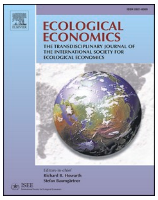
Ecological Economics 190 (2021) 107206

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon



ANALYSIS

Socio-ecological transition in a Mediterranean agroecosystem: What energy flows tell us about agricultural landscapes ruled by landlords, peasants and tourism (Mallorca, 1860-1956-2012)

O. Fullana Llinàs[a,*], E. Tello Aragay[b], I. Murray Mas[c], G. Jover-Avellà[d], J. Marull López[e]

[a] *University of the Balearic Islands, Valldemossa Road km 7.5, 07122 Palma de Mallorca, Spain*
[b] *Department of Economic History, Institutions, Policy and World Economy, University of Barcelona, Diagonal Avenue 690, 08034 Barcelona, Spain*
[c] *Department of Geography, University of the Balearic Islands, Valldemossa Road km 7.5, 07122 Palma de Mallorca, Spain*
[d] *Department of Economics, University of Girona, Montilivi Campus, 17003 Girona, Spain*
[e] *Metropolitan Laboratory of Ecology and Territory (LET) at the Barcelona Institute of Regional and Metropolitan Studies, Autonomous University of Barcelona, Bellaterra 08193, Spain*

ARTICLE INFO

Keywords:
Mediterranean agroecosystems
Socioecological transition
Energy Return on Investment (EROI)
Agrarian sustainability
Agroecology

ABSTRACT

Using several energy returns on investment indicators (multi-EROI), this article analyses the socioecological transition of an agroecosystem in the western Mediterranean on the island of Mallorca (Spain) over a period of 150 years which saw a change from traditional organic farming to a fossil fuel-based system of agriculture. This circular bioeconomic analysis evaluates the agroecosystem's capacity to produce goods by reproducing itself in 1860, 1956 and 2012. In 1860 land and livestock were mostly in the hands of a few landowners, who kept agroecosystems away from the full productive capacity of traditional organic farming so as to increase land rents by lowering wages. The bankruptcy of these large estates increased peasant access to land at the end of the nineteenth and the first third of the twentieth centuries. Peasant farms were mainly solar-based and combined polyculture with a large number of small flocks, thus creating complex and attractive Mediterranean biocultural landscapes with higher EROIs. By 1956, these had practically reached the limits of traditional organic farming and early became a residual activity within the tourism specialization of the economy. As everywhere, conventional farming reduced agrarian eco-efficiency through production increases achieved at the cost of greater dependence on external fossil fuel-based inputs, a loss of biophysical circularity and lower EROIs. In Mallorca, however, this took place at the same time as agriculture was subsumed by the tourist economy, leading to a more partial and less widespread adoption of Green Revolution techniques than in other parts of Spain. Although agroecosystem live funds were undermined and the reproduction of Mallorcan biocultural landscapes was placed at risk, an important heritage of biocultural peasant agriculture still survives as a resource for the future.

1. Introduction

In the era of what Moore (2018) has called the "Capitalocene", the co-evolution of society and nature that characterized traditional agroecosystems and their biocultural landscapes is no mere historical curiosity (Antrop, 2005). Understanding this agricultural heritage is a useful tool for redirecting current agrarian activity towards a more sustainable circular bioeconomy. World agriculture is facing a set of large-scale challenges: to improve agroecological efficiency in the use of natural resources while making them more equally accessible, to reduce the detrimental environmental impacts of industrial agrifood production, and to enhance support, regulatory and cultural ecosystem services, together with the provisioning of healthy and equitable diets. The transition to agroecology territories is a fundamental part of this task (Altieri and Nicholls, 2012; Rosset and Altieri, 2017; Nicholls and Altieri, 2018; Millward-Hopkins et al., 2020).

Since the twentieth century, the industrialization of agriculture has led to a loss of biomass recirculation within the agroecosystems that characterized traditional organic agriculture (González de Molina et al., 2020). This involved reductions in the complexity and

---

* Corresponding author.
E-mail addresses: onofre.fullana@uib.cat, nofrefullana@gmail.com (O. Fullana Llinàs), tello@ub.edu (E. Tello Aragay), ivan.murray@uib.cat (I. Murray Mas), gabriel.jover@udg.edu (G. Jover-Avellà), joan.marull@uab.cat (J. Marull López).

https://doi.org/10.1016/j.ecolecon.2021.107206
Received 31 January 2021; Received in revised form 1 August 2021; Accepted 17 August 2021

multifunctionality of agroecosystems (Marull et al., 2019a, 2019b), as well as in their resilience in the face of disturbances (Ho and Ulanowicz, 2005; Ulanowicz, 2020). The structural changes undergone by industrial farming and animal husbandry, separately from each other as well as from forestry, also meant replacing biomass recycled by external inputs derived directly or indirectly from fossil fuels in a world of cheap energy (Moore, 2015). Although not invariably the case, nor has the same path been followed everywhere, the biophysical study of agroecosystems from a historical perspective can be used to analyse their evolution in different socioeconomic contexts. These analyses will help inform the adoption of public policies that farmers' organizations claim will promote more sustainable farming practices (IAASTD, 2009; FAO, 2018; IPES-Food, 2019; European Commission, 2020; Duncan et al., 2020).

In the 1970s, an important body of research emerged focused on the energy inefficiency of industrial agriculture (Leach, 1976; Pimentel and Pimentel, 1979; Naredo and Campos, 1980). Since then, the metabolic functioning of agrarian activity has been analysed to determine the energy return per energy input invested (EROI) in each specific type of social, farm or crop system (Guzmán and González de Molina, 2017). Results differ depending on where the boundaries of the system are placed, its natural resource endowment, and whether the study is conceived as a linear input–output analysis of only one crop (Pellegrini and Fernández, 2018) or is considered from the viewpoints of circular bioeconomic and agroecological systems able to cast light on the internal recirculation of biophysical flows that reproduce agroecosystems' basic live funds of (Tello et al., 2016; Gingrich et al., 2018a, 2018b). The circular accounting methodology permits improved understanding of the sustainability of these types of farm management of agroecosystem funds (fertile soil, livestock, an agrarian community, among others), following Georgescu-Roegen's (1971) bioeconomy approach.

Our study applies a circular energy analysis to past and present agricultural systems from the bioeconomic and agroecological points of view. The justification for this novel approach is that the inward or outward directions and relative amount of each information-driven energy flow, as determined by the farmer's goals (Font et al., 2020), impact on the land-use pattern these metabolic flows imprint in the territory. These flows give rise to agroecology landscapes that are more or less diverse, ecologically disturbing and economically productive and that will be able to accommodate different levels of biodiversity, depending on the complexity of the energy flow pattern (Marull et al., 2019b). In this view, agroecosystems are interpreted in terms of human coproduction with nature that is capable first, of sustainably providing a wide range of provisioning, supporting, regulating and cultural ecosystem services, and second, of merely indulging in unsustainable agrifood provisioning at the expense of endangering other ecosystem services (Altieri, 2018).

Based on this theoretical approach, our study aims to analyse the socioecological transition of the agroecosystem in the municipality of Manacor (Mallorca, Spain), based on calculations of its funds and energy flows, and linking its fund–flow pattern with the evolution of their respective landscapes within the social and economic context of three different time-points stretching over 150 years. Our aim is to emphasize two key features of how the agroecosystem studied in Mallorca was managed that differ from other case studies: first, to test the relevance of social changes from a highly unequal, landlord-based agrarian class structure to a less unequal, peasant-based one as a fundamental socioeconomic fabric within which the socio-metabolic and landscape transformations from traditional organic to fossil fuel-based farming took place (Tello et al., 2018); and, second, to determine whether the early economic marginalization of farming due to the strong impact of mass tourism on the island actually led to a lower adoption of Green Revolution techniques. Paradoxically this helped the precarious maintenance of biocultural peasant landscapes, as previous studies on Mallorca point out (Marull et al., 2015; Murray et al., 2019).

2. Material and methods

2.1. Features of the case study

To pursue these topics, we present a case study that is biogeographically representative of a Western Mediterranean environment to highlight how historical and socioeconomic agrarian changes to that environment conditioned the socioecological transition from traditional organic to industrial agriculture, in comparison to other farm systems in the same bioregion that have been studied using the same methodology (Tello et al., 2016; Marco et al., 2018; Díez et al., 2018). Manacor (Balearic Islands, Spain) is one of the largest municipalities on the island of Mallorca, with a diversity of landscape that can be taken as a good sample of the entire island (Marull et al., 2015). Located on the eastern side of the island (Fig. 1), from the central plain to the coast, it has large flat areas with deep soils traditionally dedicated to rain-fed herbaceous crops and vineyards, as well as irrigated areas for vegetable gardens and tree orchards. Other areas have poorer soils located on hills, small valleys and mountain fringes, formerly characterized by the intercropping of almond, fig and carob trees, together with pastures used for extensive livestock rearing. In addition, two parallel mountain ranges run perpendicular to the coast reaching a height of nearly 500 m.a.s.l., where scrublands of *O. europaea var sylvestris*, *P. lentiscus* and *A. mauritanica* predominate, together with forests of *P. halepensis*. Precipitation is around 500 mm a year, with typical Mediterranean temperatures and arid summers. The municipality has historically been dedicated to agriculture and some manufacturing, but since the mid-twentieth century it has been severely affected by tourism and the subsequent waves of urbanization, initially on the coast and more recently inland (Rossello Verger, 1964; Murray et al., 2019).

The availability of records, statistics and land-use maps has enabled us to choose three time points to represent three different socio-ecological metabolic patterns of agriculture: traditional organic, intermediate, and fossil fuel-based. These patterns also represent completely different socioeconomic contexts. The starting point is 1860, when landlords had accumulated a great deal of land and power rooted in the practice of traditional organic agriculture. Just a few landowners owned 78% of the land, the remainder being distributed between 3100 people—25% of Manacor's population (Fullana, 2019). By monopolizing most of the land, landlords also controlled the supply of cheap human labour, creating a plethora of small family farmers who also had to work temporarily on the large farms or *possessions* to survive. This accumulation of property also meant the exertion of social power in the labour market and elsewhere. These *possessions* grew cereal and leguminous crops in extensive rotations with fallow and put livestock out to graze great forest and scrub areas. Around Manacor town and other villages, the remaining land was parcelled out among a myriad of smallholders practicing intensive agriculture partially irrigated, with vegetable gardens and tree orchards combined with vineyards. Land management depending on the peasants' local knowledge, adapted to site-specific conditions and resources, and was always under the baton of the *possession* managers (*amos*) serving the landlords' interests (Tello et al., 2018).

