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RESEARCH ARTICLE

Organic management of cattle and pigs in Mediterranean systems: energy efficiency and ecosystem services

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Abstract

Organic livestock farming can help to make agroecosystems more sustainable. We hypothesized, however, that not all organic farm management models contribute in the same way. One way to assess this is to perform energy analyses of livestock farms, establishing not only how efficient the systems are at producing goods and services for society, but also the investment in the fund elements that sustain the system itself and its environmental sustainability. But to be effective, such studies must go beyond a classic input-output analysis: they must also address the internal energy flows that maintain the quality of agroecosystem fund elements as well as some ecosystem services they provide. In the present work, we implemented the energy return on investment methodology and combined classic economic energy indicators with new agroecological measurements that allow to assess the quality of agroecosystem fund elements. We applied these agroecological energy indicators to organic pig and beef cattle farms with the aim of differentiating the organic forms of management that best contribute to sustainability. This is the first time that this methodology has been applied on pig farms. Based on this methodology, we identified five management models of organic beef and pork production in Mediterranean systems that presented different degrees of sustainability. The most efficient and environmentally sustainable model was the breeding of beef cattle/pigs in agrosilvopastoral *dehesa* pasturelands. These dehesa systems include farms that are highly self-sufficient in terms of animal feed as well as farms that import certain feed stuffs because they fatten animals until slaughter. It was the breed together with the stocking densities that conditioned livestock functionality more than the livestock species orientation. The results allowed us to distinguish the various forms of organic livestock management implemented and their degree of sustainability, thus providing public policy orientations on the most efficient models.

Keywords Energy flows · Organic farming · Agrarian metabolism · Ecosystemic services · EROIs

1 Introduction

Organic farming is today at the heart of European Union (EU) policies on food system sustainability, and within these food systems, energy plays a key role. The recent Farm to Fork Strategy (European Commission 2020a) has set the target of reaching 25% of agricultural land under organic farming by 2030. Various instruments have been put in place to reach this goal such as the new Common Agricultural Policy's eco-schemes (European Commission 2020b); specific lines of the Horizon Europe research program; and the new Action Plan for Organic Production in the EU (European Commission 2021). Agroecological practices will also be instrumental to reach the European Biodiversity Strategy targets (European Commission 2020c).

Organic livestock provides differentiated quality products as well as ecosystem services to society. Numerous works have demonstrated how organic livestock contributes to the conservation of biodiversity (Acharya et al. 2021; Teague and Kreuter 2020; Gutiérrez-Peña et al. 2014; Teston et al. 2020). The management of pastures and trees, when present, allows these systems to act as carbon sinks (Teague and Kreuter 2020; Díaz de Otálora et al. 2021; Horrillo

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et al. 2020; Dumont et al. 2020; Ledo et al. 2020; Liebig et al. 2021; Eldesouky et al. 2018). Grazing plays a key role in reducing the external inputs required for ruminant production and in alleviating feed-food competition, given that animals take advantage of a phytomass that humans cannot consume (Teston et al. 2020; Horrillo et al. 2020; Dumont et al. 2020; Tello et al. 2016; Pérez-Neira et al. 2018).

However, the EU legislation on organic practices (European Commission 2018) opens the door to a wide range of production management models. A number of studies have identified several types of organic livestock farms, highlighting substantial differences regarding access to factors of production, commercial strategies or intensification levels (López-i-Gelats and Bartolomé-Filella 2019; Díaz-Gaona et al. 2019; Rudolph et al. 2018). The challenge is to uncover whether these different models are equally efficient and generate similar ecosystem services. For example, integrated crop-livestock systems are encouraged in organic livestock farming because they lead to greater resilience and food self-sufficiency, while having a positive impact on a number of ecosystem services (Sanderson et al. 2013; Stark et al. 2018; Schleich et al. 2019; Sekaran et al. 2021). Nevertheless, introducing crops into integrated crop-livestock systems can generate further costs together with energy imports from authorized organic inputs (fertilizers, pesticides and seeds), more human labor, and fuel consumption for machinery (Teston et al. 2020; Schleicha et al. 2019; Jabbar 1996). All these components can ultimately depress energy efficiency as well as the state of the agroecological fund elements (land, biodiversity, livestock…). The agroecosystem structure is based on all these elements.

Extensive grazing systems under the Mediterranean climate concentrate a notable share of Spain's organic livestock production (79% of total organic permanent grassland, excluding regions with oceanic, mountain or subtropical climates) (MAPA 2021). One of the most representative pasturelands is the "*dehesa*": a complex system that combines grazing with the use of trees of different species of the *Quercus* spp. genus and, in some cases, crop production. Grazing continues to be a key economic practice that shapes forests, woodlands, shrublands and grasslands. It remains a primary source of feed for livestock breeding (Campos et al. 2018), which in turn, contributes to a lower consumption of on-farm feeds (Horrillo et al. 2020). Species such as beef cattle, sheep, goats, and pigs are bred on dehesa pastures, taking advantage of the *montanera* (a type of pasture including acorns). The montanera breeding of native pig breeds has been shown to have a lesser impact on climate change, acidification, eutrophication and cumulative energy demands than other types of pig farming (García-Gudiño et al. 2020). The dehesa example could break the ruminant/monogastric dichotomy in the study of sustainable systems. This system leads us to focus on management approaches and the functionality of livestock breeds rather than the type of species produced. Studies on organic production and climate change in Mediterranean systems are still scarce (Aguilera et al. 2018), yet the territorial basis of these systems, added to the tree mass present in dehesa pasturelands can improve carbon sequestration (Eldesouky et al. 2018) (Fig. 1).

In a context of energy transition, the energy efficiency of biomass production is a major challenge in the shift towards sustainable food and energy provision (Gingrich et al. 2018a). Several works address the relationship between agriculture and energy, seeking ways in which agriculture could contribute to overcoming humanity's socio-environmental twenty-first century challenges (Gingrich et al. 2018a; Ferraro 2012; Marshall and Brockway 2020; Martinho 2020; Hercher-Pasteur et al. 2020). The question is: How can we improve agricultural energy performance to tackle climate change, to produce food for a rising population, to facilitate the energy transition towards renewable energies, and to provide other ecosystem services, notably the maintenance of non-agricultural biodiversity?

The most frequently used indicators in agricultural energy studies derive from the cost-profit analyses proper to the domain of economics (Hercher-Pasteur et al. 2020; 2021). Energy return on investment (EROI) indicators measure the efficiency of energy use and, in recent decades, this tool has become the most widely used to evaluate this efficiency across all kinds of productive activities. The indicators consist of dividing the energy obtained by the energy invested in production (Hall 2011). Since EROIs originated in the

Fig. 1 Organic livestock farms in Mediterranean systems. Beef cattle production in a *dehesa* landscape with the Avileña local breed (left). Mixed system combining citrus orchards with the Iberian pig production (right). Photographs courtesy of María Ramos, CICYTEX, Spain.

discipline of economics, they measure only the energy flows that present an economic value. They also contribute to explaining the economic sustainability of these systems (Pimentel and Pimentel 1979). Agroecosystems, however, are regarded as a black box when these calculations are applied to them: the instruments focus exclusively on the entry and exit flows while the inner workings remain obscure (Tello et al. 2016). In recent years, this linear input–output approach has been challenged because it masks the agroecosystem's functioning, overlooking the complex energy flows that circulate within it and their role in maintaining the health of the agroecosystem's fund elements (soil, biodiversity, trees) (Tello et al. 2016; Hercher-Pasteur et al. 2020, 2021; Guzmán and González de Molina 2015, 2017). In a similar way to other methodologies applied to the study of nutrient flows at the system level (Stark et al. 2018), Hercher-Pasteur et al (2020) critically reviewed the different ways of computing farm-scale energy flows and proposed to deepen the methods by adopting a systemic perspective and integrating inflows, outflows, as well as internal flows in the calculations.

One of these systemic approaches to internal energy flows was advanced by Guzmán and González de Molina (2015, 2017). These authors proposed to add new agroecological EROIs to the classical economic EROIs. Classical economic EROIs evaluate the energy efficiency of agricultural production. Their new second set of agroecological EROIs is directed towards understanding how the energy flows circulating through the agroecosystem are capable of maintaining the quality of the agroecosystem's fund elements and, consequently, sustaining the provision of ecosystem services in the long term.

In their review, Hercher-Pasteur et al (2020) contrasted different approaches to the study of energy in agroecosystems: exergy analysis, emergy analysis as well as various energy approaches: conventional, agro-ecological or pluri-energy analyses. Pluri-energy analysis (Vigne et al. 2013) represented a first attempt to examine energy flows inside the agricultural system. However, the agroecological EROIs methodology proposed by Guzmán and González de Molina (2017) introduced an important and differential aspect in this regard. The pluri-energy analysis does not consider the net primary productivity (NPP) of an agroecosystem. It takes only a part of the phytomass produced into account: the share used for direct human food, the part reused to feed livestock or the portion used for seed. Therefore, these models fail to include an essential part of the NPP—the yearly unharvested biomass and accumulated wood biomass. Both NPP portions play an essential role in maintaining the quality of the agroecosystem's fund elements. Unharvested phytomass is essential for maintaining both aerial and edaphic wildlife, as well as soil organic matter. The accumulated biomass is the forest element that contributes to providing ecosystem services such as carbon sequestration, microclimate modification, providing a shelter for wildlife, etc. These energy flows represent a basic element in the construction of the proposed agroecological EROIs and have been recently introduced in the academic literature.

