.37		
9	63	20.05	T	68.24	34.99	69.81	116.53	289.58	289.58		90 tree /ha	173.05		
10	46	14.64	T	36.26	22.84	47.86	66.38	173.34	173.34			106.96		
11	20	6.37	B	6.79	7.38	17.61	14.96	46.74	140.23			125.27		
12	26	8.28	B	11.51	10.54	24.13	23.92	70.10	210.29			186.37		
13	26	8.28	B	11.51	10.54	24.13	23.92	70.10	210.29			186.37		
14	25	7.96	B	10.64	9.99	23.02	22.30	65.95	197.84			175.54		
15	25	7.96	B	10,64	9.99	23.02	22.30	65.95	197.84			175.54		
	area 3 Holm oak			Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 3		Total without roots A3	Total (kg) in area 3	
	circumference at 1.30 m (cm)	diameter	branches / trunks											
16	55	17.51	B	51.93	29.11	59.31	91.39	231.74	695.23	**4180.60 in 1000 m²**	**41806 a hectare**	603.84	**3581.06 in 1000 m²**	**35810.7 a hectare**
17	44	14.01	B	33.16	21.51	45.37	61.31	161.35	484.04			422.73		
18	41	13.05	B	28.77	19.54	41.69	54.03	144.03	432.08		140 tree/ha	378.05		
19	43	13.69	B	31.66	20.85	44.14	58.84	155.48	466.44			407.61		
20	32	10.19	T	17.48	13.97	30.96	34.68	97.08	97.08			62.40		
21	56	17.83	T	53.85	29.83	60.61	94.39	238.67	238.67			144.28		
22	30	9.55	B	15.35	12.80	28.65	30.90	87.69	263.07			232.18		
23	38	12.10	B	24.69	17.63	38.05	47.16	127.53	382.60			335.44		
24	22	7.00	B	8.23	8.40	19.75	17.74	54.11	162.33			144.60		

25	17	5.41	B	4.90	5.92	14.49	11.18	36.49	109.48			98.30		
26	34	10.82	B	19.74	15.16	33.30	38.65	106.85	320.55			281.90		
27	25	7.96	B	10.64	9.99	23.02	22.30	65.95	197.84			175.54		
28	14	4.46	B	3.31	4.55	11.48	7.90	27.25	81.74			73.83		
29	29	9.23	B	14.34	12.22	27.51	29.08	83.14	249.43			220.36		
	area 4 Holm oak			Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 4		Total without roots A4	Total (kg) in area 4	
	circumference at 1.30 m (cm)	diameter	branches / trunks											
30	190	60.48	T	628.26	156.33	262.66	839.95	1887.21	1887.21	**9635.91 in 1000 m²**	**96359.1 a hectare**	1047.26	**5535.45 in 1000 m²**	**55354.5 a hectare**
31	56	17.83	T	53.85	29.83	60.61	94.39	238.67	238.67			144.28		
32	51	16.23	T	44.62	26.28	54.17	79.84	204.91	204.91		110 tree/ha	125.06		
33	34	10.82	T	19.74	15.16	33.30	38.65	106.85	106.85			68.20		
34	155	49.34	T	417.18	118.62	205.71	583.50	1325.01	1325.01			741.51		
35	49	15.60	T	41.17	24.89	51.63	74.33	192.01	192.01			117.69		
36	250	79.58	T	1091.00	226.81	365.14	1372.51	3055.47	3055.47			1682.96		
37	145	46.15	T	364.82	108.36	189.89	517.87	1180.94	1180.94			663.07		
38	37	11.78	B	23.40	17.00	36.85	44.96	122.22	366.67			321.70		
39	92	29.28	T	146.13	58.48	109.98	229.45	544.04	544.04			314.59		
40	91	28.97	T	142.96	57.62	108.55	225.01	534.13	534.13			309.12		
	area 5 Cork oak			Wood	Branches	Leaves	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 5		Total without roots A5	Total (kg) in area 5	
	circumference at 1.30 m (cm)	diameter	branches / trunks											
41	177	56.34	T	1544.90	234.21	44.01	277.02	2100.14	2100.14	**22015.69 in 1000 m²**	**220157 a hectare**	1823.12	**19206.85 in 1000 m²**	**192068 a hectare**
42	196	62.39	T	2090.17	268.68	49.58	342.39	2750.81	2750.81			2408.43		
43	170	54.11	T	1370.72	221.83	41.98	254.74	1889.26	1889.26			1634.53		
44	123	39.15	T	525.16	143.48	28.76	130.04	827.44	827.44		100 tree/ha	697.40		
45	170	54.11	T	1370.72	221.83	41.98	254.74	1889.26	1889.26			1634.53		
46	120	38.20	T	488.09	138.79	27.94	123.54	778.35	778.35			654.82		
47	228	72.57	T	3272.60	329.35	59.17	468.80	4129.91	4129.91			3661.12		
48	168	53.48	T	1323.46	218.32	41.41	248.55	1831.74	1831.74			1583.18		
49	220	70.03	T	2943.78	313.89	56.75	435.26	3749.68	3749.68			3314.42		
50	176	56.02	T	1519.17	232.43	43.72	273.78	2069.09	2069.09			1795.32		
	area 6 Holm oak			Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 6		Total without roots A6	Total (kg) in area 6	
	circumference at 1.30 m (cm)	diameter	branches /											