1956, the second year studied, came at the end of a large wave of social and agroecological change starting with the Europe-wide agrarian crisis at the turn of the nineteenth to the twentieth century, which led a large number of Mallorcan landlords into bankruptcy. Many of their *possessions* were appropriated by bankers, who divided them into plots and sold them off to small family peasants (Murray et al., 2019). The decline of large-scale landed property provided an opportunity for the acquisition of more land to a lot of smallholders, who intensified agroecosystem production and dramatically transformed agricultural landscapes. Their intensive farming combined the rain-fed polyculture of dry groves and herbaceous intercropping with the raising of a few animals. Food production was directed to supplying the family's needs, as well as producing some export-oriented crops to pay the annuities on the land

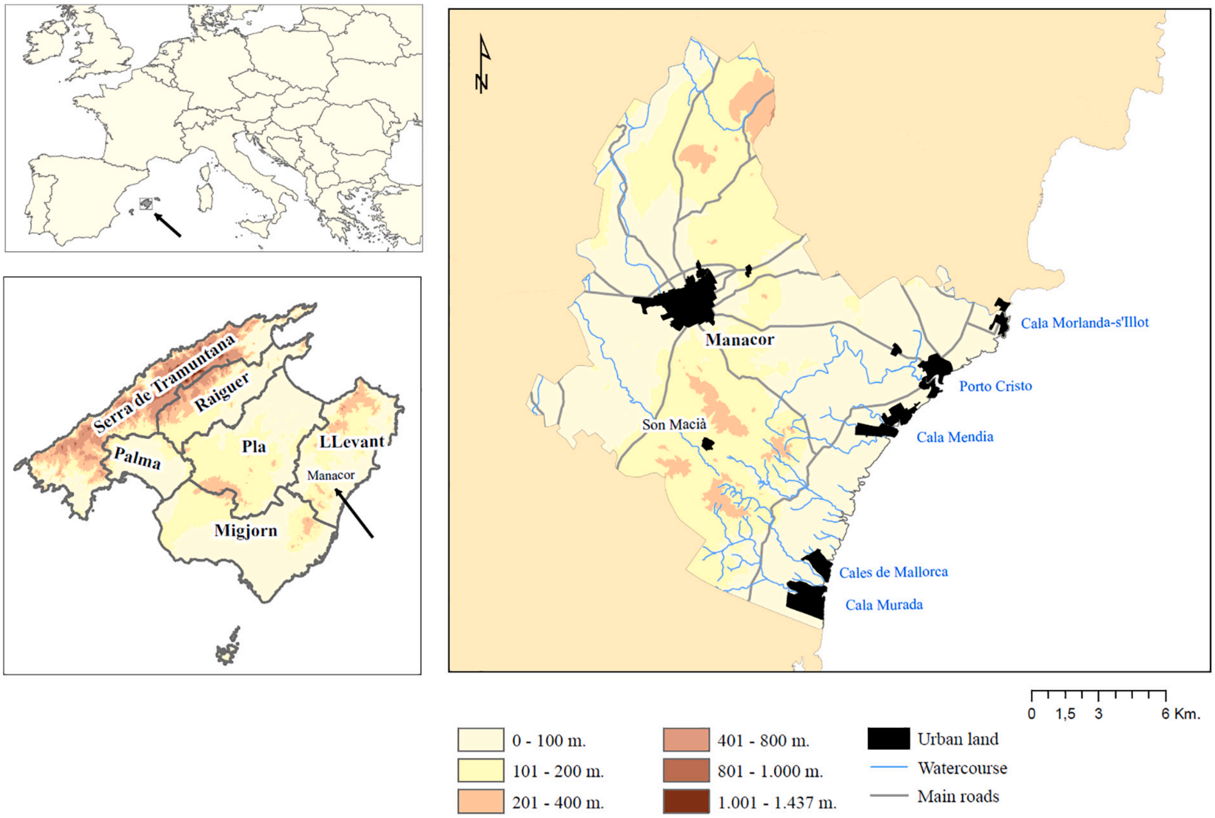


Fig. 1. Case study location. Source: own resources.

mortgage to the bank. From 1900 to 1950 the new agrarian structure integrated the organic management of cropland, livestock and forests with the small-scale, selective adoption of external inputs such as chemical fertilizers, used to supplement traditional fertilization practices: manure, *formiguers* (small kilns burning charcoal on the land to be ploughed into the soil), seaweed, fallow, rotations with legumes, and intercropping with leguminous trees like carobs. Mule-powered treshing and reaping machines began to save human labour in cereal harvesting, but only a few could afford the first oil-powered tractors. Animal traction remained the main draught power and means of transport. Traditional cultivation systems, local seed varieties and domestic livestock breeds were practically the only ones to be found, and firewood was the main fuel for home heating and cooking (Gil-Sánchez et al., 2003; Morro, 2017).

Before the Spanish Civil War (1936–1939) Mallorca had an important industrial development and agrarian intensification (Manera, 1999). In 1956, this change to intensive organic agriculture appears to have reached its limits within the then predominantly solar-based techniques, when the impoverishment created by the autarky of Franco's dictatorship, followed by the massive arrival of tourists from the 1960s onwards, marked a decisive turning point (Murray et al., 2019). Mallorca's touristification was part of Franco's political project in line with international interests. Tourism revenues were diverted to finance the development of industrial and urban poles in Spain's mainland (Murray, 2015). Since then, Mallorca's economy has been oriented towards the service sector, and tourism has become the main driving force of changes in land-use. The Mallorcan countryside suffered a growing devaluation of agricultural, livestock and forest products in a territory where urbanization pressures were increasing the prices for non-agricultural land. In 2012, the last year studied here, Mallorcan agriculture hit rock bottom with the impact of the 2008 financial crisis, despite being a heavily subsidized activity. Ageing rural communities, rising costs and the low prices paid to producers have caused many farmers to quit (Binimelis and Ordinas, 2008). The decline in profitability is also being exacerbated by climate change, which especially affects rain-fed polyculture, an example being the *X. fastidiosa* pest, which has caused massive mortality of old almond and fig trees, itself another symptom of the abandonment of agriculture (Crippa et al., 2021). Only those farms that added value through quality labels closely linked to tourism and exports are able to survive. Since 2016 the government of the Balearic Islands has implemented a public payment scheme to farmers for the maintenance of biocultural landscapes, initiating some economic return from the collection of tourist taxes (Murray et al., 2019).

2.2. Methods of calculation and sources

In this paper, we use the multi-EROI energy accountanting system, already applied to diverse case studies worldwide, to the Manacor agroecosystem (Tello et al., 2016; Galán et al., 2016; Gingrich et al., 2018a; Hercher-Pasteur et al., 2020). This allows us to quantify energy circulation and transformation, the relations between these energy flows, and their role in maintaining reproduction of the agroecosystem's funds (Table 1). For the interpretation of an energy balance, one indicator is not sufficient to explain the functioning of an agroecosystem that have changed profoundly over time. Therefore, we use a more complex set of interrelated EROI indicators as well as all the balances as a biophysical scan of their fund-flow patterns (Marco et al., 2018).

From this systemic view, a single energy flow indicator can be interpreted differently considering the entire fund-flow pattern in the historical context of each agroecosystem . By "funds", we mean the self-reproductive, live components of agroecosystems that supply matter–energy flows to society, provided their own reproductive needs are met. The funds we consider are farmland (including cropland, pastureland and forestland), the livestock–barnyard complex and farm-associated biodiversity, as well as the farming community that

Table 1

General overview of the agroecosystem fund-flow pattern considered. Source: own representation based on Tello et al. (2015, 2016). Note: secondary flows of livestock bioconversion are accounted for, but not added to the Total Consumed Inputs (TIC) to avoid double counting. The cursive text between square brackets specifies the way energy content of material flows (enthalpy) is accounted for. See more details in the Supplementary Material.

Net Primary Production (NPP_{act})	Total photosynthetic biomass produced in one year within the agroecosystem boundaries ($NPP_{act} = LP + UPH$).	
Unharvested Phytomass (*UPH*)	The part of phytomass which remains unharvested and is available to the rest of biodiversity.	
External Inputs (*EI*) [*energy content + embodied energy of transport + embodied energy of machinery amortized in the year (if so)*]	**Labour (*L*)**	Farmers' labour [*as a part of the energy content of their metabolized food intake devoted to work*].
	Societal Inputs (*SI*)	Seeds bought from outside, imported animal feed, farm machinery, fuels, fertilizers, pesticides, and herbicides.
	Farming Community Inputs (*FCI*)	Composted garbage and night soil from the rural community.
Biomass Reused (*BR*) [*only the energy content is accounted*]	**Farmland Biomass Reused (*FBR*)**	Seeds selected and sown within, green manure, biomass buried into soil and biomass burnt in "formiguers".
	Livestock-Barnyard Biomass Reused (*LBBR*)	Feed crops, fodder crops, crop by-products to animal feeding, grass, animal feeding from woodland, stall bedding and others.
Total Produce (*TP*)	**Land Produce (*LP*)**	Phytomass extracted from farmland for human purposes, also called Net Primary Production Harvested (Haberl et al., 2007). *LP* includes cropland, pastureland, and forest/ scrubland products.
	Livestock-Barnyard Produce (*LBP*)	Meat, milk, eggs, leather, wool, bones and others.
Final Produce (*FP*)	The energy that goes to Society in form of consumables ($FP = TP – BR$).	
Total Inputs Consumed (*TIC*)	The amount of energy inputs needed ($TIC = EI + BR$) to keep or renew the funds of an agroecosystem and produce certain level of *FP*.	

manages the agroecosystem and is analytically considered external to it, like the rest of society (see below, Figs. 2, 3 and 4). Using figures for the photosynthetic net primary production carried out within the boundaries of the agroecoystem, a set of flows interlinking these funds can be calculated (Table 1, and the Supplementary Material).

This multi-EROI methodology is displayed in two groups of energy indicators. On the one hand, bioeconomic EROIs are built upon the farmers' notion of energy efficiency, in terms of the energy they obtain per unit of energy they invest (Tello et al., 2015). This is an anthropocentric measure, since the matter–energy flows needed by the other non-domesticated species are considered only indirectly, and it also expresses the point of view of those who aim to make land exploitation more efficient (Guzmán and González de Molina, 2017). On the other hand, agroecological EROIs take into account the efficiency of the agroecosystem as a whole, emphasizing the role of the unharvested biomass that remains in the agroecosystem in maintaining both the remaining biodiversity and ecosystem services (Guzmán and González de Molina, 2017). Both sets of EROI provide information on different dimensions of agroecosystems' fund-flow patterns, showing us the aims of their managers, the effort they made to reproduce their live funds sustainably, their degree of dependence on external sources of inputs, and the throughputs they obtain.

In order to calculate the agricultural energy balances of Manacor in 1860, 1956 and 2012, a large body of information has been collected from a variety of sources (see details in the Supplementary Material). Data availability has conditioned our fixing of agroecosystem boundaries, as well as the selection of time-points. The main records used to reconstruct the energy balances in the mid-nineteenth century are a municipal survey of 224 questions about crops, yields, farm management and labour, compiled in 1850. To validate these data, we cross-checked them with other historical books on agricultural practices and statistics on Mallorca published by the Habsburg-Lorena (1871), Urech i Cifre (1869) and Satorras (1878, 1887, 1890). For the 1956 time-cut, we extracted data from the agricultural census of 1962 and other references, such as Rossello Verger (1964), Bisson (1977) and Bosch i Blanquer (2002). Oral statements from elderly peasants have been used to check some references and estimates. For 2012, we obtained data from the agricultural census of 2009 and the regional statistics of the Balearic Islands (INE, 2011; CMMA, 2013). To convert fresh weight values into energy values, we used the coefficients given in Aguilera et al. (2015) and Marco et al. (2018).