These new agroecological EROIs were implemented only once before at farm scale in a case study conducted by the same authors on cattle in Argentina, Brazil and Spain (Guzmán and González de Molina 2017). They were applied to livestock at a farm scale in conventional and organic farms, but have never been used in the case of pig livestock at a farm scale. Other works (Díaz-Gaona et al. 2019; Gingrich et al. 2018b; Frankova and Cattaneo 2018; Fullana et al. 2021) have applied some of these indicators to agroecosystems (including livestock) from a historical perspective, assessing how traditional farming evolved into a fossil fuel-based system of agriculture over time. Yet these studies are based on secondary and regional information—not on primary information at a farm scale.

Our hypothesis is that the shift towards organic livestock management contributes to the sustainability of Mediterranean agroecosystems of high ecological value. The benefits, however, are conditioned by an adequate adaptation to the territory and appropriate farm management. In this sense, we must remember that organic certification does not guarantee that all management models perform in the same way.

The objectives of the present work were as follows: (1) to identify the existing models of organic cattle and pig livestock meat production in southwestern Spain based on their management strategies and use of inputs; (2) to quantify internal and external energy flows; (3) to calculate the economic and agroecological EROIs for each farm and thus highlight the most energy-efficient models as well as their potential contribution to the generation of some ecosystem services.

2 Materials and methods

2.1 Data collection: cases studied

The study was conducted on a sample of 41 organic beef cattle and pig farms located in the Spanish regions of Extremadura ($n = 33$), Andalusia ($n = 6$), and Castilla-León ($n = 2$) (Fig. 2). These regions border each other and cover 67.3% of the country's organic farms specialized in these two species. Although the study focused on beef cattle and pigs, other secondary livestock species coexisted on some farms and were included in these farms' metabolic calculations.

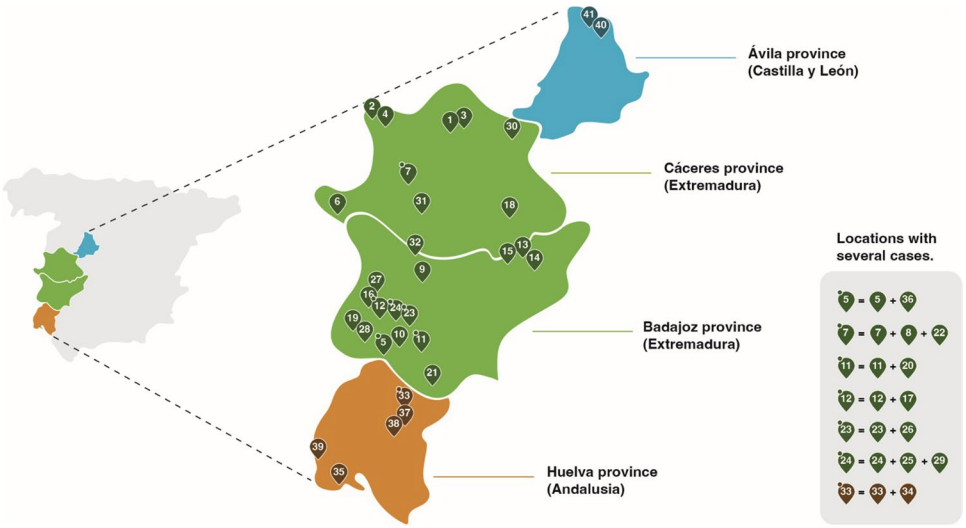

Fig. 2 Location map of the 41 cases studied in three regions of Spain: Andalusia, Extremadura, and Castilla León. The cases (points) are numbered 1 to 41.

The selection criteria of these farms are described as follows.

- They had to be certified organic in accordance with Regulation (EU) 2018/848 (European Commission 2018) and have completed the conversion period (> 3 years of activity).
- Beef or pig production had to be the main activity. In the case of cattle, farms with over 20 breeding mothers were chosen. In the case of pigs, the herd had to include at least 100 heads (with or without breeding mothers).

The study sample represented 13.6% of the organic livestock heads (certified and in the conversion period) of beef cattle and pigs in these regions. The share would have been higher with respect to the number of certified farms, but we were unable to obtain this figure because official statistics (MAPA 2020) do not differentiate between the two.

Semi-structured interviews were conducted with the farmers to characterize the farm's general structure (land uses, the presence of trees, livestock stocking rate, species, etc.), management techniques, human labor, inputs, and their origin, as well as the animal and plant product outputs, and their destination. A third of the interviews were face-to-face and the rest were conducted by telephone. The manager of the main organic feed factory that supplied the farmers was also interviewed in order to determine the raw materials used and their origin.

2.2 Farming systems

The farms studied belonged to one of the following farming systems (Table 1 summarizes their characteristics):

- *Dehesa*: extensive farming systems located in Huelva province (Andalusia) and in the region of Extremadura. A typical or semi-arid Mediterranean climate predominates with seasonal rainfall in spring and autumn combined with dry and hot summers. These dehesa farms exploit pasture and forest resources to various degrees of intensity. They are dedicated to the breeding of either a single species (beef cattle or pigs) or a combination of species (Table 1). We encountered different breeds in the case of beef cattle. Some farms had autochthonous breeds, such as the Retinta, Berrenda or Avileña, and others used breeds that provided a higher meat yield, such as the Limousin breed. In the case of pigs, the dehesas used the autochthonous Iberian breed, which is adapted to extensive farming and the *montanera* (pastures with acorns). Merina is the most common breed of sheep. Organic feed was usually purchased for the fattening. Exceptionally, the purchased organic raw materials were ground on the farms themselves. Organic feed mills were scarce and almost all the farmers interviewed bought the feed. In some cases, the farm grew crops to be used as animal feed. In these cases, the predominant crops were fodder (vetch-oats) and grains (wheat, barley, or oats) grown on dry lands. They were low input crops. Occasionally, alfalfa or corn was grown on irrigated lands. All Iberian pig farms sold fattened animals, aged 15 to 24 months and with a live-weight between 120 and 181 kg. In the case of beef cattle, 63% of farms sold non-fattened weanlings, 14% fattened only some calves, and 23% fattened all animals. Many cereals came from nearby regions (300 km away maximum). However, soybeans and soya meals came mainly from China and, to a lesser extent, from France or Brazil. This compo-

Table 1 Characteristics of the main systems studied. Average (Av), maximum (max) and minimum (min) values within each system, ha (hectare), LU (livestock units).

	Dehesa ($n = 35$)	Rain-fed pastures ($n = 4$)	White pig systems ($n = 2$)
Region	Andalusia/Extremadura	Extremadura	Castilla León
	Av/max/min	Av/max/min	Av/max/min
Farm area (ha)	645.2/3500/100	231.5/320/181	27.1/50/4.2
Natural wooded pasture (ha)	474.4/3240/78.4	34/41/0.0	0.0
Natural treeless pasture (ha)	55.17/1350/0	182.5/300/100	13.1/25/1.2
Crop land area (ha)	69.4/260/0	15/40/0	15.5/25/3
LU ha^{-1}	0.51/1.8/0.1	0.60/0.93/0.34	45.2/35.1/55.3
Herd size (nº mothers of the principal species)	153/1200/0 cows 50/99/0 sows 610/1500/0 sheeps 151/350/40 fattening pigs (with or without mothers at farm).	109/150/75	152/260/45 sows 1920 laying hens
General description of crops, livestock species and products for the market			
Main crop species	Fodder: oat, vetch-oat , yellow lupine (rain-fed), Alfalfa, maize (irrigated) Grains: barley, wheat, oat , triticale, peas (rain-fed) Olive tree (rain-fed) Citrus (irrigated)	Fodder vetch-oat mixture (rain-fed)	Wheat,barley,sunflower (rain-fed) Alfalfa (irrigated)
Livestock species	Meat cattle/pigs/meat sheep	Meat cattle	Pigs, laying hens
Main breeds	Cattle: Limousin, Avileña, Retinta, Blanca Cacereña, Charolaise, Blonde d´Aquitaine Pigs: Iberian breed Sheep: Merina	Limousin breed cross	White pig x Duroc
Main products for the market	Meat/firewood/olives/citrus fruits	Meat/firewood	Meat/eggs