			trunks											
										5313.31	**53133.1**		**2992.2**	**29922**
51	157	49.97	T	428.08	120.70	208.90	597.04	1354.72	1354.72	**in 1000 m²**	**a hectare**	757.68	**in 1000 m²**	**a hectare**
52	143	45.52	T	354.77	106.34	186.75	505.16	1153.01	1153.01			647.86		
53	110	35.01	T	209.32	74.51	136.29	315.90	736.02	736.02		50 tree/ha	420.12		
54	150	47.75	T	390.56	113.46	197.77	550.25	1252.05	1252.05			701.79		
55	117	37.24	T	236.97	81.01	146.77	352.77	817.51	817.51			464.75		
56										**7325.97**	**73259.7**		**4144.65**	**41446.5**
57	166	52.84	T	478.86	130.18	223.36	659.66	1492.05	1492.05	**in 1000 m²**	**a hectare**	832.39	**in 1000 m²**	**a hectare**
58	120	38.20	T	249.35	83.84	151.30	369.11	853.60	853.60			484.48		
59	112	35.65	T	217.04	76.35	139.27	326.25	758.92	758.92		80 tree/ha	432.67		
60	126	40.11	T	275.05	89.57	160.43	402.79	927.84	927.84			525.05		
61	155	49.34	T	417.18	118.62	205.71	583.50	1325.01	1325.01			741.51		
62	87	27.69	T	130.60	54.21	102.85	207.62	495.27	495.27			287.66		
63	106	33.74	T	194.29	70.86	130.37	295.64	691.16	691.16			395.52		
64	114	36.29	T	224.91	78.20	142.27	336.75	782.12	782.12			445.38		