3. Results: Structural changes in agroecosystem funds and flows

Figs. 2, 3 and 4 present Sankey flowcharts of the three energy balances (1860, 1956, 2012). Funds are represented by boxes, and flows are shown as vectors, with a thickness proportional to the GJ per hectare of farmland.

It is apparent that the traditional organic farming of 1860 was less productive in terms of final produce (*FP*) per unit of farmland. However, it was mainly sustained through internal biomass reuse (*BR*), which was larger than the *FP* extracted, while agroecosystem functioning required a very small amount of external inputs (*EI*). The intermediate or mixed organic and industrial farming of 1956 was able to extract larger energy flows per unit of farmland (*FP*) through the land-use intensification of small peasant families. This increase in land produce (*LP*) was mainly obtained through greater biomass reuse (*BR*), with only a slight increase in external inputs (*EI*), on which the agroecosystem was still not overly dependent. By 2012 the farm system had increased further the final produce extracted (*FP*), but only at the expense of a much larger flow of external inputs (*El*) on which the agroecosystem was now highly dependent, while the share of internal *BR* declined. To identify the main drivers behind these systemic changes, we need to examine what was happening within the three flowcharts by decomposing and scanning their components and flows.

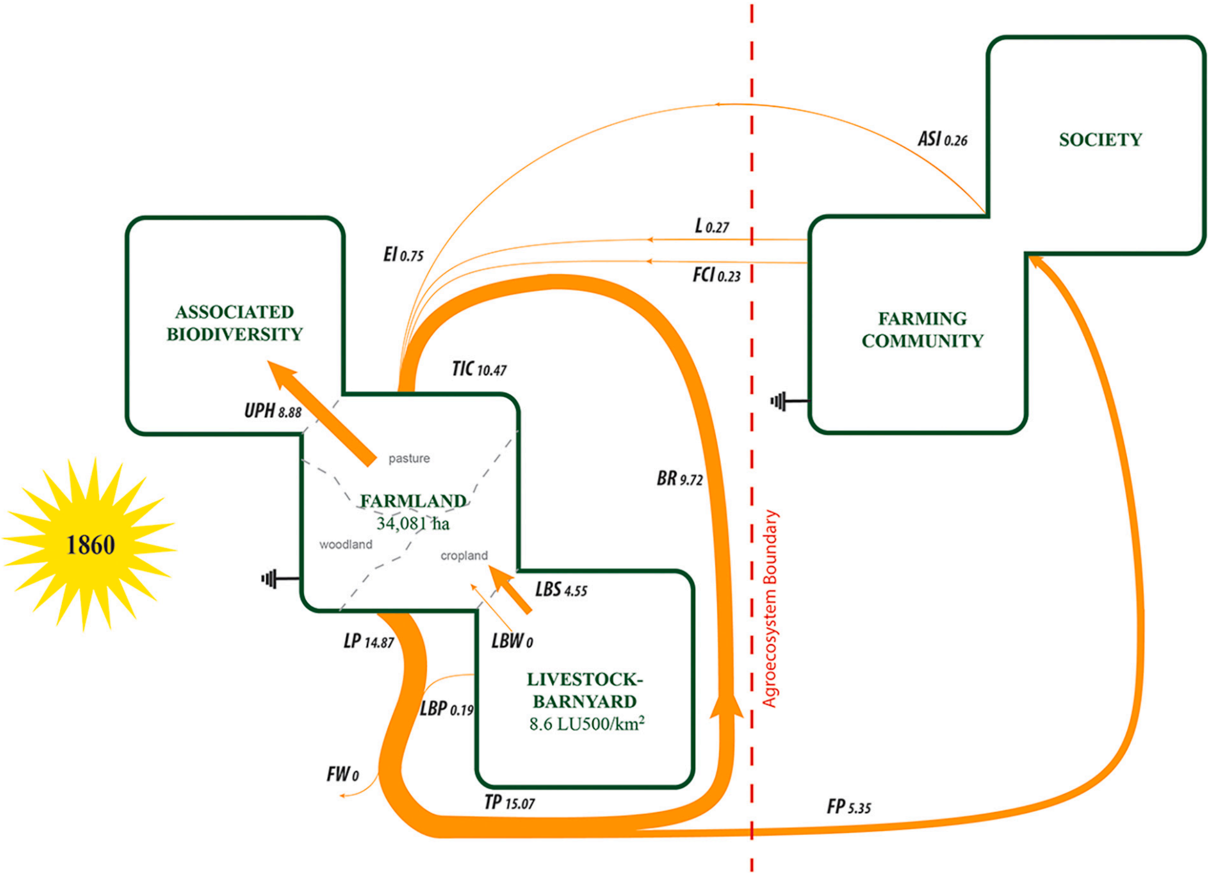


Fig. 2. Flowchart of the energy balance of the agroecosystem of Manacor c. 1860. Flow values in GJ/ha. Source: own representation from different sources referred to in the text.

3.1. Structural changes in the agroecosystem's funds

Along the passage from a landscape dominated by large farms in 1860 to an agroforestry mosaic modelled by a swarm of peasant plots in 1956, there was a significant reduction of forest and scrubland areas in favour of crops, specially the intercropping of almond, carob and fig trees with cereals and pastures (Table 1 of the Supplementary Material). In 2012 this land-use pattern does not seem to have changed much at this scale of analysis, confirming that the traditional biocultural landscape with heterogeneous land-cover mosaics was still in place (Marull et al., 2016). The most salient change between 1956 and 2012 was the increase in "unproductive" land due to the expansion of the city of Manacor and coastal urbanization.

Measured in standardized livestock units (LUs) of 500 kg, in 1860 there was a small livestock density of 8.62 LU500 per km^2 of farmland, similar than in the past (Jover, 2019) and to other Mediterranean agroecosystems in Spain (Marco et al., 2018; Díez et al., 2018; Soto et al., 2016). This figure more than doubled to 18.07 in the mixed organic-industrial farming of 1956, and slightly decreased to 16.03 in the mechanized farming of 2012 (Table 2 of the Supplementary Material).

This long-term change in livestock densities is very different from other case studies of Catalonia (Marco et al., 2018; Díez et al., 2018). Starting from very similar figures in 1860, livestock density in Manacor grew to double or triple the Catalan figures attained in the 1950s. Thereafter, however, by 2012 livestock density had been reduced by 11% in Manacor in relation to 1956, whereas industrial feedlots in 1999 indicated a 27-fold (Vallès) or 25-fold increase (Segarra) in these Catalan counties (Table 3 of the Supplementary Material). A noteworthy feature of the socioecological transition experienced in Manacor is the very low presence of industrial feedlots. The shift towards extensive sheep-grazing instead of pigs and hens fattening in large feedlots has meant the maintenance of a relatively circular, integrated cropland and livestock form of management with significant consequences for the energy performance of this agroecosystem and the corresponding agrocological landscape (Krausmann, 2004).

The population of Manacor grew from 37 inhabit. /km^2 in 1860 to 74 in 1956, and more than doubled to 157 inhabit. /km^2 in 2012. The active agrarian population fell from 10.3 workers/km^2 in 1860 to 4.1 in 2012. However, in 1956 it reached 18.9 workers/km^2 of farmland, highlighting the strong labour intensity of the mixed organic-industrial farm system. Mechanization allowed better working conditions in 2012, but this went hand in hand with the tertiarization of the economy, the shrinkage of Spanish farmers' incomes (González de Molina et al., 2020) and a steady decrease in the agrarian working population (Table 4 of the Supplementary Material).

3.2. Structural changes in the energy flows

From 1860 to 2012 the total photosynthetic land productivity (NPP_{act}/ha of farmland) was multiplied by 2.1 (Table 5 of the Supplementary Material). The 1.8-fold increase up to 1956 was mainly due to cropland expansion, shorter and more intensive rotations, and the planting of dry-nut trees intercropped with grains. These methods were combined with an increase in yields thanks to high biomass reuses (*BR*) into croplands (26.25 GJ/ha, the highest of the three periods studied). External inputs (*EI*) grew considerably compared to 1860, highlighting the addition of significant amounts of industrial fertilizers (1.35 GJ/ha), machinery (0.69 Gj/ha) and electric water-pumping for irrigation (0.21 GJ/ha). Nonetheless, the use of industrial *EI* was still very limited. Then

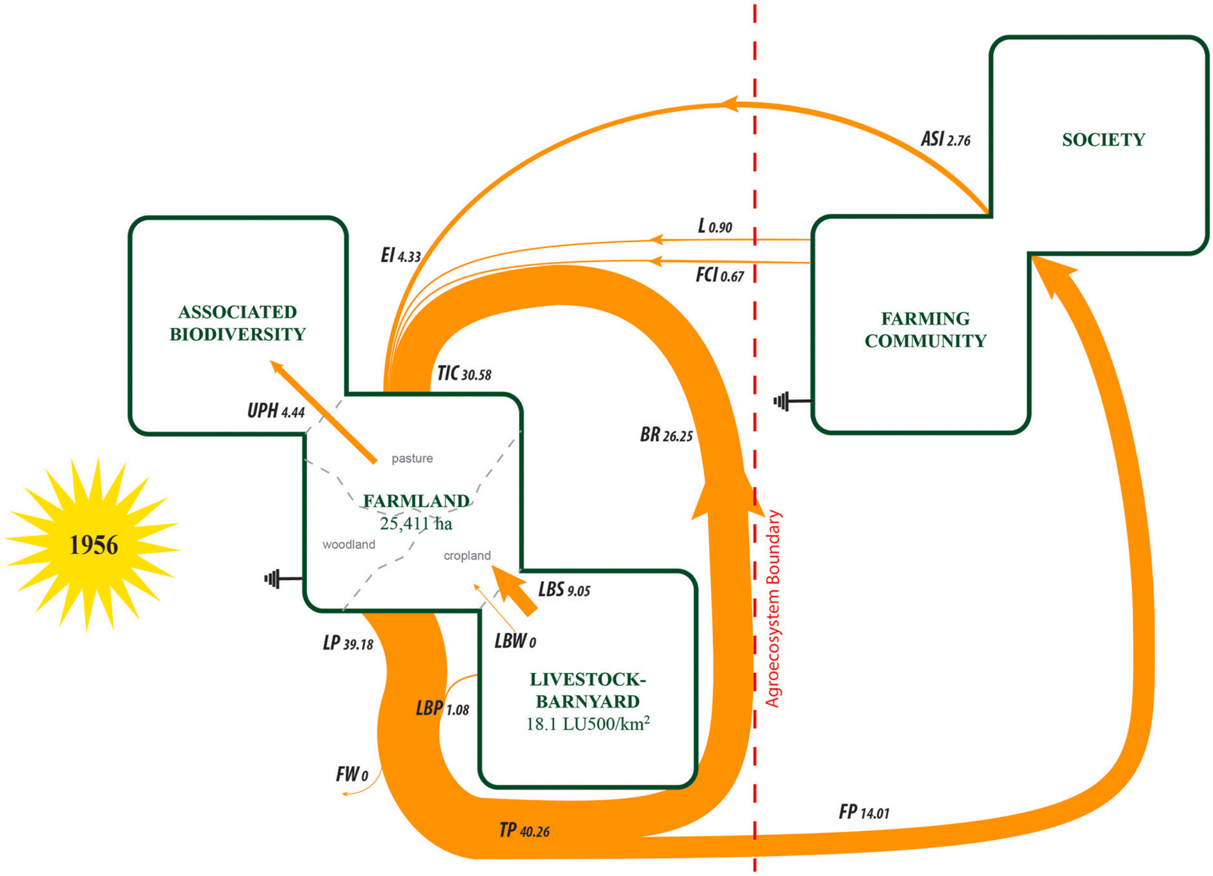


Fig. 3. Flowchart of the energy balance of the agroecosystem of Manacor c.1956. Flow values in GJ/ha. Source: own representation from different sources referred to in the text.