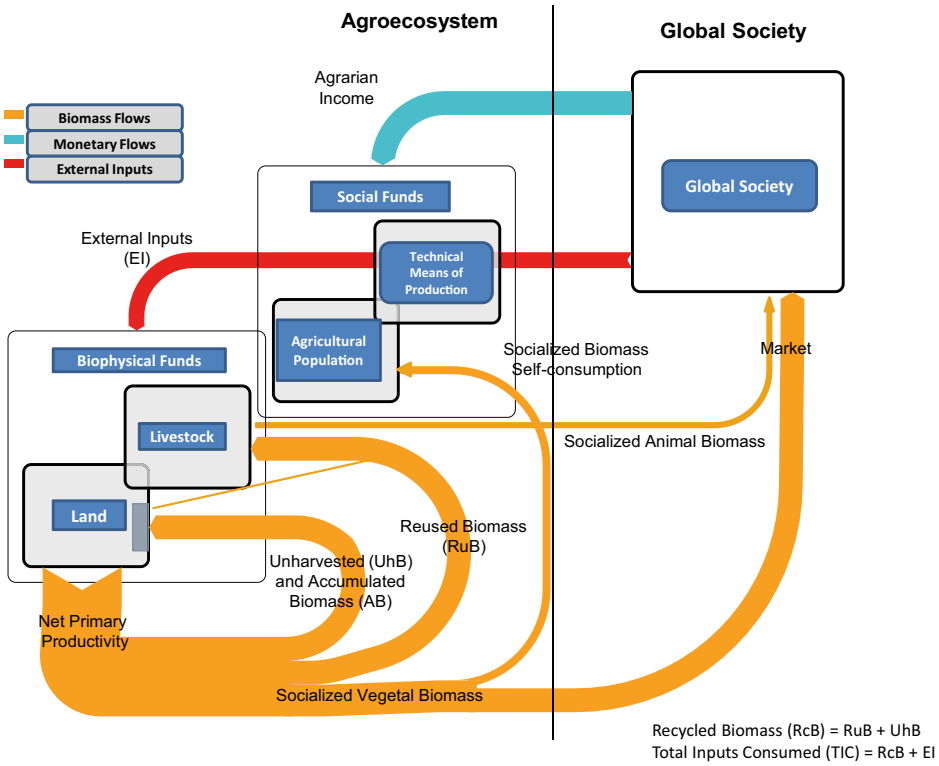

Fig. 3 Theoretical diagram of external inputs, monetary, and biomass flows between the agroecosystem and society. Adapted from González de Molina M, Soto D, Guzmán GI, Infante-Amate J, Aguilera E, Vila J, García R. The Social Metabolism of Spanish Agriculture,1900–2008. The Mediterranean Way Towards Industrialization. Environmental History 10. pp.14, 2020, licensed under the terms of the Creative Commons Attribution 4.0 (https://link.springer.com/book/10.1007/978-3-030-20900-1).

nent accounted for 10% of the mothers' feed in the case of beef cattle, 15% in the case of pigs, and 20% in the case of poultry.

– *Rain-fed pasturelands*: also extensive farming systems, with a similar climate to that of dehesas. They are characterized by pasturelands with no or very few wooded areas or crops and are only found in Extremadura. The few crops present are usually fodder crops, similar to that of the dehesas. They only breed cattle and usually sell non-fattened calves. The farms that grow crops have higher stocking rates, while those without crops present 0.3 LU/ha.
– *White pig systems*: semi-intensive systems located in the Province of Avila (Castilla León region). They are under a Mediterranean climate though with a continental influence and with pronounced daily and annual temperature ranges, i.e., hot summers and very cold winters (even with snow and frost episodes). The breeds used were industrial crossbreeds belonging to the white pig group. Their productivity per mother was much higher than that of the Iberian breed: 3 births per year with an average of 7 piglets per birth, sold at a weight ranging from 125 to 150 kg and aged 8 to 12 months. The available surface area per animal was lower and their feed did not depend on the territory but on the purchase of feed stuffs. They bought large quantities of cereals and soybeans to ground on the farm itself. Soybeans came from Brazil and France. One farm combined pig production with organic laying hens. They made a greater use of closed spaces and heating systems for pregnant mothers and piglets.

2.3 System boundaries

The system boundaries separate the farm-agroecosystem from society (Fig. 3). Such boundaries are crossed by energy flows coming into the agroecosystem (human labor, fossil fuel products, feed, farm implements, and other inputs) as well as outflows towards society of plant or animal biomass prior to any form of processing (grain, wood, firewood, live animals, eggs, etc.). The cases studied in this paper concern flows within the agroecosystem at a farm level and the agrosystem's exchanges with society (external inputs for crop or animal production and socialized firewood, meat, and eggs). Each metabolic variable is explained in the next section.

2.4 Metabolic flows and EROIs

We followed the methodology proposed by Guzmán and González de Molina (2015; 2017). This method is based on the calculation of all the phytomass produced within

Table 2 Energy flow variables and indicators derived from these variables used for the organic farms assessment. GJ (gigajoules), ha (hectare), MJ (megajoules), EROIs (energy return on investment indicators).

	Variable/indicator	Calculation method	Sources
Energy flow variables (GJ ha^{-1})	Actual net primary productivity (NPP*act*)	Conversion of phytomass to gross energy through converters (produced phytomass calculated from literature on production under the Mediterranean climate and data provided by the farmers)	Guzmán et al. (2014), Aguilera et al. (2015), DGTA (2000, 2005), CICYTEX (2015), GENVCE (2010), Matilla (2011), Almoguera (2007), López-Díaz et al. (2016), Guzmán and González de Molina (2017), crop production data provided by the farmers
	Socialized vegetal biomass (SVB)	Conversion of phytomass to gross energy through converters (firewood, citrus fruits, olives and grains in the case of the farms studied)	Guzmán et al. (2014), Aguilera et al. (2015), CICYTEX (2015), GENVCE (2010), López-Díaz et al. (2016), Guzmán and González de Molina (2017), crop production data provided by the farmers
	Socialized animal biomass (SAB)	Conversion of Animal Biomass to gross energy through converters (live weight of farm animals sold for slaughter or fattening, eggs).	Guzmán et al. (2014), Aguilera et al. (2015), Guzmán and González de Molina (2017), Kauffman (2012), animal production data provided by the farmers
	Socialized biomass (SB)	SVB+SAB	Guzmán et al. (2014) Guzmán and González de Molina (2015)
	Reused biomass (RuB)	Conversion of phytomass to gross energy through converters (taking into account: the metabolizable energy requirement of each species, the livestock breed and the animal's age)	Guzmán et al. (2014), FEDNA (2019), Feedipedia (2020), Aguilera et al. (2007) Alibes and Tisserand (1990), Hossain et al. (2016), Guzmán and González de Molina (2017)
	Accumulated biomass (AB)	Conversion of phytomass to gross energy through converters	Guzmán and González de Molina (2015, 2017), Almoguera (2007), Roccuzzo et al. (2012), Velázquez-Martí et al. (2011)
	Unharvested biomass (UhB).	(NPP_{act} aboveground-RuB-SVB-AB aboveground)+(NPP_{act} belowground-AB belowground) (The root phytomass (belowground) is calculated with root: shoot index.)	Guzmán et al. (2014), Guzmán and González de Molina (2015),
	Domestic extraction (DE)	SVB+RuB	Guzmán et al. (2014)
	Recycled biomass (RcB)	RuB+UhB	Guzmán et al. (2014)
	External inputs (EI)	Conversion of phytomass, animal biomass, fuel, industrial inputs and human labor (2.2MJ h^{-1}), to gross energy through converters	Guzmán et al. (2014), Aguilera et al. (2015) Guzmán and González de Molina (2017)
	Total inputs consumed (TIC)	EI+RcB	Guzmán et al. (2014)
Economic EROIs	Final EROI (FEROI)	SB/(RuB+EI)	Tello et al. (2015), Guzmán and González de Molina (2015)
	External final EROI (EFEROI)	SB/EI	Tello et al. (2015), Guzmán and González de Molina (2015)
	Internal final EROI (IFEROI)	SB/RuB	Tello et al (2015), Guzmán and González de Molina (2015)
	Forestry FEROI (For-FEROI)	$SVB_{\textit{from forestland}}$/(Rub+EI)	Guzmán and González de Molina (2017)
	Livestock FEROI (Liv-FEROI)	SAB/(RuB+EI)	Guzmán and González de Molina (2017)

Table 2 (continued)

	Variable/indicator	Calculation method	Sources
Agroecological EROIs	NPP*act* EROI	NPP*act*/TIC	Tello et al. (2015), Guzmán and González de Molina (2015)
	Biodiversity EROI	UhB /TIC	Guzmán and González de Molina (2017)
	Woodening EROI	AB/TIC	Guzmán and González de Molina (2017)

the agroecosystem's boundaries (Guzmán et al. 2018) as described below. First, we calculated the variables that define the inputs, outputs and recirculation of energy in the agrosystem. The EROI indicators were then obtained from these variables (Table 2).

2.4.1 Actual net primary productivity (NPP_{act})

NPP_{act} is the amount of energy truly incorporated into plant tissues as a result of the opposite processes in an ecosystem of photosynthesis and respiration, per unit of time and space. In this study, the NPP_{act} is expressed in terms of gross energy per hectare and year. The NPP_{act} adds the phytomass from the farms' pastures, trees and crops to the accompanying herbage. It includes both the aboveground parts of plants (harvested and unharvested), and the roots. Subsequently, conversion factors were used to transform the NPP_{act} into gross energy, applying converters from various bibliographic sources (Table 2). The conversion factors allowed to calculate the total biomass; to convert the fresh biomass into dry biomass and vice versa, and lastly, to convert the biomass into gross energy (Guzmán and González de Molina 2015). Total NPP_{act} was divided into different components according to their destination:

2.4.2 Socialized vegetal biomass (SVB)

The share of biomass that goes out of the system and is used by society, prior to any type of processing.

2.4.3 Reused biomass (RuB)

The biomass intentionally reinvested by the farmer into the agroecosystem through seed sowing or the use of raw materials for livestock feed (crops, fodder, pastures).

The sum of SVB and RuB makes up domestic extraction (DE).