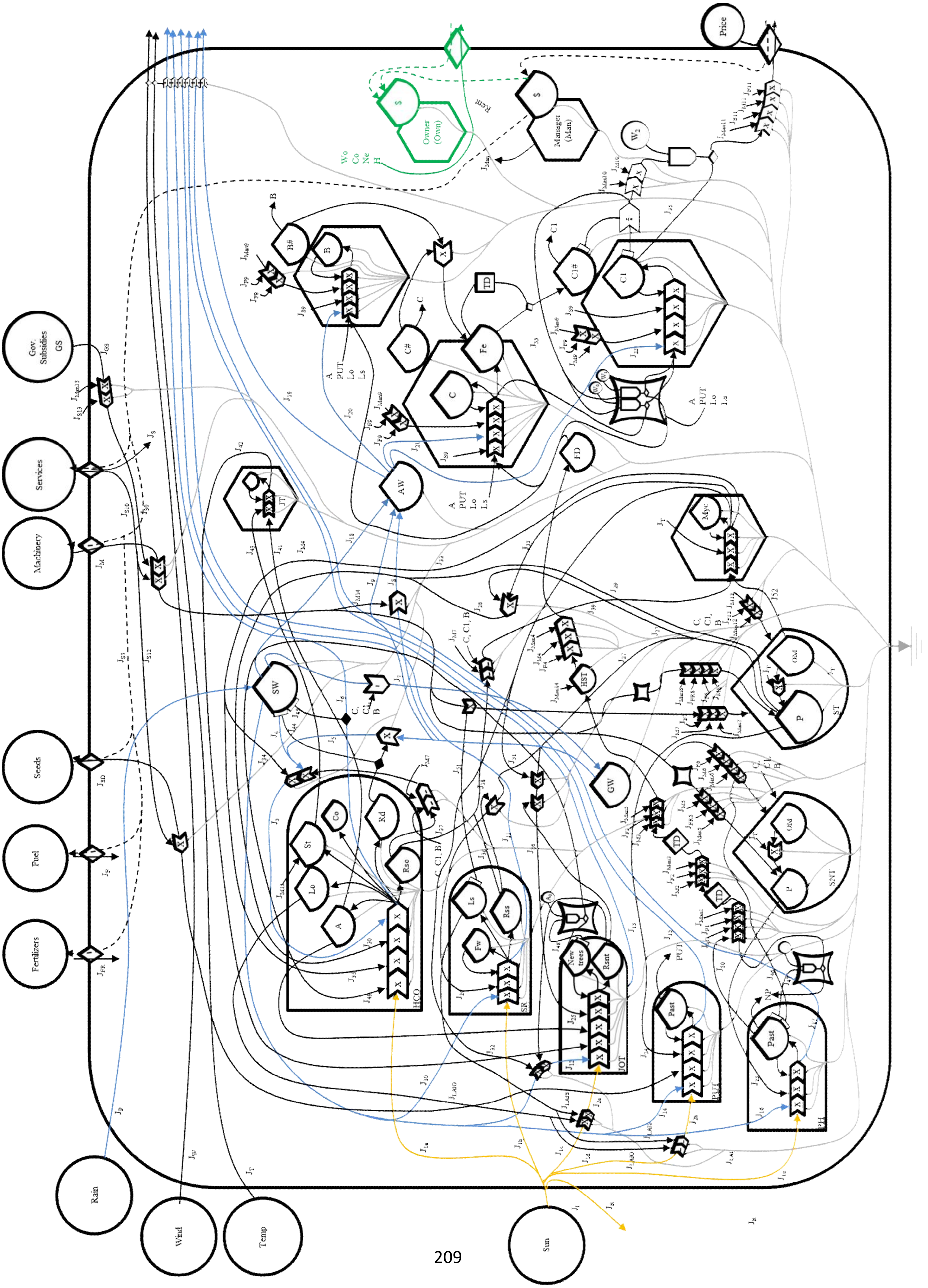
Tree	Estimation of the annual growth in diameter		Holm oak area 1	Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 1		Total without roots A1	Total (kg) in area 1	
			branches / trunks							**31.72**	**317.17**		**30.23**	**302.34**
1	0.79	0.00	B	0.10	0.44	1.44	0.36	2.33	6.99	**in 1000 m²**	**in a ha**	6.63	**in 1000 m²**	**in a ha**
2	0.59		B	0.06	0.29	1.01	0.21	1.58	4.73			4.52		
3	0.61		B	0.06	0.31	1.06	0.23	1.65	4.95			4.73		
4	0.61		B	0.06	0.31	1.06	0.23	1.66	4.99			4.77		
5	0.62		B	0.06	0.31	1.07	0.23	1.68	5.04			4.81		
6	0.62		B	0.06	0.31	1.07	0.23	1.67	5.02			4.79		
	Estimation of the annual growth in diameter		Holm oak area 2	Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 2		Total without roots A2	Total (kg) in area 2	
			branches / trunks											
7	0.61		B	0.06	0.31	1.05	0.22	1.64	4.91	**39.02**	**390.21**	4.69	**36.74**	**367.37**
8	0.61		B	0.06	0.31	1.05	0.22	1.64	4.93	**in 1000 m²**	**in a ha**	4.71	**in 1000 m²**	**in a ha**
9	0.92	0.00	T	0.14	0.54	1.74	0.47	2.89	2.89			2.42		
10	0.65		T	0.07	0.33	1.13	0.25	1.78	1.78			1.53		