NPP_{act}/ha scarcely increased during the full industrialization of farming from 1956 to 2012, when the total amount of farmland societal inputs (FSIs) experienced a 9.7-fold increase with the spread of tractors and other combustion motors (10.71 GJ/ha), greenhouses (7.30 GJ/ha) and imported animal feed (4.59 GJ/ha). The energy flow of synthetic fertilizers slightly decreased (from 1.35 to 1.15 GJ/ha), while the use of herbicides (0.73 GJ/ha) or the energy spent by industrial feedlots (0.60 GJ/ha) remained relatively low.

In 1860, a large amount of produced biomass was left in the agroecosystem for other non-domesticated species: 37% of biomass was left unharvested, whereas biomass reuse (*BR*) driven by farmers accounted for 41% of all NPP_{act}, meaning that 78% of the photosynthetic biomass produced was left in the agroecosystem. This *BR* flow was only 9.72 GJ/ha in 1860 compared to 26.25 in 1956 and 14.79 in 2012, one of the lowest values of *BR*/ha found among the international cases studied using this methodology so far (Cunfer et al., 2018; Díez et al., 2018; Fraňková and Cattaneo, 2018; Gingrich et al., 2018a; Gingrich and Krausmann, 2018; Guzmán and González de Molina, 2015; Guzmán et al., 2018; Marco et al., 2018; McFadyen and Watson, 2018; Parcerisas and Dupras, 2018). The 14.87 GJ/ha harvested in 1860 also contrasts with the *LP* that reached 39.18 Gj/ha in 1956, when agrarian activity attained its highest intensity with peasant production of a complex polyculture (Fig. 5, and Table 5 of the Supplementary Material).

In 1860 the unharvested phytomass (*UPH*) left available for other species and trophic chains (8.88 Gj/ha) was double the quantity in 1956 (4.44 Gj/ha), when it reached its lowest level because of the pressure from peasant-based intensive polyculture. In 2012 the abandonment of farms led to a significant increase in *UPH* (14.4 Gj/ha). The structural changes that separated the agroecosystem funds from one another extensively modified the character and role of these reused (*BR*) and unharvested (*UPH*) flows. Currently, a large amount of by-products such as straw (*BR*) are left on the fields because the collection cost is higher than their market value, whereas reforestation accumulates too much *UPH* that spreads wildfires in the unmanaged woodland and scrubland.

The total produce (*TP*) resulting from the sum of land produce (*LP*) and livestock-barnyard produce (*LBP*) was multiplied by 2.7, from 15.1 to 40.3 GJ/ha throughout the 150 years studied. However, about two-thirds of this was reinvested in the agroecosystem until 1956, whereas these *BR* flows fell to just one-third in 2012. Therefore, in 1956 Mallorcan farmers were returning the same proportion of energy to the agroecosystem that their ancestors had done in 1860 (64.5%, or 65.2% of *TP*). This means that, despite the socioeconomic and technological changes, traditional biocultural knowledge was still being applied one hundred years later.

However, livestock densities doubled from 1860 to 1956. In order to reduce the competition for land between animal feeding and human food, in 1956 livestock was fed to a large extent by reusing crop by-products, which grew from 2.63 Gj/ha to 5.16 and was obtained from a combination of woody crops (e.g. almond and fig trees) intercropped with cereals. Cropland expansion reduced animal feeding on fallow land and weed pastures from 2.65 to 1.09 GJ/ha, which was compensated for by increasing livestock grazing in woodland from 0.99 to 3.12 GJ/ha. All biomass reuses (*BR*) were multiplied by 2.7, from 9.7 GJ/ha in 1860 to 26.3 in 1956 (Fig. 5, and Table 5 of the Supplementary Material).

The *FP* extracted from the agroecosystem grew from 22% in 1860 to 30% of the photosynthetic biomass produced in 1956 by increasing biomass reuse from 41% to 60%. This strengthened the links between the agroecosystem funds, the agroecosystem's complexity and landscape heterogeneity (Marull et al., 2015). Agroecological intensification also required a lot of human labour and available sources of biomass, which

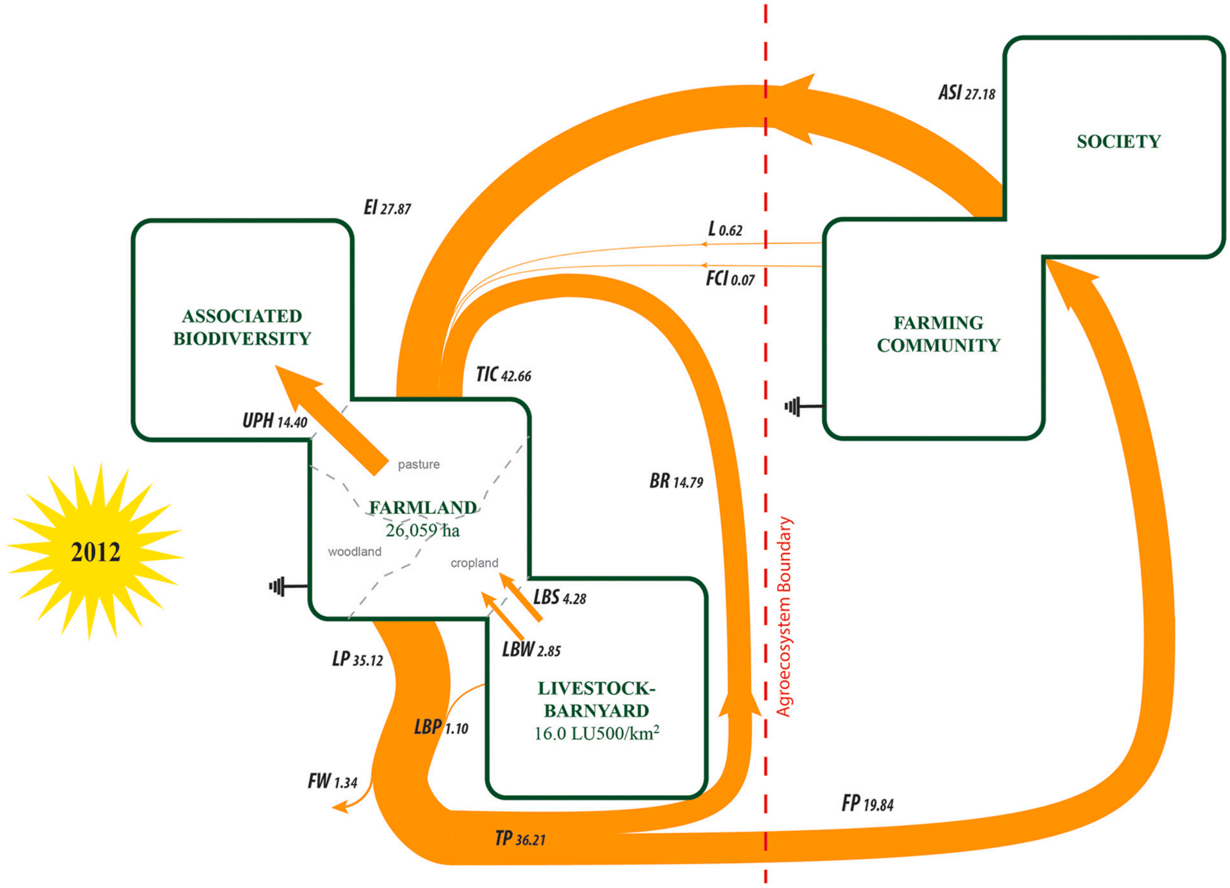


Fig. 4. Flowchart of the energy balance of the agroecosystem of Manacor c. 2012. Flow values in GJ/ha. Source: own reproduction from different sources referred to in the text.

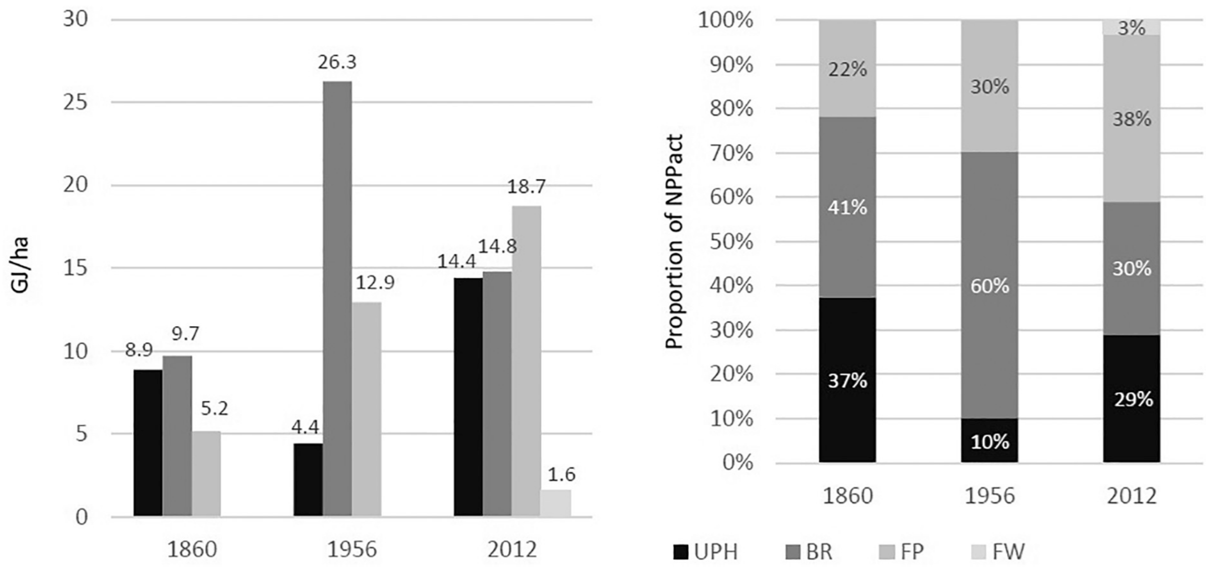


Fig. 5. NPP_{act} flow composition, expressed in GJ/ha and percentage values of NPP_{act}, in Manacor (1860–1956-2012). UPH = Unharvested Phytomass; BR = Biomass Reused; FP = Final Produce; FW = Farmland Waste. Source: own representation. See the Supplementary Material.

were becoming increasingly scarce for the peasant smallholders. Despite their strong efforts, the functioning of the agroecosystem already required a certain amount of external fossil fuel-based inputs (*ASI*) to supplement organic farm management: 2.76 GJ/ha, compared to 0.26 in 1860. This amount was ten times smaller than the *ASI* used in 2012 (Table 5 of the Supplementary Material), but it reveals the growing agroecological stress due to the high land-use intensification achieved.