2.4.4 Unharvested biomass (UhB)

The biomass that returns to the system, by abandonment, without human intervention (e.g., unused aerial phytomass, non-accumulated root systems).

The sum of RuB and UhB constitutes the total biomass that is recycled within the *recycled biomass (RcB)* agrosystem.

2.4.5 Accumulated biomass (AB).

The accumulated biomass of woody species due to the growth of trunks, branches, and roots. It is calculated using the production per hectare of these fractions, in accordance with the literature.

The livestock breeding allows obtaining the socialized animal biomass (SAB). The sum of the SVB plus the SAB is called *socialized biomass* (SB).

The following variables describe the agroecosystem's energy performance with respect to the external inputs (EI) consumed on the farm.

2.4.6 External inputs

EI represents the farm's gross energy inputs. They include industrial inputs (fertilizers, pesticides, machinery, irrigation, heating, etc.), and non-industrial inputs (human labor and biomass, such as seeds, feed, grains, fodder and replacement animals). All energy carriers coming from outside the system's boundaries, except phytomass and human labor, are accounted for based on their direct energy content and their indirect embodied energy (Tello et al. 2016), including transportation to the farm. None of the cases studied incorporated manure from other agroecosystems. No manure was exported either. Almost all generated manure remained on the farms and in most cases, there was no human intervention to collect it—especially in the absence of fattening processes. In the rest of the cases, the manure was collected and applied to the farm crops. Therefore, manure was considered as a reused good and its calculation was not disaggregated. Manure energy was already contained in both the reused biomass flow and the imported feed energy flow.

In the case of phytomass, we considered only its enthalpy and its transport from the production location to the farm. Human labor was accounted for as the fraction of the average diet of the farm operators that corresponded to the work time performed in the agroecosystem (Guzmán and González de Molina 2017).

2.4.7 Total inputs consumed (TIC)

TIC represents the total energy that allows the agroecosystem to operate and includes both the EI and the RcB.

We elaborated a number of energy flow figures to illustrate the energy value of each variable. To do so, we used the E-Sankey 4 software (i-Point Systems. License owner: Pablo de Olavide University),

Based on the obtained metabolic variables, the proposed indicators were as follows:

2.5 Economic EROIs

EROIs inform us of the return on the energy intentionally invested in agroecosystems by society (Tello et al. 2016). As explained above, these EROIs are linked to economic sustainability since they account for the energy flows that present an economic value only (i.e., inputs, reused biomass in the form of feed stuff and seeds, and SB).

2.5.1 Final EROI (FEROI)

Describes the energy return on what society invested in the form of socialized biomass. It can be divided into two indicators, based on the origin of the energy invested: EFEROI reflects the system's net efficiency with respect to the investment of external inputs; and IFEROI provides information about the return in the form of SB with respect to the phytomass reinvested by the farmer (RuB) in the agroecosystem.

The FEROI can also be divided into several indicators that reflect the farm's production orientation, that is, the extent to which the return of the invested energy is found in the form of plant or animal biomass: Forestry FEROI and Livestock-FEROI (see Table 2).

Biomass outflows consisted almost entirely of animal biomass or firewood. None of the farms exported grain, fodder or manure outside the system except for one pig farm that produced citrus fruit for sale and three farms that sold olives (the biomass has been included in the SVB flows). The straw, grain and fodder produced were for animal on-farm consumption.

2.6 Agroecological EROIs

Agroecological EROIs reflect the agroecosystem's actual productivity, not just the portion that is socialized, but the reinvestment made in the fund elements, that is, in the structure of the agroecosystem that provides basic ecosystem services. Three indicators were used:

2.6.1 NPP_{act} EROI

Estimates the agroecosystem's real productivity regardless of the origin of the energy received. This indicator gives integrative information on the state of the agroecosystem, beyond the particular situation of each fund element. A decreasing trend of NPP_{act}-EROI values over time indicates a degradation in the agroecosystem's production capacity.

2.6.2 Biodiversity EROI

Biodiversity-EROI provides useful information on the extent to which energy invested in the agroecosystem contributes

to sustaining the food chains of heterotrophic species. For this EROI, a decreasing trend indicates a deterioration of the agroecosystem's capacity to sustain biodiversity.

Ecologists have explored the relationship between energy flows and biodiversity. Based on empirical studies, they have shown that systems with larger amounts of energy entering the food web are able to support longer food chains and more biodiversity (Giampietro 1997; Edwards et al. 1993; Barners et al. 2018; Yang et al. 2021). In organic farming, a number of authors (Rundlöf et al. 2008; Carrié et al. 2022) have attempted to differentiate the effects of management on biodiversity, considering that organic farms are not homogeneous but rather constitute a gradient in land use intensity and structure complexity. Some studies have addressed the relationship between unharvested biomass and biodiversity. They have focused, in particular, on how an increase in forage resources fosters greater biodiversity, associated with the transition of conventional farms towards organic farms (Döring and Kromp 2003; Rundlöf et al. 2008; Gabriel et al. 2013; Feber et al. 2015). Gabriel et al. (2013) showed that there were differences in the degree of diversity of some insect species (bumblebees, solitary bees, butterflies, epigeal arthropods) between organic and conventional fields. These differenceswere explained by the lower grain yields in organic fields, which are also related to the larger amount of unharvested biomass. In other words, for a given amount of yield (that is, socialized biomass in our terminology), there were no differences between management types in terms of biodiversity. However, there was a greater amount of weeds (unharvested biomass) and arthropod biodiversity in lower-yielding organic farms. In summary, greater diversity was related to an increase in unharvested biomass and not to organic management per se.

In recent years, several studies have been conducted on the relationship between internal biomass flows in agroecosystems, EROIs and biodiversity, applying the ELIA (Energy-Landscape Integrated Analysis) model. This model shows the strong relationships that exist between internal energy loops in agroecosystems and biodiversity (Marull et al. 2019a; 2019b)

2.6.3 Woodening EROI

This indicator reflects the amount of energy invested in the system that is stored in woody species, providing ecosystem services such as carbon sequestration in the forest fraction of the system.

2.7 Variable selection and statistical analysis

To classify the farms, eight original variables were selected according to management, diversity of land uses and livestock feeding options, because they presumably have a direct influence on energy flows.

The variables used were as follows:

- *Complexity of land uses* (LANDUSE). The different land uses confer management complexity, but they also generate ecosystem services. Five use types were found in the farms studied: natural treeless pastureland, natural wooded pastureland, cultivated grassland, cropland, and woodlands. We assigned a value of 1 to each use, and the number of uses was then summed up and divided by 5 for each farm (values varied from 0.2–one use to 1–five uses).
- *Animal food crops index* (AFCROP). Represents the ratio of animal feed needs covered by self-produced crops. AFCROP is a continuous variable between 0 and 1. The value is zero for farms where there are no crops and 1 for farms whose only source of food comes from their own crops.
- *Livestock orientation index* (LIVEOR). This is the ratio of socialized biomass on the farm that comes from livestock farming (calves, pigs, eggs, lambs, sold replacement heifers, culled cows, sheep and sows…) in terms of gross energy. LIVEOR is a continuous variable between 0 and 1. The value is 0 for farms that do not produce any livestock products, and 1 for farms that only breed animals without any other vegetal products to be exported out of the system.
- *Forestry orientation index* (FORESTOR) The ratio of socialized biomass on the farm that comes from forests or woodlands. FORESTOR is a continuous variable between 0 and 1. The value is 0 for farms that do not harvest any timber or firewood.
- *Stoking rate* (STOCKING) Measured in terms of grazing livestock units (LUs) per hectare. An LU is equivalent to 33,915 MJ of metabolizable energy from food per year (250 kg barley month^{-1}, where the metabolizable energy from one kilogram of barley is 11.305 MJ kg^{-1}) (Guzmán and González de Molina 2017). It is calculated by subtracting the metabolizable energy from feed and crops from the total energy demanded by livestock. The remaining energy is supplied by the pastures. Such energy is divided by 33,915 to obtain the LUs that are actually grazing.
- *Grazing intensity* (GRAZint). This is the consumption ratio of aboveground NPP of pasturelands by livestock. Overgrazing has a negative impact on biodiversity, the regeneration of pastures and it affects the soil structure, or its capacity to capture carbon (Teague and Kreuter 2020; Aguilera et al. 2013). In semi-arid Mediterranean systems, a use of more than 50% of the aboveground pasture biomass (Le Houerou and Hoste 1977; Robles 2008) is considered to pose overgrazing risks. On the other hand, a low utilization ratio depresses sustainability, because low rates of reuse

of a farm's own resources must be complemented by greater imports of external raw materials, resulting in a poor fire control service. GRAZint is a continuous variable between 0 and 1. Farms making an optimal use of pastures (50%) were attributed a value of 1, and at the extremes, those making a 100% or 0% use were given a value of 0. The effective percentage of pasture consumed was obtained by subtracting the metabolizable energy supplied by feed, fodder and crops from the livestock's total needs. The remaining energy is supplied by the pastures.