11	0.60		B	0.06	0.30	1.03	0.22	1.60	4.81			4.59		
12	0.61		B	0.06	0.31	1.05	0.22	1.64	4.93			4.71		
13	0.61		B	0.06	0.31	1.05	0.22	1.64	4.93			4.71		
14	0.61		B	0.06	0.31	1.05	0.22	1.64	4.91			4.69		
15	0.61		B	0.06	0.31	1.05	0.22	1.64	4.91			4.69		
	Estimation of the annual growth in diameter		Holm oak area 3 branches / trunks	Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 3		Total without roots A3	Total (kg) in area 3	
16	0.66		B	0.07	0.34	1.17	0.26	1.85	5.54	**64.40**	**644.02**	5.28	**61.11**	**611.10**
17	0.64		B	0.07	0.33	1.12	0.25	1.77	5.31	**in 1000 m^2**	**in a ha**	5.06	**in 1000 m^2**	**in a ha**
18	0.64		B	0.07	0.33	1.11	0.24	1.75	5.24			5.00		
19	0.64		B	0.07	0.33	1.12	0.25	1.76	5.29			5.04		
20	0.62		T	0.06	0.31	1.08	0.23	1.69	1.69			1.45		
21	0.67		T	0.07	0.35	1.17	0.26	1.85	1.85			1.59		
22	0.62		B	0.06	0.31	1.07	0.23	1.67	5.02			4.79		
23	0.63		B	0.07	0.32	1.10	0.24	1.73	5.18			4.94		
24	0.60		B	0.06	0.30	1.04	0.22	1.62	4.85			4.63		
25	0.59		B	0.06	0.29	1.02	0.21	1.58	4.75			4.54		
26	0.62		B	0.06	0.32	1.08	0.23	1.70	5.10			4.86		
27	0.61		B	0.06	0.31	1.05	0.22	1.64	4.91			4.69		
28	0.59		B	0.06	0.29	1.01	0.21	1.56	4.69			4.48		
29	0.61		B	0.06	0.31	1.06	0.23	1.66	4.99			4.77		
	Estimation of the annual growth in diameter		Holm oak area 4 branches / trunks	Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 4		Total without roots A4	Total (kg) in area 4	
30	0.74	0.00	T	0.09	0.40	1.34	0.32	2.16	2.16	**26.53**	**265.28**	1.83	**23.09**	**230.90**
31	0.67		T	0.07	0.35	1.17	0.26	1.85	1.85	**in 1000 m^2**	**in a ha**	1.59	**in 1000 m^2**	**in a ha**
32	0.66		T	0.07	0.34	1.15	0.26	1.82	1.82			1.56		
33	0.62		T	0.06	0.32	1.08	0.23	1.70	1.70			1.46		