Another Mallorcan peculiarity can be seen by comparing the different content of *BR* flows. The proportion of energy reinvested in livestock fell from 81% in 1860 to 67% in 2012. In 1860, half of this

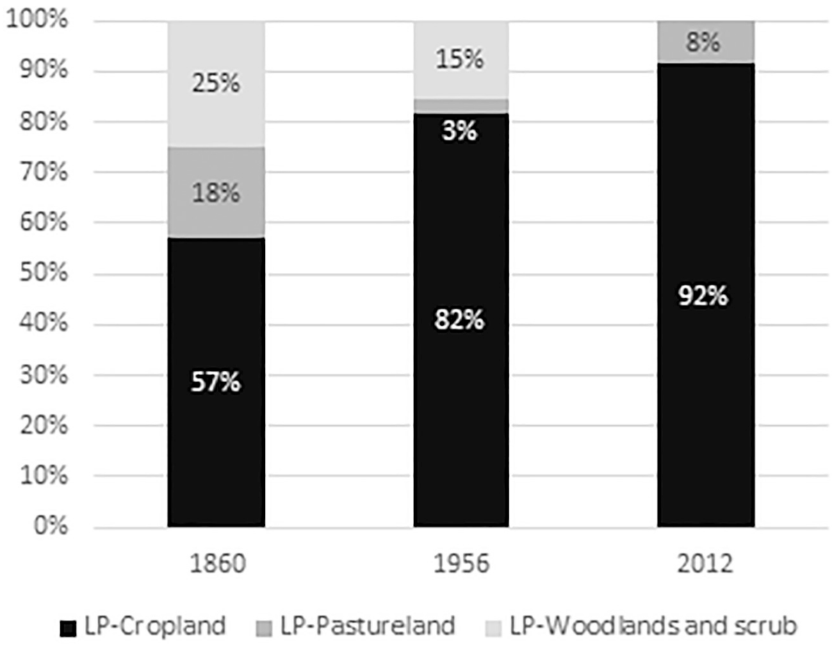


Fig. 6. Origin of land produce (LP) in the Manacor agroecosystem in 1860, 1956 and 2012. Source: own representation, from sources referred in Supplementary Material.

consisted of crop by-products and weeds for grazing. In 1956, the main source of animal feed was grain crops, in addition to crop by-products. By 2012, the extensive sheep grazing of stubble and weeds had been recovered and fodder crops had been introduced, many of them using irrigation. The main source of animal feeding continues to be livestock-oriented crops (*LBBR*), despite their being supplemented by feed bought in from outside the agroecosystem (*LBSI*). This level of feed crops is 30% lower than in 1956, indicating that Manacor has not followed the same path from food to feed-oriented cropping as other Spanish areas (Soto et al., 2016; Padró et al., 2017; Díez et al., 2018; González de Molina et al., 2020).

What Manacor's land managers, whether landlords or farmers, extracted from the agroecosystem has also changed completely (Fig. 6). In 1860, with a population density of only 37 inhabit. /km^2, 57% of the harvested biomass came from cropland and the rest from forest, scrub and fallow pastures. Then cropland harvesting grew by up to 82% in 1956, with 74 inhabit./km^2, meaning an intense agriculturalization that was more related to the market-oriented specialization of the area than to the local requirements of Manacor's inhabitants. In 2012, 92% of biomass was being extracted from cropland as a result of the forestland being abandoned. This describes a transition from a multifunctional agroecosystem that integrated different land uses through a high circulation of energy flows to a more disintegrated system.

Due to the higher energy content of wood compared to food per unit of weight, in 1860 final produce (*FP*) consisted of 44.8% of biomass from forests and scrubland, and 33.5% of cereals and legumes sold to the market. These proportions changed in 1956 as a result of the spread of peasant polyculture: 24.6% of *FP* consisted of wood pruned from tree crops, firewood from forests (18.8%), almonds, carobs and figs (9.8%), and only 9.4% of cereals and legumes. This productive diversification increased smallholders' resilience to bad harvests and market fluctuations, compared to the simpler and more extensive agroecosystem maintained by landlords in 1860. In 2012 the proportion of marketed cereals and legumes stood at 35.2%, followed by 26.8% of straw and other by-products for animal feed, and 14.5% of wood from pruning and felled crop trees (Murray et al., 2019).

The livestock-barnyard produce (*LBP*) experienced a five-fold increase from 1860 to 1956, the latter level being maintained till the present day. The big difference is that in 1860 livestock was fed from sources available in the Manacor agroecosystem (*LBBR*), while later the external input of livestock-barnyard societal inputs (*LBSI*) acquired more relevance. The *LBBR*:*LBSI* ratio shifted from 221:1 in 1860 to 2:1 in 2012 due to the increase in feed imports. This decoupling of animal feeding from the land is in line with what has taken place all over Spain (González de Molina et al., 2020), but it has been much lower in Manacor due to the insignificant spread of industrial feedlots compared to other Mediterranean agroecosystems (Díez et al., 2018; Marco et al., 2018). The partial energy efficiency of the livestock-barnyard subsystem, calculated by the energy content of livestock products (*LBP*) and Livestock-barnyard services (*LBS*) per unit of the total inputs consumed in the bioconversion, was 60% in 1860 and 1956, but only 36% in 2012. This clearly shows that the replacement of animal traction by tractors involved a loss of livestock multifunctionality that was key to the eco-efficient integration of animal feeding with farming in the organic agriculture of the past (Tello et al., 2016).

Agroecosystem societal inputs (*ASI*) grew 104 times during the whole period due to the incorporation of machinery, agrochemicals, imported seeds, electricity and greenhouses. In 2012 *ASI* were ten times larger than in 1956. Indeed, *ASI* account for 98% of all the *EI* spent in 2012, far above the 35% of 1860 or 64% of 1956. This increase in *EI* flows has taken place despite some decreases experienced at the same time in the embodied energy per unit of external input thanks to energy-efficiency improvements in their manufacture and delivery, indicating a clear rebound effect of the so-called Jevons paradox: the efficiency gains in production have been reversed by greater increases in consumption (Aguilera et al., 2015). In 1956 fertilizers, herbicides, machinery, fossil fuels and electricity for irrigation already represented 52% of the *EI* flows, a figure that reassesses the still mixed organic-industrial character of that peasant polyculture compared to the 79% of 2012. Currently, the *EI* flows entering Manacor's agroecosystem are more than half its NPP$_{act}$. This shows to what extent conventional farming has become dependent on fossil fuels, even though in Manacor this has happened at a lower level than in other places like the Catalan Vallès County, where the equivalent figure is 1.6 times greater that the entire photosynthetic production (Tello et al., 2016).

Human labour (*L*) fell from 35% of the whole *EI* flow in 1860 to 21% in 1956 and only 2% in 2012 (Table 6 and Fig. 1 of the Supplementary Material). Although the two earlier farm systems were more labour-intensive, especially in 1956, the energy invested in labour in absolute terms was 8.6 times higher in 2012 than in 1860. This is due to the greater amount of embodied energy required in the production, processing, preservation and transportation of human food, and the change to diets with much more meat consumption (Cussó and Garrabou, 2010; Infante-Amate and González de Molina, 2013; Infante-Amate et al., 2018). Therefore, shifting towards lower meat and dairy products would have major implications for the energy flows of agroecosystems and the future of agriculture (Godfray et al., 2018).

Labour and other farmland inputs provided by the local community (composted garbage, night soil, etc.) accounted for 65% in 1865, 36% in 1956 and only 2% in 2012 (Fig. 1 of the Supplementary Material), demonstrating the loss of self-reliance and the agroecosystem's growing external dependence.

3.3. *Multi-EROI results*

As the Table 2 shows, final EROI *(FEROI)* reached a comparatively higher level of system efficiency in 1860, when, for each energy unit introduced into the agroecosystem, 0.51 units of final produce (*FP*) were extracted. This final efficiency slightly fell to 0.46 in 1956 and 0.47 in 2012. The same happened with the NPP_{act} *EROI*. Although reinforcing the conclusion that there has been a general trend in western agriculture to reduce the energy efficiency of farm systems (Gingrich et al., 2018a), Manacor's *FEROI* reduction is the lowest in comparison to the other case studies in Catalonia or the whole of Spain (Díez et al., 2018; Guzmán et al., 2018; Marco et al., 2018). This confirms the precarious continuity of the Mallorcan biocultural heritage of traditional organic farming through a limited and selective adoption of the external inputs of the Green Revolution (Murray et al., 2019).

In 1860 the *EFEROI* was quite low in Manacor (7.09) compared to the Catalan municipalities of the Vallès (21.53) and Segarra (19.14) counties at that time, or even to Spain as a whole in 1900 (17.26). The *IFEROI* in 1860 (0.55) was also very low, again far from the Catalan Vallès figure in 1860 (1.13) or Spain in 1900 (0.82) (Marco et al., 2018; Guzmán et al., 2018). However, it was closer to the arid grain-growing county of La Segarra (0.71) in Catalonia (Díez et al., 2018).

The comparatively low *FEROI* and *EFEROI* values for Manacor in 1860 can be explained with reference to three factors: first, the arid or semi-arid edafoclimatic conditions that involve low yields in cropland and forestry (Yousefi et al., 2020); secondly, a greater area of forest and scrubland used extensively for grazing livestock, cutting firewood and hunting; and third, the extensive crop rotations, with only one harvest every three or four years, since the amount of arable land was not a limiting factor in the landlord's system. Meanwhile, the low *IFEROI* is evidence of the great efforts made to recirculate biomass into the agroecosystem in order to maintain reproduction of its funds, which also contributed to the low joint final return (*FEROI*). This recirculation of energy was then mainly produced by livestock (81% of *BR*), a strategy that fits with the landowners' objective of saving wages through extensive farming (Jover and Morey, 2003). These socioeconomic conditions, combined with the poor natural resource endowment, meant a much lower figure for total produce (*TP*) in 1860 (Table 5 of the Supplementary Material): 15.07 GJ/ha in Manacor, compared to 42.0 in the Catalan municipalities of the Vallès, or 31.2 in La Segarra (Díez et al., 2018; Marco et al., 2018).

Table 2

Values of the Bio-economic EROI and the Agroecological EROI indicators. Source: own representation based on Table 5 of the Supplementary Material.