- *Self-sufficiency for livestock feed* (SELFfeed). This indicator describes the dependency on external feed to maintain livestock, expressed in terms of gross energy. SELFfeed is a continuous variable between 0 and 1. The value would be 0 for farms that rely completely on imported feed, and 1 for farms that produce all the livestock feed required.
- *Orientation to animal fattening index* (FATTENING). Fattening animals on the farm itself until slaughter often involves the import of feed. This indicator represents the share of SAB (socialized animal biomass) coming from animals that complete their fattening cycle on the farm based on external feed and other external stuffs. FATTENING is a continuous variable between 0 and 1. The value is 0 in the case of farms that only sell weanlings or fatten calves using their own crops, and 1 for farms in which all socialized animal biomass comes from animals fattened using externally sourced feed.

After having calculated the original variables, a principal component analysis (PCA) was conducted, which allowed the grouping of the correlated variables and the highlighting of the components that determined a greater difference between production models. The chosen PCAs presented eigenvalues above 1.

We chose to group similar farms in clusters using the *K-means* method based on the values corresponding to the PCs previously obtained. This method allows generating clusters within which farms present a negligible variance and among which maximum variance is found. Models including 3 to 7 clusters were tested. The *Elbow method* was also used to verify that the 5-cluster option was the most appropriate (Syakur et al. 2018).

Finally, using the Pearson correlation coefficient, partial correlations were made between the PCs and the EROIs for all 41 farms.

All statistical calculations were performed using the STATISTICA 7.0 software (Statsoft. License owner: Extremadura University)

3 Results

We detected a number of differences among the distinct types of organic management. They are detailed in the following sections. Each farm's individual characteristics can be found in the Supplementary materials (Table S1)

3.1 PCA

The PCA produced three components with eigenvalues above 1 used to form the clusters. Together, they accounted for 77.2% of the cumulative variance. Eigenvalues are illustrated in the Supplementary materials (Table S3), together with their variances and the relationship of each original variable with each PC (principal component) (Table S4). The values of the original variables per farm are also provided (Table S2).

The number of livestock species on the farm was initially considered as one more classification variable. We observed, however, that no direct relationship could be established between this amount and the use of production resources. Nor did it generate any differences among farms after applying the PCA and the cluster analysis. We therefore discarded it.

PC1. Intensification of livestock production (41.6% of the variance). Strongly related to livestock orientation index and fattening, and inversely related to self-sufficiency, forest orientation and the grazing index. Farms presenting a high value for this component were those whose SAB had a notable weight in total outputs.

PC2. Diversification (19.2% of the variance). Positively related to the presence of livestock feed crops and other land uses, and negatively related to the stocking rate and grazing index. Farms with a high value for this component made use of their own crops and presented satisfactory food self-sufficiency.

PC3. Forest orientation (16.3% of the variance). Positively related to forest orientation and negatively to livestock orientation and diversity of land uses. Farms presenting a high value for this variable were linked to production on non-cultivated dehesas, where the weight of the forest biomass was much greater than that of livestock production.

3.2 Clusters and farm models

The 5-cluster solution showed better results due to its lower intra-cluster variability and higher between-cluster variability, as well as satisfactory significance regarding the three PCs (Table S4). Figure 4 illustrates all clusters.

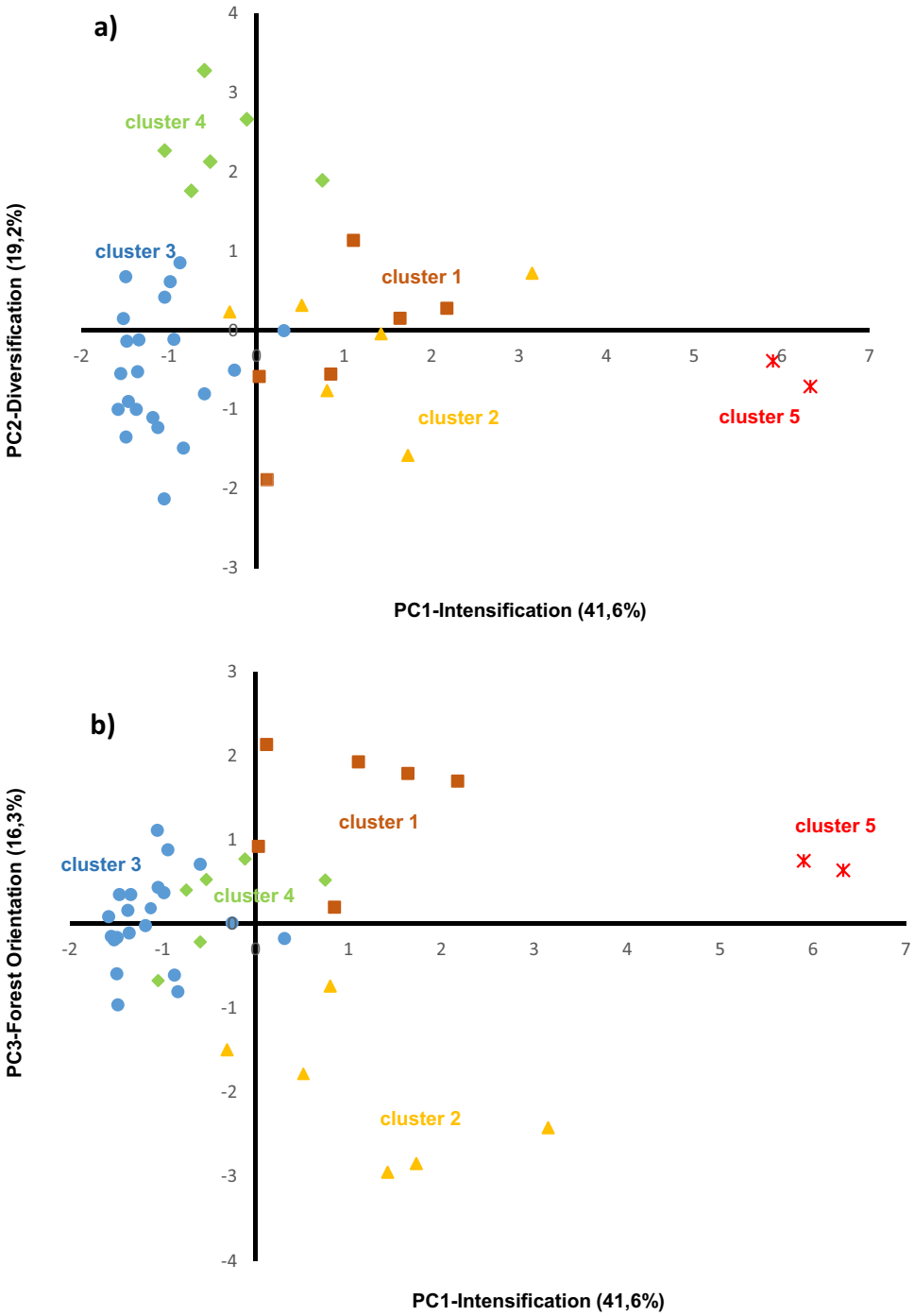

Fig. 4 Farm clusters based on principal component 1 (PC1-intensification of livestock production), principal component 2 (PC2-Diversification), and principal component 3 (PC3-Forest Orientation). Representation of the clusters according to PC1 with respect to PC2 (**a**) and PC3 (**b**).

3.2.1 Cluster 1: Dehesa farms oriented towards fattening

This cluster includes 3 farms dedicated to beef fattening and 3 to Iberian pig fattening (one of these also included beef cattle and goats). It was mainly related to PC3, because most of the *SB* was forest biomass, but also to PC1 because all the animals were fattened on the farm. They grew crops for animal feed, but the latter accounted for reduced amounts of the necessary quantities, so they imported feed, forages or straw. They presented intermediate stocking rates and their levels of pasture use represented approximately 30% of the availability, that is, a sub-optimal level (Table 3).

3.2.2 Cluster 2: Farms with little woolands or less amount of forest products

This cluster included 6 cattle farms. Among these farms, 3 combined beef cattle and pig livestock (two were dedicated

Table 3 Characteristics of each farm cluster and its EROIs indicators. [1]Ratio of pasture biomass consumed by animals with respect to the pasture's aboveground net primary productivity. [2]Ratio of feed covered by stuffs external to the farm with respect to total feed consumed, ha (hectare), LU (Livestock units), FEROI (Final Energy Return on Investments), For-FEROI (forestry FEROI), Liv-FEROI (livestock FEROI), EFEROI (external FEROI), IFEROI (internal FEROI), NPPact-EROI (Actual Net Primary Productivity FEROI). Significance (Sig.) has been calculated by the ANOVA analysis (a,b,c mean groups with significant differences among them; n.s means no significance).