34	0.80	0.00		T	0.10	0.44	1.45	0.36	2.36	2.36			2.00				
35	0.65			T	0.07	0.34	1.14	0.25	1.80	1.80			1.55				
36	0.65	0.00		T	0.07	0.34	1.15	0.26	1.81	1.81			1.56				
37	0.81	0.00		T	0.11	0.45	1.48	0.37	2.42	2.42			2.04				
38	0.63			B	0.06	0.32	1.10	0.24	1.72	5.16			4.92				
39	0.88	0.00		T	0.13	0.51	1.65	0.44	2.72	2.72			2.29				
40	0.89	0.00		T	0.13	0.51	1.65	0.44	2.73	2.73			2.29				
	Estimation of the annual growth in diameter			Cork oak area 5	Wood	Branche s	Leaves	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 5		Total without roots A5	Total (kg) in area 5		Cork production in a year (kg)	
				branches / trunks												60.49	Kg
			Perimeter													74.05	
41	0.85	0.00	2.66	T	0.01	0.82	0.33	0.05	1.20	1.20	**12.06**	**120.57**	1.15	**11.60**	**116.00**	55.83	
42	0.82	0.00	2.56	T	0.01	0.78	0.31	0.04	1.14	1.14	**in 1000 m^2**	**in a ha**	1.10	**in 1000 m^2**	**in a ha**	29.38	
43	0.86	0.00	2.70	T	0.01	0.84	0.33	0.05	1.22	1.22			1.17			55.83	
44	0.93	0.00	2.93	T	0.01	0.94	0.36	0.06	1.36	1.36			1.31			27.97	
45	0.86	0.00	2.70	T	0.01	0.84	0.33	0.05	1.22	1.22			1.17			99.97	
46	0.94	0.00	2.95	T	0.01	0.94	0.37	0.06	1.37	1.37			1.32			54.54	
47	0.76	0.00	2.40	T	0.00	0.71	0.29	0.04	1.04	1.04			1.01			93.13	
48	0.86	0.00	2.71	T	0.01	0.84	0.33	0.05	1.23	1.23			1.18			59.81	610.99
49	0.78	0.00	2.44	T	0.00	0.73	0.29	0.04	1.07	1.07			1.03				Total y
50	0.85	0.00	2.67	T	0.01	0.82	0.33	0.05	1.20	1.20			1.16				
	Estimation of the annual growth in diameter			Holm oak area 6	Wood	Bark	Crown	Roots	Sub-total for each tree	Correction for the branches	Total (kg) in area 6		Total without roots A6	Total (kg) in area 6			
				branches / trunks													
51	0.79	0,00		T	0.10	0.44	1.45	0.36	2.35	2.35	**12.36**	**123.61**	1.99	**10.43**	**104.32**		
52	0.81	0,00		T	0.11	0.45	1.49	0.38	2.43	2.43	**in 1000 m^2**	**in a ha**	2.05	**in 1000 m^2**	**in a ha**		
53	0.86	0,00		T	0.12	0.49	1.59	0.42	2.62	2.62			2.20				
54	0.80	0,00		T	0.11	0.45	1.47	0.37	2.39	2.39			2.02				
55	0.85	0,00		T	0.12	0.48	1.57	0.41	2.58	2.58			2.17				

56	0.80	0.00	T	0.12	0.45	1.54	0.39	2.45	2.45					
57	0.78	0,00	T	0.10	0.43	1.42	0.35	2.29	2.29	**20.34**	**203.41**	1.95	**17.14**	**171.38**
58	0.85	0,00	T	0.12	0.48	1.56	0.40	2.56	2.56	**in 1000 m^2**	**in a ha**	2.16	**in 1000 m^2**	**in a ha**
59	0.86	0,00	T	0.12	0.49	1.59	0.41	2.61	2.61			2.19		
60	0.84	0,00	T	0.11	0.47	1.54	0.40	2.53	2.53			2.13		
61	0.80	0,00	T	0.10	0.44	1.45	0.36	2.36	2.36			2.00		
62	0.89	0,00	T	0.13	0.51	1.66	0.44	2.75	2.75			2.31		
63	0.87	0,00	T	0.12	0.49	1.61	0.42	2.64	2.64			2.22		
64	0.85	0,00	T	0.12	0.48	1.58	0.41	2.60	2.60			2.19		