Bio-economic EROI indicators	**1860**	**1956**	**2012**
FEROI ($\frac{FP}{BR+EI}$)	0.51	0.46	0.47
EFEROI ($\frac{FP}{EI}$)	7.09	3.24	0.71
IFEROI ($\frac{FP}{BR}$)	0.55	0.53	1.34
NPP_{act}EROI ($\frac{NPPact}{BR+EI}$)	2.27	1.43	1.16
NPP_{act}EROI - Final EROI	1.76	0.97	0.66
FEROI on Labour ($\frac{FP}{L}$)	20.15	15.54	32.13
Agroecological EROI indicators	**1860**	**1956**	**2012**
NPP_{act}EROI land ($\frac{NPPact}{UPH+BR+EI}$)	1.23	1.25	0.87
AFEROI ($\frac{FP}{UPH+BR+EI}$)	0.28	0.40	0.35
Biodiversity EROI ($\frac{UPH}{UPH+BR+EI}$)	0.46	0.13	0.25
HANPP ($\frac{TP}{NPPact}$)	63%	92%	73%

The subsequent reduction in energy returns with the transition to a mixed organic–industrial farming system in 1956 was also among the smallest of those that have been found (Cunfer et al., 2018; Díez et al., 2018; Fraňková and Cattaneo, 2018; Gingrich et al., 2018a; Gingrich and Krausmann, 2018; Guzmán and González de Molina, 2015; Guzmán et al., 2018; Marco et al., 2018; McFadyen and Watson, 2018; Parcerisas and Dupras, 2018). The slow pace in the decline in agricultural energy returns continued even during the following transition to a fossil fuel-based agriculture. In Manacor *EFEROI* fell to 0.71 in 2012, against 0.25 in the Vallès County, but more comparable to the 0.55 of La Segarra in Catalonia in 1999. *IFEROI*, in turn, grew to only 1.34 against 2.25 in the Vallès and 4.28 in La Segarra. The joint *FEROI* fell to 0.47, compared to 0.22 in the Vallès and 0.49 in La Segarra (Díez et al., 2018; Marco et al., 2018).

Several aspects also stand out from the agroecological multi-EROI evaluation. The NPP_{act} *EROI land* assesses the biological photosynthetic production attained by the agroecosystem per unit of the total energy invested or reinvested, together with the amount of unharvested biomass. This was quite high in 1956 (1.25) and again in 1860 (1.23), but fell by a third in 2012 (0.87). This fall can be attributed to a loss of productive and reproductive capacity on the part of the agroecosystem as a result of the degradation of funds experienced, alleviating which requires greater amounts of energy to be invested (Guzmán and González de Molina, 2017).

The lower energy final produce (*FP*) obtained in 2012 per unit of energy recirculated (*AFEROI*) has a lot to do with land having been abandoned under the current tourist-based economy. This contrasts with the intensity of land-use practised by small peasants in 1956, while the lowest value obtained in 1860 denotes the extensive management applied to large *possessions*. This is confirmed by the other side of the coin, the appropriation by farming of the biomass produced by photosynthesis (*HANPP*). This amounted to 63% in 1860 but increased to 92% with the industrial-agroecological intensification that followed the turn to peasantization in 1956, the lowest share left available for other non-domesticated species and trophic chains. The same happens with the proportion of unharvested phytomass in the whole internal turnover of the agroecosystem, which is accounted for by the *Biodiversity EROI*, which fell from 0.46 in 1860 to 0.13 in 1956, only to experience a slight recovery to 0.25 in 2012. The whole set of agroecological EROIs clearly shows that the associated peasant polyculture of herbaceous and tree crops reached a point of stress in 1956. Manacor's agroecosystem could be understood as an expression of a "constrained productivism" (Short and Winter, 1999), characterized by multi-functional landscapes providing quality food and high levels of biodiversity. Nonetheless, in 2012 the decline in agroecological EROIs is an evidence of a serious degradation of the agroecosystem's funds despite the maintenance of an important biocultural heritage.

4. Discussion: the social fabric underpinning the agroecosystem's energy performance

The most salient feature of the agrarian social metabolism of Manacor in 1860 was the low values for land produce (14.87 GJ/ha) and total produce (15.07 GJ/ha, including animal products) when compared to those found in other traditional organic agroecosystems around the Mediterranean in the same period (e.g. 42.0 or 31.2 GJ/ha of TP in the Catalan Vallès and Segarra counties). The low land-use intensity of Mallorcan farming also explains the low HANPP (63%), and the comparatively high level of phytomass left unharvested for other non-domesticated species (8.88 GJ/ha), which, combined with a relatively high effort to reuse biomass (9.72 GJ/ha), meant a quite balanced form of agroecosystem management. Adding *BR* and *UPH* flows (18.60 GJ/ha) indicates an internal recirculation of matter–energy devoted to reproducing agroecosystem funds (soil fertility, livestock and farm-associated biodiversity) 3.5 times greater than the final product extracted. All this is evidence of the environmental "sustainability" of this agrarian system, maintained for the benefit of a handful of landlords who had accumulated much of the farmland by 1860.

However, considering this a truly sustainable farm system would mean neglecting another key agroecosystem fund: the peasant community. That form of extensive agriculture was pursued by the landowners, who monopolized much of the land and forced many poor peasant families to offer their labour in a market where wages remained very low. That is, it was accompanied by a highly unequal agrarian class structure that must be considered unsustainable in itself (Tello et al., 2018; Murray et al., 2019). The 1956 results emphasize that the previous limits reached by the extensive form of farm management of 1860 were not simply agroecological, but social, being a matter of the concentration of power and wealth. The comparison between the socio-agroecological profiles of 1860 and 1956 demonstrates that there was room to intensify land and livestock uses by disseminating the polyculture of small farmers. Most of the agricultural landscapes of the island that are now considered so appealing to tourists were created during the turn to peasantization (Bisson, 1977).

At the same time, however, the results also show the agroecological limits of this form of agricultural intensification that were reached through a more equitable agrarian pathway. The fall in the energy return on labour (from 20.15 GJ per labour-energy unit in 1860 to 15.54 in 1956) makes clear the extraordinary labour intensity that the land redistribution path required, something that makes the opposition of the large landowners to following this road as long as they continued to rule this agrarian society more understandable, though it does not justify it. The energy balance in 1956 also provides evidence of the strong environmental stress that was then occurring: 92% of HANPP, with only 4.44 GJ/ha of unharvested phytomass, meant that it was only because small peasants actively reused a very large amount of biomass that the internal recirculation amounted to 26.25 GJ/ha, reflecting the attempt to sustain the extraction of 14.01 GJ/ha of final produce from the agroecosystem (Table 5 of the Supplementary Material). These signs of environmental stress were not simply due to having reached some absolute agroecological limits, as here too they were socio-agroecological limits. The Mallorcan turn to peasantization was driven by top-down land redistribution by the commercial and financial bourgeoisie, not a bottom-up social land reform driven by law. Many family farmers obtained better access to land, but at the price of paying a very expensive annuities for very long time periods to the same banks who sold the land to them, which obliged them to intensify their use of land, livestock and labour far beyond what would have been required simply to meet their own needs (Murray et al., 2019).

Another salient feature of Manacor's agrarian energy balances is the less pronounced fall experienced in 2012 compared to all the comparative multi-EROI studies performed so far. In Manacor the industrialization and mechanization of farming led to the same types of structural change in the fund-flow patterns of agroecosystems as elsewhere: the declines in cropping, forestry and livestock, the abandonment of forests and scrubland, the increasing linearity of energy throughputs, and greater dependence on inputs of industrial energy. This also implied a decline in the value-added retained by farmers compared to the income concentrated by the big corporations that sold these inputs to them and traded their products to the final consumer through ever larger and more global agrifood chains (Dorward, 2013; Tello and González de Molina, 2017). Yet, all these common features of fossil fuel-based agriculture had a lower impact in Manacor than in other Mediterranean case studies (Díez et al., 2018; Marco et al., 2018; Padró et al., 2017).

The milder impacts of conventional agriculture and the lower decrease in the corresponding EROIs explain the early but slow and partial adoption of the Green Revolution technological package by Mallorcan family farmers. The higher price of land due to urbanization and the jobs offered by tourism and derived services both grew so rapidly that farmers experienced faster and stronger marginalization than in the rest of Spain. Those families that continued to farm did so with the aim of keeping their lands in good agricultural condition in order to maintain a family patrimony that had been difficult to acquire. Many of them could only do this as a part-time activity due to the low economic profitability of traditional Mallorcan farms in a global market. All this explains why they were not eager to buy too many synthetic fertilizers, which reduced their weight from 1.35 to only 1.15 GJ/ha from 1956 to 2012, or to spread the vegetables they were going to eat with agrochemicals (Murray et al., 2019). They adopted tractors, but were not too interested in investing in big feedlots for fattening animals with imported feed. The continuation of the extensive rearing of sheep and goats also meant maintaining some degree of integration and biophysical circularity in the polycultural peasant agroecosystem. Our results provide new empirical verification of the maintenance of a biocultural heritage that is still recognizable in the agricultural landscapes of Mallorca (Marull et al., 2015, 2016) – so recognizable, indeed, that it has been widely used as an intangible asset in the marketing of this global tourist hotspot.

However, our multi-EROI results also indicate that this Mediterranean farm system has experienced a loss of energy efficiency as a result of the degradation of its funds, which has damaged its capacity to both produce agrifood goods and reproduce the agroecosystem. This is becoming a dangerous scenario at a time when a greater degree of sustainability and food sovereignty have to be achieved in order to tackle a global crisis marked by climate change and new pandemics (Gössling et al., 2020; Manzanedo and Manning, 2020). Currently, only 15% of food consumed is locally made (GOIB, 2020). Therefore, Mallorcan farmers will only be able to increase the food sovereignty of the island if their economic marginalization is overcome through a profound change in the socioeconomic model that entails a tourist degrowth and a rural renaissance. To that aim, public policies must be reinforced to upgrade the landscape by scaling up current agroecology farming as an integrated territory that again relies on peasants' local knowledge, resources and genetically rich heritage (Agnoletti and Rotherham, 2015; Koohafkan and Altieri, 2011).

5. Conclusion

In this paper, we have described the socioecological transition of the Mediterranean agroecosystem of Manacor by means of the agricultural energy balances of 1860, 1956 and 2012, which we have used to analyse how the biophysical flows provided by their living funds, and reinvested in them for their reproduction, have deeply changed in accordance with the prevailing social fabric and economic goals that have ruled the island of Mallorca. The results show some similarities and many differences between the agroecosystem's performance in the traditional organic farming of 1860 and the mixed organic–industrial farming of 1956. A common feature was keeping the internal reinvestment of matter–energy, either as biomass reused or biomass left unharvested, comparable or larger than the final product extracted. This was an important condition for the sustainable reproduction of those traditional organic agroecosystems that meant a very low level of dependence on external inputs. Beyond that, the extensive grain-growing regime of management that prevailed in 1860 under the rule of a handful of landowners contrasted with the intensive polyculture of many smallholders who cropped cereals associated with dry fruit trees after the turn to peasantization from the end of the nineteenth century to 1956. The intensification of peasant land-use doubled the amount of final produce and tried to compensate for this by a high increase in the biomass reused through a mixed organic-industrial farming system that reached the then prevailing socio-agroecological limits under the heavy burden of paying for land to the bankers who had set the redistribution of land in motion.