	Cluster 1 ($n = 6$)	Cluster 2 ($n = 6$)	Cluster 3 ($n = 21$)	Cluster 4 ($n = 6$)	Cluster 5 ($n = 2$)	Sig. (*$p <$ 0.05; **$p <$ 0.01)
General characteristics						
Average surface (ha)	301.5 ± 174.3	319.9 ± 168.0	586.2 ± 863.2	385.0 ± 99.1	27.1 ± 32.4	n.s
Total Stocking rate (LU ha^{-1})	0.47 ± 0.47a	0.83 ± 0.36a	0.47 ± 0.35a	0.44 ± 0.22a	45.22 ± 14.29b	< 0.001**
Grazing Stocking rate (LU ha^{-1})	0.20 ± 0.21ab	0.37 ± 0.21b	0.34 ± 0.12b	0.08 ± 0.05ab	0.00 ± 0.00a	< 0.001**
Grazing (ratio)[1]	0.32 ± 0.31ab	0.56 ± 0.29b	0.51 ± 0.18b	0.15 ± 0.09ab	0.00 ± 0.00a	0.001**
Self-sufficiency (ratio)[2]	0.34 ± 0.16a	0.12 ± 0.09ab	0.03 ± 0.05b	0.04 ± 0.10b	0.97 ± 0.04c	< 0.001**
Economic EROIs						
FEROI	1.17 ± 1.30a	0.12 ± 0.11b	0.37 ± 0.18ab	0.54 ± .50ab	0.15 ± 0.06b	0.017*
For-FEROI	0.99 ± 1.24a	0.04 ± 0.05ab	0.34 ± 0.18ab	0.51 ± 0.57ab	0.00 ± 0.00b	0.026*
Liv-FEROI	0.05 ± 0.04a	0.08 ± 0.07a	0.03 ± 0.01a	0.03 ± 0.03a	0.15 ± 0.06b	< 0.001**
EFEROI	2.81 ± 2.16	1.48 ± 1.77	53.91 ± 87.84	13.25 ± 10.1	0.15 ± 0.05	n.s
IFEROI	2.68 ± 3.26a	0.13 ± 0.12a	0.39 ± 0.18a	0.73 ± 0.92a	16.97 ± 21.11b	< 0.001**
Agroecological EROIs						
NPP_{act}-EROI	1.14 ± 0.10a	1.02 ± 0.03b	1.13 ± 0.05a	1.13 ± 0.02a	0.13 ± 0.05c	< 0.001**
Biodiversity EROI	0.76 ± 0.19a	0.59 ± 0.19a	0.72 ± 0.12a	0.77 ± 0.09a	0.10 ± 0.02b	< 0.001**
Woodening EROI	0.07 ± 0.01a	0.03 ± 0.02ab	0.06 ± 0.02a	0.06 ± 0.01a	0.00 ± 0.00b	< 0.001**

to Iberian pig breeds and one to white pigs) and 1 combined beef cattle with sheep. They consist mainly of extensive rain-fed pasturelands with or without a share of dehesa. They grew crops for animal feed and their SVB was reduced, mostly because they were non-wooded pastures and, in two cases, because of restricted pruning to avoid the proliferation of the disease caused by the *Phytophthora* spp. fungus. Their relationship with respect to PC1 was positive and all farms, except one, fattened the animals. The use of pasture was high, in some cases reaching optimum levels and in others leading to overgrazing (Table 3). The relationship with PC3 was negative (Fig. 4).

3.2.3 Cluster 3: Self-sufficient dehesas without crops or little oriented towards agriculture

This was the cluster with the largest number of farms (21 farms). All were beef cattle farms, among which 4 also specialized in sheep production, 3 in Iberian pigs and one combined the three types of cattle. It was negatively related to PC1 and to PC2 (Fig. 4). Animals were not fattened, or, if they were, the amount of external raw materials used was very low. A third of all farms did not have their own crops and the rest had moderate shares of crops with respect to their livestock needs. Livestock densities were adequate and pasture use levels were close to optimal (Table 3).

3.2.4 Cluster 4: Self-sufficient dehesas with their own crops

Formed by 5 beef cattle farms (one also had sheep) and one Iberian pig farm. They presented a high ratio with respect to PC2 and a low ratio with respect to PC1 (Fig. 4). These farms were dehesa farms that were all combined with treeless grasslands with crops. Most of them sold weanlings. They presented low livestock intensities (Table 3). From the viewpoint of livestock production, the dehesa pastures were underexploited since most of the reused biomass came from crops and not from the available pasture.

3.2.5 Cluster 5: Semi-intensive pig farms

Included 2 semi-intensive farms that fattened white pigs, were strongly oriented towards livestock production (PC1) and little diversified. They presented a negative relationship with respect to PC2 (Fig. 4). They had pasture plots and some crops of their own that represented a low share of their livestock needs. As far as pasture use was concerned, livestock densities could be considered nil. Almost all animal feed came from raw materials purchased off-farm and ground in their own mills (Table 3).

Given the differences between cluster 5 and the rest regarding the PC values, Mahalanobis distances were calculated in order to identify whether these points were

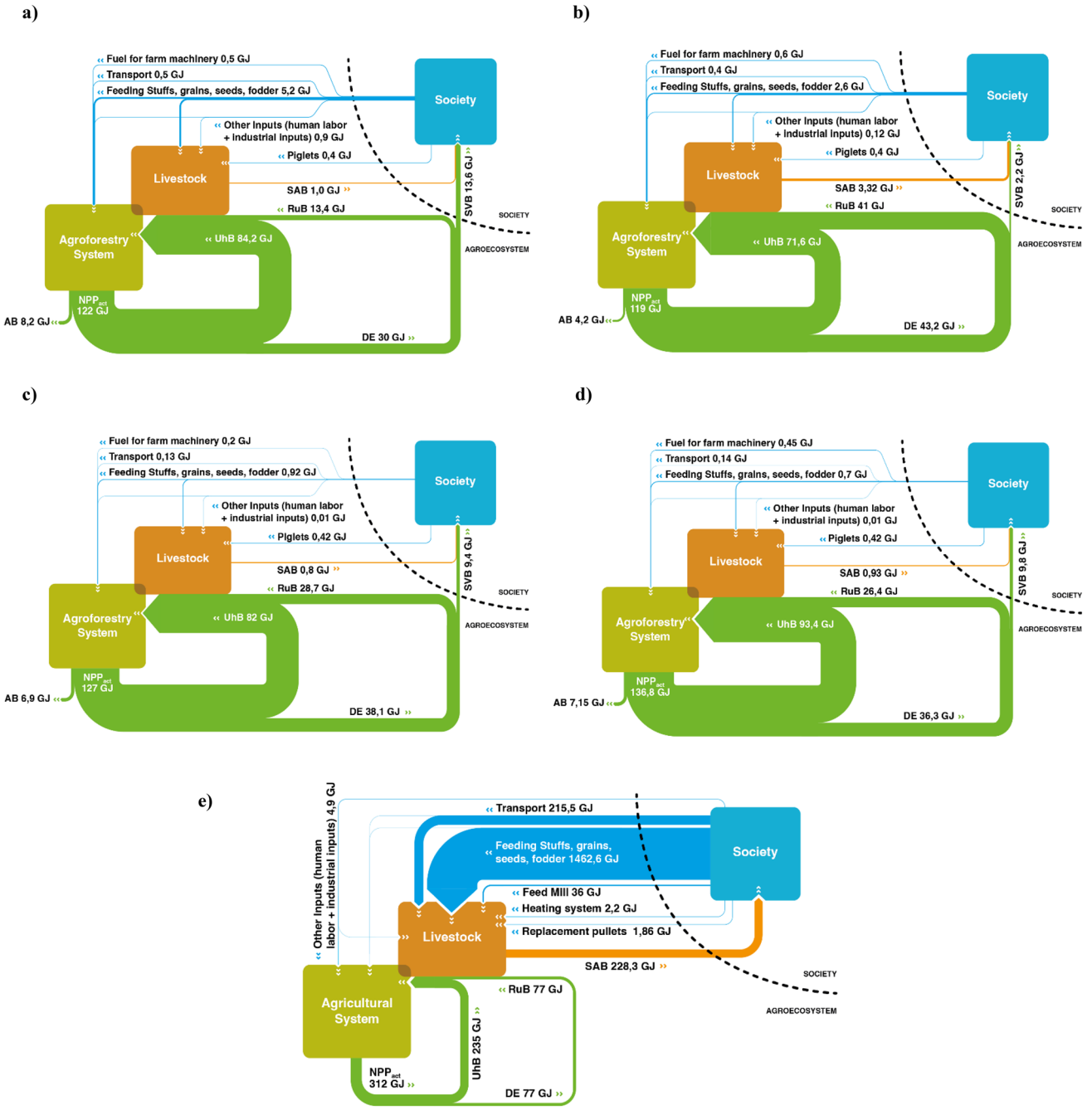

Fig. 5 Energy flows (GJ ha^{-1}) regarding inputs, outputs, and recycled biomass within the farms. **a** Cluster 1: dehesa farms oriented towards fattening; **b** cluster 2: farms with little woolands or less amount of forest products; **c** cluster 3: self-sufficient dehesas without crops or little oriented towards agriculture; **d** cluster 4: self-sufficient dehesas with their own crops; **e** cluster 5: semi-intensive pig farms. SAB, socialized animal biomass; SVB, socialized vegetal biomass; RuB, reused biomass; UhB, unharvest biomass; DE, domestic extraction; NPP_{act}, actual net primary productivity; AB, accumulated biomass.

outliers with respect to the three set variables (Table S6). The Mahalanobis probability was calculated based on the significance function of Chi-q with three degrees of freedom. None showed a *p*-value below 0.001, therefore, no case was an outlier and the cluster 5 points should remain in the analysis.

Further characteristics of the farms of each cluster are summarized in Table 3.

Regarding the management characteristics of the clusters, significant differences were observed in total stocking rates. The white pig cluster presented a more intense stocking rate than the others. The most notable variation, however, was

the grazing stocking rate, which presented the same significant difference observed for the grazing ratio: clusters 2 and 3 exerted more pressure on pasture utilization than the rest due to higher grazing rates. Cluster 5 had no grazing at all, and, at the same time, it displayed the greatest degree of dependency on external feeds, and thus, the worst rate of self-sufficiency. Clusters 3 and 4 presented the most favorable self-sufficiency values and clusters 1 and 2, where all cattle are fattened, showed intermediate values for this variable.