B. Extended ESL diagram of the Holm Oaks Farm.



Price
Manager (Man)
Owner (Own)
Rent
Gov. Subsidies GS
Services
Machinery
Seeds
Fuel
Fertilizers
Rain
Wind
Temp
Sun
HCO
SR
IOT
PUT
PH
ST
SNT
SW
GW
AW
FD
TD
Fe
C
C#
B
B#
Cl
Cl#
JT
Myc
HST
OM
P
Co
Rd
St
Lo
A
Rso
Ls
Rss
Fw
New trees
Rsnt
Past
NP

C. *Legend to the extended ESL diagram of the Holm Oaks Farm.*

Symbol	Definition
Forcing functions	
J_I	Incident solar radiation
J_A	Albedo
J_T	Temperature of the air
J_W	Wind velocity
J_R	Rain in the farm
J_F	Fuel
J_{FR}	Fertilizers
J_{SD}	Seeds
J_M	Machines
J_S	Services
J_{GS}	Government subsidies
System components or storages	
HCO	Holm and cork oaks
SR	Shrubs
NP	Natural pasture
IP	Improved pasture
JT	Jays and thrushes
FD	Feed
B	Bulls
C	Cows
C1	Calves
W0	Calves selling weight
Fe	Fetus
Myc	Mycorrhizas
Man	Farm's manager
Own	Farm's owner
HST	Haystack
B	Biodiversity that uses the trees as shelter
IPS	Improved pastures soil
SOS	Shrubs and oaks soil
GW	Ground water
SW	Superficial water
AW	Water available to the cattle
A	Acorns
Lo	Oak's leaves
St	Stems
Wo	Wood
Co	Cork
Rd	Deep roots of the oaks
Rso	Superficial roots of the oaks
Fw	Flowers
Ne	Nectar
Ls	Shrubs leaves
Rss	Superficial roots of the shrubs
H	Hunting
OM	Organic matter
J_{1a}	Insolation captured by oaks
J_{1b}	Insolation captured by shrubs
J_{1c}	Insolation on natural pasture
J_4	Height of improved pasture
J_5	Hay available to cattle
J_6	Amount of water available to the cattle
J_7	Water consumed by bulls
J_8	Water consumed by cows
J_9	Water consumed by calves
J_{10}	Water evaporated
J_{11}	Total infiltration of water to the ground
J_{12}	Ground water absorbed by trees
J_{13}	Superficial water absorbed by trees
J_{14}	Superficial water absorbed by shrubs
J_{15}	Superficial water absorbed by natural pasture
J_{16}	Superficial water absorbed by improved pasture
J_{F1}	Total fuels spent with works on improved pasture
J_{F2}	Fuels spent with works on natural pasture
J_{F3}	Fuels spent taking calves to the auction
J_{F4}	Fuels spent with cattle care
J_{F5}	Fuels spent opening firebreaks
J_{F6}	Fuels spent baling and keeping the bales of natural pasture
J_{F7}	Fuels spent baling and keeping the bales of improved pasture
J_{F8}	Fuels spent to transport bales to the cattle
J_{FR1}	Fertilizers used on improved pasture
J_{FR2}	Fertilizers used on natural pasture
J_{17}	Phosphorus absorbed by the improved pasture
J_{18}	Phosphorus absorbed by the natural pasture
J_{19}	Phosphorus available for absorption by the trees
J_{20}	Extra intake of phosphorus provided by the mycorrhizas to the trees
J_{21}	Impact of cutting the mycorrhizas with soil mobilization
J_{22}	Impact of cutting superficial roots with soil mobilization
J_{23}	Cutting shrubs when they have some height
J_{24}	Height of the shrubs
J_{25}	Support to mycorrhizas net continuity provided by superficial roots of trees and shrubs
J_{26}	Protection of tree's health by the mycorrhizas
J_{27}	Acorns production
J_{28}	Stems providing refuge to the jays and thrushes
J_{29}	Acorns providing food for jays and thrushes
J_{30}	Acorns stored by the jays and thrushes under the soil
J_{31}	Fertility of cows
J_{32}	Pregnancy period
J_{33}	Birth moment when calves start to breastfeed
J_{34}	Breastfeeding gradually substituted by pastures
J_{35}	Sale of the calves
J_{M1}	Machinery used to mobilize the soil
J_{M2}	Machinery used to fertilize the soil
J_{M3}	Machinery used to transport the cattle
J_{M4}	Machinery used to pump the water to the cattle
	J_{M5}
J_{M6}	Machinery to bale and keep the bales of natural pasture
J_{M7}	Machinery to bale and keep the bales of improved pasture
J_{M8}	Machinery to weight the calves