The fossil fuel-based farming of 2012 inherited many biocultural traits from that organic past, such as the associated crops, the integrated use of sheep to fertilize them, local varieties and domestic breeds of livestock, agricultural landscapes and traditional knowledge of how to manage the agroecosystem. It also inherited the consequences of the agroecological stress that the functioning of this intensive polyculture had reached. The maintenance of a large part of this agricultural heritage has only been possible thanks to the selective and partial adoption of the external inputs provided by the Green Revolution. This feature has been paradoxically linked to the rapid marginalization of agriculture in what has become a globalized tourist hotspot. Now Mallorca finds itself at a crucial, historical crossroads: either to let this biocultural heritage die, or to start regenerating it to open the way to a more diversified and less unsustainable agrifood model.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was supported by the international Partnership Grant SSHRC-895-2011-1020 funded by the Social Sciences and Humanities Research Council of Canada and two coordinated Spanish projects, RTI2018-093970-B-C32 and C33 (MCIU/AEI/FEDER, UE). We want to give a special thanks to Geoff Cunfer for his help in the Sankey diagrams.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2021.107206.

References

Agnoletti, M., Rotherham, I.D., 2015. Landscape and biocultural diversity. Biodivers. Conserv. 24, 3155–3165. https://doi.org/10.1007/s10531-015-1003-8.

Aguilera, E., Guzmán Casado, G., Infante Amate, J., Soto Fernández, D., García Ruiz, R., Herrera, A., Villa, I., Torremocha, E., Carranza, G., González de Molina, M., 2015. Embodied energy in agricultural inputs. Incorporating a historical perspective. DT-SEHA 1507. http://repositori.uji.es/xmlui/bitstream/handle/10234/141278/DT-SEHA%201507.pdf?sequence=1&isAllowed=y.

Altieri, M.A., 2018. Agroecology: The Science of Sustainable Agriculture. CRC Press, Boca Raton.

Altieri, M.A., Nicholls, C.I., 2012. Agroecology scaling up for food sovereignty and resiliency. In: Lichtfouse, E. (Ed.), Sustainable Agriculture Reviews. Springer, Dordrecht, pp. 1–29. https://doi.org/10.1007/978-94-007-5449-2_1.

Antrop, M., 2005. Why landscapes of the past are important for the future. Landsc. Urban Plan. 70 (1–2), 21–34. https://doi.org/10.1016/j.landurbplan.2003.10.002.

Binimelis, J., Ordinas, A., 2008. La pagesia illenca als albirs del segle XXI. Agricultura i postproductivisme a les Illes Balears. El Gall Editor, Pollença.

Bisson, J., 1977. La Terre et l'Homme aux Îles Baléares. Édisud, Aix-en-Provence.

Bosch i Blanquer, T., 2002. Foravila segle XX. Ajuntament de Manacor, Gràfiques Muntaner, Manacor.

CMAA [Conselleria de Medi Ambient i Agricultura] 2013. Estadístiques agràries i pesqueres 2011. Serveis de Millora Agrària (SEMILLA). Govern de les Illes Balears, Palma.

Crippa, M., Solazzo Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food 2, 198–209. https://doi.org/10.1038/s43016-021-00225-9.

Cunfer, G., Watson, A., McFadyen, J., 2018. Energy profiles of an agricultural frontier: the American Great Plains, 1860–2000. Reg. Environ. Chang. 18 (4), 1021–1032. https://doi.org/10.1007/s10113-017-1157-x.

Cussó, X., Garrabou, R., 2010. La globalización de la dieta en España en el siglo XX. X Congreso Español de Sociología, Public University of Pamplona, Pamplona.

Díez, L., Cussó, X., Padró, R., Marco, I., Cattaneo, C., Olarieta, J.R., Garrabou, R., Tello, E., 2018. More than energy transformations: a historical transition from organic to industrialized farm systems in a Mediterranean village (Les Oluges, Catalonia, 1860–1959–1999). Int. J. Agric. Sustain. 16 (4–5), 399–417. https://doi.org/10.1080/14735903.2018.1520382.

Dorward, A., 2013. Agricultural labour productivity, food prices and sustainable development impacts and indicators Food Policy 39, 40–50. https://doi.org/10.1016/j.foodpol.2012.12.003.

Duncan, J., Rivera-Ferre, M., Claeys, P., 2020. The Importance of Food Sovereignty for the Farm to Fork Strategy and the New Green Deal. Insights and limits of the SAM and SAPEA reports, Academic Brief. Available at: https://www.foodsovereignty.org/wp-content/uploads/2020/05/Academic_Brief_F2F_20200514_FINAL_ENG.pdf (accessed Sept. 21, 2020).

European Comission, 2020. Farm to Fork Strategy – for a fair, healthy and environmentally-friendly food system. Available at: https://ec.europa.eu/food/farm2fork_en. (Accessed 10 June 2020).

FAO, 2018. Scaling up Agroecology Initiative: Transforming Food and Agricultural Systems in Support of the SDGs. FAO, Rome. http://www.fao.org/3/I9049EN/i9049en.pdf. (Accessed 18 January 2020).

Font, C., Padro, R., Cattaneo, C., Marull, J., Tello, E., Alabert, A., Farré, M., 2020. How farmers shape cultural landscapes. Dealing with information in farm systems (Valles County, Catalonia, 1860). Ecol. Indic. 112, 106104. https://doi.org/10.1016/j.ecolind.2020.106104.

Fraňková, E., Cattaneo, C., 2018. Organic farming in the past and today: sociometabolic perspective on a central European case study. Reg. Environ. Chang. 18 (4), 951–963. https://doi.org/10.1007/s10113-016-1099-8.

Fullana, O., 2019. L'agroecosistema manacorí al llarg dels darrers 150 anys. Evolució del paisatge com a expressió dels canvis en l'activitat agraria i la propietat de la terra (1860-2012). X Jornades d'Estudis Locals de Manacor. 13 i 14 d'abril de 2018, coord. Antoni Ferrer Febrer, pp. 17–37.

Galán, E., Padró, R., Marco, I., Tello, E., Cunfer, G., Guzmán, G.I., González de Molina, M., Krausmann, F., Gingrich, S., Sacristán, V., Moreno-Delgado, D., 2016. Widening the analysis of Energy Return on Investment (EROI) in agro-ecosystems: socio-ecological transitions to industrialized farm systems (the Vallès County, Catalonia, c. 1860 and 1999). Ecol. Model. 336, 13–25. https://doi.org/10.1016/j.ecolmodel.2016.05.012.

Georgescu-Roegen, N., 1971. The Entropy Law and the Economic Process. Harvard University Press, Cambridge.

Gil-Sánchez, L., Valdés, C.M., Díaz-Fernández, P., 2003. La transformación histórica del paisaje forestal en las islas Baleares. Ministerio de Medio Ambiente, Madrid.

Gingrich, S., Krausmann, F., 2018. At the core of the socioecological transition: Agroecosystem energy fluxes in Austria 1830–2010. Sci. The Total Environ. 645 (15), 119–129. https://doi.org/10.1016/j.scitotenv.2018.07.074.

Gingrich, S., Cunfer, G., Aguilera, E., 2018a. Agroecosystem energy transitions: exploring the energy-land nexus in the course of industrialization. Reg. Environ. Chang. 18 (4), 929–936. https://doi.org/10.1007/s10113-018-1322-x.

Gingrich, S., Theurl, M.C., Erb, K., Krausmann, F., 2018b. Regional specialization and market integration: agroecosystem energy transitions in Upper Austria. Reg. Environ. Chang. 18 (4), 937–950. https://doi.org/10.1007/s10113-017-1145-1.

Godfray, H.C.J., Aveyard, P., Garnett, T., Hall, J.W., Key, T.J., Lorimer, J., Jebb, S.A., 2018. Meat consumption, health, and the environment. Science 361 (6399). https://doi.org/10.1126/science.aam5324.

GOIB, 2020. Anàlisi de les Cadenes Alimentàries i de Diagnosi del Sector de Producció Local. Ecològica, Agroindustrial i Artesanal de Mallorca. http://www.caib.es/microsites/sobirania_alimentaria/CadenesalimentariesMallorca.pdf. (Accessed 19 June 2021).

González de Molina, M., Soto Fernández, D., Guzmán Casado, G.I., Infante-Amate, J., Aguilera Fernández, E., Vila Traver, J., García Ruiz, R., 2020. The Social Metabolism of Spanish Agriculture, 1900–2008. The Mediterranean Way Towards Industrialization. Spriger, Cham. https://doi.org/10.1007/978-3-030-20900-1.

Gössling, S., Scott, D., Hall, C.M., 2020. Pandemics, tourism and global change: a rapid assessment of COVID-19. J. Sustain. Tour. 29 (1), 1–20. https://doi.org/10.1080/09669582.2020.1758708.

Guzmán, G.I., González de Molina, M., 2015. Energy efficiency in agrarian systems from an Agroecological perspective. Agroecol. Sust. Food. 39 (8), 924–952. https://doi.org/10.1080/21683565.2015.1053587.

Guzmán, G.I., González de Molina, M. (Eds.), 2017. Energy in Agroecosystems. A tool for assessing sustainability. CRC Press, Boca Raton.

Guzmán, G.I., González de Molina, M., Soto Fernández, D., Infante-Amate, J., Aguilera, E., 2018. Spanish agriculture from 1900 to 2008: a long-term perspective on agroecosystem energy from an agroecological approach. Reg. Environ. Chang. 18, 995–1005. https://doi.org/10.1007/s10113-017-1136-2.

Haberl, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Fischer-Kowalski, M., 2007. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proc. Natl. Acad. Sci. 104 (31), 12942–12947. https://doi.org/10.1073/pnas.0704243104.

Habsburg-Lorena, L.S., 1871. Die Eigentlichen Balearen Die Balearen in Wort und Bild geschildert. Brockhaus, Leipzig, vol VI. Spanish translation (1982–1993). In: Las Baleares por la palabra y el grabado. Caja de Ahorros de Baleares Sa Nostra, Palma.

Hercher-Pasteur, J., Loiseau, E., Sinfort, C., Hélias, A., 2020. Energetic assessment of the agricultural production system. A review. Agron. Sustain. Dev. 40, 29. https://doi.org/10.1007/s13593-020-00627-2.

Ho, M., Ulanowicz, R., 2005. Sustainable systems as organisms? BioSystems 82, 39–51. https://doi.org/10.1016/J.BIOSYSTEMS.2005.05.009.

IAASTD, 2009. Agriculture at a Crossroads. International Assessment of Agricultural Knowledge, Science and Technology for Development. Global Report. Washington, Island Press with UNDAP, FAO, UNEP, UNESCO, The World Bank, WHO and Global Environmental Facility. http://www.fao.org/family-farming/detail/en/c/286358/. (Accessed 2 August 2019).

INE [Instituto Nacional de Estadística], 2011. Censo Agrario 2009. https://www.ine.es/CA/Inicio.do. (Accessed 3 July 2016).