3.3 Energy flows and energy efficiency

Figure 5 shows the energy flows of the five clusters described and the average value per hectare of its variables expressed in Gigajoules (GJ). Table 3 shows the corresponding EROIs.

Dehesa clusters (1, 3, and 4) presented the greatest energy performance. Though fattening-oriented dehesa farms were expected to be less self-sufficient than cluster 3 and 4 farms, they actually stood out for their FEROI, For-FEROI, and NPPact-EROI values. Cluster 1 showed a substantial NPP_{act}, of which 11% was reused (RuB) by livestock and another 11% was transferred to society. The rest remained in the agroecosystem in the form of forest biomass (Woodening-EROI) and unharvested biomass (UhB) available to feed wild food chains (Biodiversity-EROI), and improving the agrosystem's fund elements (greater NPP-EROI). These dehesa farms presented the highest energy investment (7.5 GJ ha^{-1}) corresponding mainly to purchased feed. They maintained good economic and agroecological EROIs. The former reached values above or close to 1, which indicates a good return in terms of goods for society, both in relation to external energy investment and the agroecosystem's biomass itself. This was due to a high return in the form of firewood and animal biomass, and a fairly efficient combination of the use of its own resources (pastures, crops) as well as external ones (feed).

The agroecological indicators of the three dehesa clusters were similar. They achieved the best results and maintained the strength of the internal biomass flows that sustain the agroecosystem's fund elements.

The self-sufficient *dehesas* (without or with crops, clusters 3 and 4, respectively) presented lower external investment than the previous ones because they hardly fattened animals, they took advantage of the pasture and/or, where appropriate, their own crops. Therefore, the return in relation to the EI was very high. SAB was lower than in cluster 1, especially that of cluster 3. Surprisingly, cluster 4, which incorporates agricultural production, did not generate a better return on livestock product (Liv-FEROI) than cluster 3, whose production was based on natural pastures. The reason is that crop productivity in low-quality soils of dry dehesa lands is very low. Both clusters showed the lowest rates of conversion to livestock products (Liv-FEROI). Indeed, no significant differences were found for this indicator among the four extensive farming groups.

Cluster 2 as well as cluster 3 farms were the ones that put the most pressure on the pastureland. Cluster 2 reused the most biomass, including the farms' own crops. Domestic extraction with respect to the NNP_{act} amounted to 36.3%, compared to 24.6-30.0% in the case of the dehesa clusters. This means a lesser share of unharvested biomass is left for the feeding of trophic chains. The lower strength of the internal flows of phytomass dedicated to feeding the fund elements depressed the NPPact-EROI. The SAB was higher than in dehesa farms (Fig. 5), due largely to fattening performance. They presented similar livestock conversion rates (Liv-FEROI) compared to dehesa clusters, while the FEROI economic indicators were significantly worse (and more similar to those of cluster 5). The EI was limited (4.12 GJ ha^{-1}) and the inputs with the biggest weight were feed purchases. This cluster performed less well than the other extensive farms due to the total energy investment being less efficient at producing socialized biomass and at maintaining the fund elements.

Lastly, cluster 5 clearly differed from the rest. These farms had small surface areas but very high NPP_{act} because of their irrigated crops. A total of 24.6% of the NPP_{act} was reused by crops, while grassland was barely used by white pigs. The energy flows directed towards the maintenance of the agroecosystem's fund elements were very low or non-existent, generating very low agroecological-EROIs. A total of 97% of the feed was imported. Added to a very high total stocking rate (Table 3), large energy inputs in the form of feed were necessary. The entire breeding cycle, including artificial insemination took place on the farm, leading to much higher labor costs than the other four models. Heating systems (using pine wood pellets) were installed in the animals' accommodation and represented an expense of 2.2 GJ ha^{-1}. The Liv-FEROI and the IFEROI were the most favorable: the total and internal energies invested showed high returns in terms of animal feed, both because the SAB was very high, and because the RuB was low. The lack of SVB depressed the For-FEROI and the FEROI.

Despite the notable differences between mean EFEROI values, the ANOVA analysis did not show significant differences among the clusters. We can therefore conclude that no cluster was more efficient at using external energy to produce socialized goods.

3.4 The correlation between PCs and EROIs

Table 4 shows the statistical analysis of the correlation between EROIs and PC.

Two principal components showed a direct and significant correlation with some EROIs

Table 4 Pearson's correlation coefficient between Energy return on investments indicators (EROIs) and principal components (PC). *n.s.* nonsignificant; $^{**}p < 0.01$; $^{***}p < 0.001$, SD (standard deviation), FEROI (Final Energy Return on Investments), For-FEROI (forestry FEROI), Liv-FEROI (livestock FEROI), EFEROI (external FEROI), IFEROI (internal FEROI), NPPact-EROI (actual net primary productivity EROI).

	Mean	SD	*r* (*x*,*y*)	R^2	*t*	*p*
PC1-Intensification	0	1.83				
FEROI	0.47	0.61	0.03	0.00	0.17	n.s
For-FEROI	0.4	0.57	-0.06	0.00	− 0.38	n.s
Liv FEROI	0.05	0.04	0.64	0.41	5.24	***
EFEROI	30.19	67.02	-0.29	0.08	− 1.87	n.s
IFEROI	1.55	5.08	0.61	0.38	4.84	***
NPPact-EROI	1.07	0.23	-0.81	0.65	− 8.59	***
Biodiversity EROI	0.69	0.20	-0.54	0.29	− 4.01	***
Woodening EROI	0.06	0.02	-0.53	0.28	− 3.91	***
PC2-Diversification	0	1.24				
FEROI	0.47	0.61	0.24	0.06	1.54	n.s
For-FEROI	0.40	0.57	0.25	0.06	1.59	n.s
Liv FEROI	0.05	0.04	0.00	0.00	− 0.01	n.s
EFEROI	30.19	67.02	− 0.10	0.01	− 0.61	n.s
IFEROI	1.55	5.08	− 0.03	0.00	− 0.2	n.s
NPPact-EROI	1.07	0.23	0.15	0.02	0.93	n.s
Biodiversity EROI	0.69	0.20	0.23	0.05	1.47	n.s
Woodening EROI	0.06	0.02	0.14	0.02	0.88	n.s
PC3-Forest Orientation	0	1.14				
FEROI	0.47	0.61	0.53	0.28	3.86	***
For-FEROI	0.40	0.57	0.51	0.26	3.73	***
Liv FEROI	0.05	0.04	− 0.03	0.00	− 0.16	n.s
EFEROI	30.19	67.02	0.11	0.01	0.69	n.s
IFEROI	1.55	5.08	0.23	.0.05	1.48	n.s
NPPact-EROI	1.07	0.23	0.04	0.00	0.27	n.s
Biodiversity EROI	0.69	0.20	0.18	0.03	1.12	n.s
Woodening EROI	0,06	0.02	0.41	0.17	2.82	**

The intensification component (PC1) presented a positive correlation with Liv-FEROI and IFEROI, and a negative one with NPP act-EROI, Biodiversity-EROI, and Woodening-EROI. This means that farms that are highly specialized in animal production and fattening will present an appropriate level of efficiency regarding certain economic converters: a good level of energy investment in meat production, as well as the utilization of internal energy flows for meat production, since they are dependent on external materials and barely reuse phytomass. They will not, however, favor the maintenance of long-term farm productivity, biodiversity conservation, carbon sequestration and other benefits generated by the accumulated and recycled phytomass.

The forest orientation component (PC3) was positively related to the FEROI, For-FEROI, and Woodening FEROI. There was no significant correlation with the rest of the indicators. As expected, the forest orientation component related to the indicators that showed efficiency in the production of forest goods and in the generation of ecosystem services derived from the accumulated forest biomass. Yet, it is also interesting to observe how the farms in which this component stood out showed adequate overall economic efficiency with respect to internal and external energy flows to produce goods for society.

The diversification component (PC2) was not significantly related to any indicator. This means that land use diversification, including crop production, does not necessarily entail higher energy efficiency in the Mediterranean systems studied, probably because the crops are mostly rainfed and low input.

4 Discussion

Although all farms were certified by the same European regulation on organic production, clear differences among the different clusters emerged. Organic certification comes with recommendations but does not establish mandatory requirements regarding measures such as the share of feed that should originate from the farm or from nearby sources; the association of livestock farming with other crop or forestry production; the adjustment of the stocking rate to the availability of local feed resources; or concrete practices to preserve biodiversity. A diversity

of management practices can thus be found, all of which are certified.