Symbol	Definition		
J_{1d}	Insolation on improved pasture	J_{M9}	Machinery to open firebreaks
J_{LAI}	Leaf area index of shrubs	J_{M10}	Machinery to transport bales to the cattle
J_{2a}	Insolation on natural pasture considering the shadow effect	J_{Man}	Total of manager’s working hours at the farm
J_{2b}	Insolation on improved pasture considering the shadow effect	J_{M8}	Machinery to weight the calves
J_{2c}	Insolation on new trees considering the shadow of the tree	J_{M9}	Machinery to open firebreaks
J_3	Height of natural pasture		
J_{M10}	Machinery to transport bales to the cattle	J_{Man8}	Working hours baling and keeping the bales of natural pasture
J_{Man}	Total of manager’s working hours at the farm	J_{Man9}	Working hours baling and keeping the bales of improved pasture
J_{Man1}	Working hours to mobilize the improved pasture’s soil	J_{Man10}	Working hours to transport bales to the cattle
J_{Man2}	Working hours to fertilize the improved pasture’s soil	J_{Man11}	Working hours maintaining the haystack
J_{Man3}	Working hours to mobilize the shrubs and oak’s soil	J_{Man12}	Working hours weighting the calves
J_{Man4}	Working hours to fertilize the shrubs and oak’s soil	J_{Man13}	Working hours opening firebreaks
J_{Man5}	Working hours to take care of the cattle	J_{S1}	Veterinary services to the cattle
J_{Man6}	Working hours to take and sell calves in the auction	J_{S2}	Technical services supporting the subsidies
J_{Man7}	Working hours responding to governmental control and bureaucracy	J_{S3}	Services to maintain the machinery

*D.	Simplified movements statement with the subsidies received in 2012 for the farm.*

EXTRATO SIMPLIFICADO DE MOVIMENTOS

Data de início: 2012-01-01 Nome : AGROROBUSTA LDA.