Infante-Amate, J., González de Molina, M., 2013. 'Sustainable de-growth' in agriculture and food: an agro-ecological perspective on Spain's Agri-food system (year 2000). J. Clean. Prod. 38, 27–35. https://doi.org/10.1016/j.jclepro.2011.03.018.

Infante-Amate, J., Aguilera, E., González de Molina, M., 2018. Energy transition in Agri-food systems. Structural change, drivers and policy implications (Spain, 1960–2010). Energy Policy 122, 570–579. https://doi.org/10.1016/j.enpol.2018.07.054.

IPES-Food [International Panel of Experts on Sustainable Food Systems], 2019. Towards a common food policy for the European Union. The Policy Reform and Realignment That Is Required 1–112. http://www.ipes-food.org/_img/upload/files/CFP_FullReport.pdf. (Accessed 8 February 2020).

Jover, G., 2019. Une crise de l'engrais a-t-elle sévi à Majorque dans le premier tiers du XVIIe siècle? Le cas du domaine Ballester-Togores de 1550 à 1870. In: Geltner, G., Conesa, M., Poirier, N. (Eds.), Fumiers! Ordures! Gestion et usage des déchets dans les campagnes de l'Occident médiéval et moderne. Actes des XXXVIIIes Journées internationales d'histoire de l'abbaye de Flaran, 14 et 15 octobre 2016, Toulouse (Presses universitaires du Midi) 2019. Francia-Recensio, 2020.

Jover, G., Morey, A., 2003. Les possessions mallorquines: una modalitat d'organització de l'espai agrari i de l'explotació del treball. In: Congost, R., Jover, G. i Biagioli, G. (Eds.), L'Organització de l'espai rural a l'Europa mediterrània: masos, possessions, poderi. CCG Edicions-AHR, Girona, pp. 127–238.

Koohafkan, P., Altieri, M.A., 2011. Globally Important Agricultural Heritage Systems. A Legacy for the Future, FAO, Rome. http://worldagriculturalheritage.org/wp-content/uploads/2014/12/GIAHS_Booklet_EN_WEB2011.pdf. (Accessed 11 November 2019).

Krausmann, F., 2004. Milk, manure, and muscle power. Livestock and the transformation of preindustrial agriculture in Central Europe. Hum. Ecol. 32 (6), 735–772. https://doi.org/10.1007/s10745-004-6834-y.

Leach, G., 1976. Energy and Food Production. IPC Science & Technology Press, Surrey.

Manera, C., 1999. Cambio agrario y desarrollo industrial no fabril en la isla de Mallorca, 1830-1930. Revista de Historia Económica Año XVII primavera-verano 1999 n. 2 pp, pp. 371–410.

Manzanedo, R.D., Manning, P., 2020. COVID-19: lessons for the climate change emergency. Sci. Total Environ. 742, 140563. https://doi.org/10.1016/j.scitotenv.2020.140563.

Marco, I., Padró, R., Cattaneo, C., Caravaca, J., Tello, E., 2018. From vineyards to feedlots: a fund-flow scanning of sociometabolic transition in the Vallès County (Catalonia) 1860–1956–1999. Reg. Environ. Chang. 18, 981–993. https://doi.org/10.1007/s10113-017-1172-y.

Marull, J., Tello, E., Fullana, N., Murray, I., Jover, G., Font, C., Coll, F., Domene, E., Leoni, V., Decolli, T., 2015. Long-term bio-cultural heritage: exploring the intermediate disturbance hypothesis in agro-ecological landscapes (Mallorca, c.1850–2012). Biodivers. Conserv. 24 (13), 3217–3251. https://doi.org/10.1007/s10531-015-0955-z.

Marull, J., Font, C., Tello, E., Fullana, N., Domene, E., Pons, M., Galán, E., 2016. Towards an energy-landscape integrated analysis? Exploring the links between socio-metabolic disturbance and landscape ecology performance (Mallorca, Spain, 1956–2011). Landsc. Ecol. 31, 317–336. https://doi.org/10.1007/s10980-015-0245-x.

Marull, J., Cattaneo, C., Gingrich, S., González de Molina, M., Guzmán, G.I., Watson, A., McFadyen, J., Pons, M., Tello, E., 2019a. Comparative Energy-Landscape Integrated Analysis (ELIA) in past and present agroecosystems of North America and Europe from the 1830s to the 2010s. Agric. Syst. 175, 46–57. https://doi.org/10.1016/j.agsy.2019.05.011.

Marull, J., Herrando, S., Brotons, L., Melero, Y., Pino, J., Cattaneo, C., Pons, M., Tello, E., 2019b. Building on Margalef: testing the links between landscape structure, energy and information flows driven by farming and biodiversity. Sci. Total Environ. 674, 603–614. https://doi.org/10.1016/j.scitotenv.2019.04.129.

McFadyen, J., Watson, A., 2018. Energy in a woodland-livestock agroecosystem: Prince Edward Island, Canada, 1870–2010. Reg. Environ. Chang. 18 (4), 1033–1045. https://doi.org/10.1007/s10113-018-1315-9.

Millward-Hopkins, J., Steinberger, J.K., Rao, Narasima D., Yannick, O., 2020. Providing decent living with minimum energy: a global scenario. Global Enviromental Change 65. https://doi.org/10.1016/j.gloenvcha.2020.102168.

Moore, J.W., 2015. Capitalism in the Web of Life: Ecology and the Accumulation of Capital. Verso Books, London.

Moore, J.W., 2018. The Capitalocene part II: accumulation by appropriation and the centrality of unpaid work/energy. J. Peasant Stud. 45 (2), 237–279. https://doi.org/10.1080/03066150.2016.1272587.

Morro, M., 2017. L'agricultura mallorquina del segle XX (1891–1960). Lleonard Muntaner, Palma.

Murray, I., 2015. Capitalismo y turismo en España. In: Del «milagro económico» a la «gran crisis». Barcelona, Alba Sud.

Murray, I., Jover-Avellà, G., Fullana, O., Tello, E., 2019. Biocultural heritages in Mallorca: explaining the resilience of peasant landscapes within a Mediterranean tourist hotspot, 1870–2016. Sustainability 11 (7), 1926. https://doi.org/10.3390/su11071926.

Naredo, J.M., Campos, P., 1980. Los balances energéticos de la agricultura española. Agric. Soc. 15, 163–256.

Nicholls, C.I., Altieri, M.A., 2018. Pathways for the amplification of agroecology. Agroecol. Sustain. Food Syst. 42 (10), 1170–1193. https://doi.org/10.1080/21683565.2018.1499578.

Padró, R., Marco, I., Cattaneo, C., Caravaca, J., Tello, E., 2017. Does your landscape Mirror what you eat? A long-term socio-metabolic analysis of a local food system in Vallès County (Spain, 1860–1956–1999). In: Fraňková, E., Haas, W., Singh, S. (Eds.), Socio-Metabolic Perspectives on the Sustainability of Local Food Systems. Human-Environment Interactions, vol 7. Springer, Cham. https://doi.org/10.1007/978-3-319-69236-4_5.

Parcerisas, L., Dupras, J., 2018. From mixed farming to intensive agriculture: energy profiles of agriculture in Quebec, Canada, 1871–2011. Reg. Environ. Chang. 18 (4), 1047–1057. https://doi.org/10.1007/s10113-018-1305-y.

Pellegrini, P., Fernández, R.J., 2018. Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. P. Natl. Acad. of Sci. USA 115 (10), 2335–2340. https://doi.org/10.1073/pnas.1717072115.

Pimentel, D., Pimentel, M., 1979. Food, Energy and Society. Edward Arnold, London.

Rossello Verger, V.M., 1964. Mallorca. El sur y el sureste. Cámara Oficial de Comercio, Industria y Navegación, Palma.

Rosset, P.M., Altieri, M.A., 2017. Agroecology: Science and Politics. Practical Action Publishing, Rugby.

Satorras, F., 1878. Informe sobre el estado de la agricultura en la provincia de las Baleares. Imprenta de Pedro José Gelabert, Palma.

Satorras, Francisco, 1887. Memoria sobre el estado de la agricultura en la provincia de Baleares. Servei Agronòmic Provincial, Palma.

Satorras, F., 1890. Memoria sobre el cultivo de cereal y leguminosas asociadas en la provincia de Baleares. Junta Provincial de Baleares, Palma.

Short, C., Winter, M., 1999. The problem of common land: towards stakeholder governance. J. Environ. Plan. Manag. 42 (5), 613–630. https://doi.org/10.1080/09640569910911.

Soto, D., Infante-Amate, J., Guzmán, G.I., Cid, A., Aguilera, E., García, R., González de Molina, M., 2016. The social metabolism of biomass in Spain, 1900–2008: from food to feed-oriented changes in the agro-ecosystems. Ecol. Econ. 128, 130–138. https://doi.org/10.1016/j.ecolecon.2016.04.017.

Tello, E., Galán, E., Cunfer, G., Guzman, G., González de Molina, M., Krausmann, F., Gingrich, S., Sacristán, V., Marco, I., Padró, R., Moreno-Delgado, D., 2015. A proposal for a workable analysis of energy return on investment (EROI) in agroecosystems. Part I: Analytical approach. IFF Social Ecol. Working Papers. 156, 1–110. http://hdl.handle.net/2117/77586.

Tello, E., Galán, E., Sacristán, V., Cunfer, G., Guzmán, G.I., González de Molina, M., Kraussmann, F., Gingrich, S., Padró, R., Marco, I., Moreno-Delgado, D., 2016. Opening the black box of energy throughputs in agroecosystems: a decomposition analysis of final EROI into its internal and external returns (the Vallès County, Catalonia, c.1860 and 1999). Ecol. Econ. 121, 160–174. https://doi.org/10.1016/j.ecolecon.2015.11.012.

Tello, E., González de Molina, M., 2017. Methodological challenges and general criteria for assessing and designing local sustainable Agri-food systems: A socio-ecological approach at landscape level. In: Fraňková, E., Haas, W., Singh, S. (Eds.), Socio-Metabolic Perspectives on the Sustainability of Local Food Systems. Springer, Cham, pp. 27–67. https://doi.org/10.1007/978-3-319-69236-4_2.

Tello, E., Jover, G., Murray, I., Fullana, O., Soto, R., 2018. From feudal colonization to agrarian capitalism in Mallorca: peasant endurance under the rise and fall of large estates (1229–1900). J. Agrar. Chang. 18 (3), 483–516. https://doi.org/10.1111/joac.12253.

Ulanowicz, R., 2020. Quantifying sustainable balance in ecosystem configurations. Curr. Res. Environ. Sustain. 1, 1–6. https://doi.org/10.1016/j.crsust.2019.09.001.

Urech i Cifre, C., 1869. Estudios sobre la riqueza territorial de las Islas Baleares dedicados a las Cortes Constituyentes (Palma).

Yousefi, M., Darvishi, A., Padró, R., Barghjelveh, S., Dinan, M.N., Marull, J., 2020. An energy-landscape integrated analysis to evaluate agroecological scarcity. Sci. Total Environ. 739, 139998. https://doi.org/10.1016/j.scitotenv.2020.139998.