The use of local resources was a key factor to determine the production management that best contributed to the energy transition. Grazing was an important part of the livestock feed, except in the case of cluster 5. The higher the grazing ratio, the lower the dependence on external feed (Table 3). This contributed to maintaining high self-sufficiency in clusters 1 to 4, limiting the dependence on external feed (which ranged from 3 to 34% of livestock needs) and also providing other services such as animal welfare, especially in relation to behavior. These data presented much lower values than those found by Pérez-Neira et al. (2018) in the case of conventional extensive goat farming (48.9–66.8%). Self-sufficiency was proposed as a criterion to diagnose the attributes of agricultural sustainability (Gliessman 1997; Masera et al. 1999). The greater the self-sufficiency, the higher the sustainability. In our case, maximum energy efficiency did not correspond to highest self-sufficiency (3-4% dependence), since cluster 1 (34% dependence) presented similar agroecological EROIs to that of clusters 3 and 4 as well as better FEROI and For-FEROI values. It is usual practice under the Mediterranean climate to import feed facilities to fatten animals during the driest years, that is, when the farm's own resources are insufficient. In the absence of such inputs, the stocking density must adapt to years of lower productivity or shift the fattening to other intensive farms (clusters 3 and 4). However, the high level of dependence on external supply clearly depressed the sustainability of cluster 5.

In the case of cluster 4, the poor use of pastures showed that these farms could increase their SAB. The possible explanation of the low utilization of pastures could be, rather than technical factors, the fact that they abandoned the activity, thus maintaining the collection of CAP subsidies and in particular those relating to organic production. The reduced consumption of pasture would imply a low contribution to fire control, which is an essential ecosystem service in Mediterranean systems. These pastures shed light on the "refuge" phenomenon of organic certification for many low-income livestock farms. In our study, we estimated that 9 to 25% of the farms' gross income came from organic livestock subsidies (data not shown), a figure similar to that obtained by Díaz-Gaona et al. (2019) for organic livestock in Andalusia. These payments offset the generation of ecosystem services (López-i-Gelats and Bartolomé-Filella 2019; Díaz-Gaona et al. 2019) but the service of providing organic meat to society falls far short of its potential.

Another key element influencing EROIs is forestry. The dehesa landscape has been built throughout history by society, without whose intervention it would not exist as such (Guzmán 2016; Mesías et al. 2010). The presence of trees increases carbon storage and feeds food chains (Ledo et al. 2020; Liebig et al. 2021; Eldesouky et al. 2018) in addition to providing feed resources to livestock or improving self-sufficiency and renewable energy sources (firewood). Sustainability may be compromised as production intensifies, especially if it loses the agroforestry benefits coming from the integration of trees into livestock systems (Díaz-Gaona et al. 2019). The latter occurred on Cluster 2 farms with no trees or with weakened trees. It would therefore be appropriate to encourage the forestry component of farms via public policies. A similar situation was found in the Brazilian grassland cases studied by Guzmán and González de Molina (2017) where the integrated livestock-forestry systems were designed to improve energy efficiency and to contribute to agrarian sustainability (Murgueitio et al. 2015). Conversely, the three dehesa models evaluated in this work reached values that were even greater than those obtained by Guzmán and González de Molina (2017) for organic dehesa farms in economic and similar EROIs with respect to agroecological ones. The latter indicates a greater capacity to provide biomass to society, while maintaining the state of the agroecosystem in similar conditions. This improvement may be due to the optimization found in organic management practices as the conversion time of each farm increases. It may also be due to the inherent advantages of a larger critical mass of organic producers in terms of accumulation of collective knowledge, better marketing infrastructures, etc. as the organic sector matures. This hypothesis would need to be verified in further studies.

White pig farms (cluster 5) generated the least ecosystem services. This model, with a high livestock density, a small territorial base, and no presence of forest biomass, depressed its capacity to generate ecosystem services despite its production being certified as organic. The highest energy expenditures corresponded to the purchase of feed, as in the case of other studies that evaluated similar models (Pérez-Neira et al. 2014; Rudolph et al. 2018). However, they did bring about environmental and animal welfare improvements compared to conventional production and it is important to explore improvements that could increase their sustainability. Such improvements could consist, for example, in cooperating with local farmers to consume local feed, or substituting soya with other grain-legume crops that can be grown in Spanish rain-fed croplands.

The classification obtained in this study did not group farms by species (beef cattle or pigs); only the two white pig cases were distinguished. Nor was the number of distinct species on the farm a factor of differentiation. Rowntree et al. (2020) found that species rotation in pasture utilization was useful for the environmental improvement of systems. Martin et al. (2020) highlighted the potential of associating multispecies to improve sustainability but also the possible undesirable effects, such as competition for resource acquisition during grazing, parasitic cross-infection and more

intense work peaks if relevant practices were not observed. However, as Magne et al. (2019) point out, the functional biodiversity of mixed farming systems can increase their benefits by implementing an adequate type of management that takes into account the different metabolic and biological needs of each species and adapts the resources (forage, human labor, etc.) to each of them. Based on the results of this study, as far as taking advantage of resources was concerned, the degree of sustainability was not conditioned by the extent of species diversification but by livestock functionality. This was obtained from the stocking densities and the breeds used. Livestock breeds constitute an agro-ecosystem fund element with different functionality in terms of agricultural metabolism because they encapsulate different information flows. That is, a livestock breed alters energy and material flows and therefore, other fund elements (soil, biodiversity, etc.) differently. The latter results in the need to maintain traditional livestock breeds adapted to local agro-ecosystems when applying sustainability criteria (Verrier et al. 2005). In our study, this question was particularly evident in the case of the Iberian pig breed, which, compared to the white pig breed, is adapted to grazing outdoors and takes advantage of the dehesa's resources providing these farms with adequate self-sufficiency levels. This is the case of the Iberian pig farms in clusters 1 and 4 (Table 3). The Iberian pig has been praised in other works for its functionality, notably its capacity to adapt to the montanera (Rodríguez-Estévez et al. 2009), its relationship with carbon footprint reductions, and the generation of other ecosystem services (Horrillo et al. 2020; García-Gudiño et al. 2020). In the case of cattle breeds, these differences have not been observed according to the indicators studied and would require further studies.

The presence of crops on dehesa farms was not a differentiating factor in terms of energy efficiency. This may be because dehesa crop productivity was very low, and inputs as well as labor requirements were reduced. In their study in Catalonia, Teston et al. (2020) did not find any productivity or efficiency differences either when pastures were transformed into crops for animal feed on organic beef cattle farms. Ecosystem services in mixed semi-arid climate systems may be affected depending on the type of management and crop employed (Liebig et al. 2021). Additional studies are necessary to assess benefits at the farm level, which largely depend on the degree of intensification (Stark et al. 2018) and on the type of model, for example, with respect to the share of grazing in the animal feed. However, if we go beyond the farm scale, crop-livestock integration has a clear impact on environmental externalities (Martin et al. 2020). A large proportion of organic soybeans come from distant lands and they have a direct impact on the deforestation of the large Amazonian masses and tropical savannas (Fuch and Alexander 2019). The extension of the areas cultivated for soybeans destined for feed competes with the production of other crops intended for human consumption (Díaz-Gaona et al. 2018). Therefore, the stocking of local feed stuffs has been recommended to increase sustainability globally (Billen et al. 2019). The organization of producers at the territorial level (between crop and livestock farms) could represent an economically and environmentally viable alternative (Martin et al. 2016; Moraine et al. 2014).

5 Conclusions

In this work, we demonstrated that the calculation of EROIs in economic and agroecological terms applied to the organic livestock was useful to differentiate several production models that coexist under this umbrella term, their different levels of energy efficiency, as well as their capacities to produce ecosystem services.

The differences were mainly due to distinct production strategies (the fattening or the selling of weanlings) and production diversification. The forestry orientation, which is complementary to the livestock orientation in the dehesa systems, provided greater overall efficiency in terms of economic indicators. In addition, the forestry orientation was more efficient at maintaining high phytomass productivity with scarce external inputs (NPPact-EROI) as well as sustaining biomass flows that feed the fund elements, improving the capacity to provide ecosystem services. Livestock species orientation did not play a relevant role, partly because it is the breed more than the species that conditions livestock functionality in the agroecosystem. This was the case of the Iberian pig versus the white pig.

A self-sufficiency of nearly 100% in livestock feeding did not entail a better performance than that of the dehesa cluster—that fattened animals until slaughter and depended, to some extent, on imported feed to do so (34%). This means that fattening is not less efficient if it is adequately combined with the use of the farm's resources (pastures, trees and crops) and a proper management. Furthermore, these fattening systems are better able to provide organic meat to society.

At the other extreme, the organic model of semi-intensive white pig production on farms with little land, using feed purchased outside the farm, presented the worst agroecological EROIs, raising doubts as to the ecosystem services provided.

We can conclude that some organic livestock contributes to the energy transition in terms of an optimal use of local resources, a reduced use of external inputs, satisfactory efficiency in the production of organic meat for society, together with other vegetal products, and the presence of forest mass on farms. The studied models that best reflected this objective were dehesa farms. Those specialized in animal

fattening exported more organic meat to society (socialized animal biomass) than the other two dehesa models—though they maintained the same level of efficiency. Three other extensive farming models could be improved through public policy incentives. In the case of pasturelands with small amounts of forest products, support could be given to increase the number of trees or to make sanitary improvements to allow tree pruning. In the case of self-sufficient dehesa farms, fattening could be encouraged as well as the sustainable growth of stocking rates to increase their main service to society: providing organic meat. Since the extensive farming systems studied are not as meat-productive as semi-intensive systems, the productivity and efficiency debate remains subordinated to the debate on society's needs in the context of new sustainable diets. To finish, the agro-ecological inefficiency of semi-intensive certified organic pig farms leads us to question whether they contribute to reducing energy dependence. Therefore, from this perspective, they should not be encouraged by public policies.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare no competing interests.

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