Data de fim: 2012-12-31 NIFAP: 7569072 NIF: 509354718

PAGAMENTO POR TRANSF. BANCÁRIA NIB:004563904023558538718

Data Valor	Descrição	Processo	Valor	
2012-02-29	PRÉMIO MONTADO AZINHO ARTº 68	2011/PCO/188678	-224,85	a)
2012-02-29	PRÉMIO MONTADO AZINHO ARTº 68	2011/PCO/188678	2.498,31	
2012-04-26	ADULTOS - CONTINENTE	2011/PAB/48231	-8,33	a)
2012-04-26	DESFAVORECIDA NATURA ITI	2011/MZD/486688	588,44	
2012-04-27	ADULTOS - CONTINENTE	2011/PAB/48231	92,55	
2012-05-30	SECA 2012 - BOVINOS ANE I	2012/SEC/5719	1.529,89	
2012-05-30	AGRO-SILVO-AMBIENTAIS-C01	2011/ASA/7569072	6.797,31	
2012-06-21	PAGAMENTO ÚNICO	2011/RPU/188678	-294,14	a)
2012-06-21	PAGAMENTO ÚNICO	2011/RPU/188678	-167,89	e)
2012-06-21	VACAS ALEITANTES	2011/VAL/56410	406,88	
2012-06-21	VACAS ALEITANTES	2011/VAL/56410	-36,62	a)
2012-06-21	PAGAMENTO ÚNICO	2011/RPU/188678	3.268,27	
2012-06-21	PRÉMIO MONTADO AZINHO ARTº 68	2011/PCO/188678	-25,53	e)
2012-06-21	PRÉMIO MONTADO AZINHO ARTº 68	2011/PCO/188678	-4,93	a)
2012-06-21	PRÉMIO MONTADO AZINHO ARTº 68	2011/PCO/188678	54,78	
2012-06-21	ADULTOS - CONTINENTE	2011/PAB/48231	-0,96	e)
2012-06-21	ADULTOS - CONTINENTE	2011/PAB/48231	-0,24	a)
2012-06-21	ADULTOS - CONTINENTE	2011/PAB/48231	2,66	
2012-06-21	VACAS ALEITANTES	2011/VAL/56410	-4,07	e)
2012-06-21	COMPLEMENTO NACIONAL	2011/VAL/56410	13,16	
2012-06-21	COMPLEMENTO FEOGA	2011/VAL/56410	-17,81	e)
2012-06-21	COMPLEMENTO FEOGA	2011/VAL/56410	-4,51	a)
2012-06-21	COMPLEMENTO FEOGA	2011/VAL/56410	50,14	
2012-07-30	DESFAVORECIDA NATURA ITI	2012/MZD/486688	1.628,74	
2012-09-27	AGRO-SILVO-AMBIENTAIS-C01	2012/ASA/7569072	5.271,17	
2012-10-30	VACAS ALEITANTES	2012/VAL/19046	-1.200,00	a)
2012-10-30	VACAS ALEITANTES	2012/VAL/19046	12.000,00	
2012-10-30	PAGAMENTO ÚNICO	2012/RPU/190627	-351,15	a)
2012-10-30	PAGAMENTO ÚNICO	2012/RPU/190627	8.511,54	
2012-12-28	VACAS ALEITANTES	2012/VAL/19046	2.006,80	
2012-12-28	VACAS ALEITANTES	2012/VAL/19046	-200,68	a)
2012-12-28	COMPLEMENTO FEOGA	2012/VAL/19046	1.711,14	
2012-12-28	COMPLEMENTO FEOGA	2012/VAL/19046	-171,11	a)
2012-12-28	PAGAMENTO ÚNICO	2012/RPU/190627	-766,04	a)
2012-12-28	PAGAMENTO ÚNICO	2012/RPU/190627	7.660,39	
2012-12-28	COMPLEMENTO NACIONAL	2012/VAL/19046	427,88	
2012-12-28	DESFAVORECIDA NATURA ITI	2012/MZD/486688	665,80	
		Total Líquido do Extracto	**51.706,99**	

a) Modulação - Regulamento (CE) nº 73/2009 artigo 7º e Regulamento (UE) nº 671/2012 artigo 1º nº 2

b) Disciplina Financeira - Regulamento (CE) nº 73/2009 artigo 11º e Regulamento (UE) nº 1307/2013 artigo 8º

c) SIGC - Regulamento (CE) nº 1122/2009 e Regulamento (UE) nº 1306/2013

d) Condicionalidade - Regulamento (CE) nº 1122/2009 e Regulamento (UE) nº 1306/2013

e) Redução Linear - Regulamento (CE) nº 73/2009 artigo 8º e Regulamento (UE) nº 1307/2013 artigo 7º

f) Dotações transitadas - Disciplina Financeira - Regulamento (UE) nº 1306/2013, artigo 26º, nº 5

g) Modulação - Capping Regulamento (UE) n.º 1307/2013 artigos 11.º e 22.º

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