https://doi.org/10.1016/j.jclepro.2022.134999

Towards an agroecological transition in the Mediterranean: A bioeconomic assessment of viticulture farming

Jaume Gil[1], Elena Alter[2], María José La Rota[2], Enric Tello[1], Vittorio Galletto[2], Roc Padró[3], Teresa Martínez[4], Soazig Darnay[4], Joan Marull[2,*]

[1] Department of Economic History, Institutions, Policy and World Economy, University of Barcelona, 08034 Barcelona, Spain. [2] Barcelona Institute of Regional and Metropolitan Studies, Autonomous University of Barcelona, 08193 Bellaterra, Spain. [3] Department of Economics and Economic History, Autonomous University of Barcelona, 08193 Bellaterra, Spain. [4] Gramona SA, Carrer de la Indústria 63, 08770 Sant Sadurní d'Anoia, Spain.

[*] Corresponding author: joan.marull@uab.cat.

Acknowledgements

This work has been supported by the MA4SURE project *Mediterranean Agroecosystems for Sustainability and Resilience under Climate Change* funded by the European Commission (PRIMA-H2020), and the BIOLANDSCAPEs project *Agroecological history for designing sustainable landscapes. Case studies from the Mediterranean world* funded by the Spanish Ministry of Science, Innovation and Universities (RTI2018-093970-B-C32-C33).

Abstract

Transformations in the agri-food system since the early 19th century have led to an unprecedented increase in food production. However, the structure of this system has generated many negative environmental and social impacts that threaten the sustainability at the local, regional and global scale. This situation entails the need for an agroecological transition that leads to an agri-food model that is aware of the planetary boundaries and guarantees the reproduction of human and all other forms of life. Agroecology is crucial for the Mediterranean, where the negative environmental and social impacts of industrial agriculture are particularly evident. The aim of this paper is to present a best practice viticulture farming that is in an advanced level of agroecological transition in the region. The results show that the energy efficiency of this agroecosystem is greater to conventional farms in the region, while generating similar financial returns but more equally distributed than the big agro-industrial companies in the sector. Based on this best practice case study, we provide several methodological and practical insights on the energy balance of the farm system, supplemented by data on the value-added distribution from wholesaler selling back to the industrial winemaking and vine-growing incomes, and the final financial returns of the company. The results highlight the need of multifactorial analyses that contribute to a systemic perspective on the synergic elements and leverage points for scaling-up the agroecological transition of Mediterranean viticulture.

Keywords

agroecological transition; energy efficiency; value-added distribution; profitability; circular economy

1. Introduction

Since the 20th century agricultural industrialization fostered deep changes in agricultural production systems driven by the growing use of machinery, synthetic fertilizers and pesticides, the increasing specialisation of production through monocultures, and trade globalization (Pingali, 2012). While the world's agricultural primary crop production doubled (53%) only between 2000 and 2019, the number of social and environmental negative side effects of the agro-industrial model has steadily increased (FAO, 2021). Today, agri-food systems face the challenge of reversing the loss of agricultural efficiency in the use of natural resources, tackling environmental and social impacts of food production, and guaranteeing the enhancement of ecosystem services necessary for healthy food provision.

In the political arena, it has only recently been realized that agriculture plays a two ways role for sustainability. On the one hand, it contributes to global climate change and local biodiversity loss, and on the other hand, it can potentially provide solutions to address these issues (Clark et al., 2020; Crippa et al. 2021). There is a growing scientific and social consensus on the need to transform the agri-food system. To that end, the Food and Agricultural Organisation (FAO) are promoting agroecology as an alternative practice for food and farming that can tackle multiple crises in the agri-food system, contribute to the Sustainable Development Goals (Millennium Institute, 2018), counteract climate change, and meet the world's food needs (FAO, 2018; HLPE, 2019; IFAD, 2021; IPES-Food, 2018). This agroecological transition aims at creating more resilient and energy-efficient landscapes to strengthen their capacity for local climate change mitigation and adaptation, increase soil organic matter regeneration, guarantee fresh water supply, and enhance biodiversity (Gliessman, 2015).

The promotion of agroecology is crucial for the Mediterranean, where the negative environmental and social impacts of industrial agriculture are particularly strong. Intensification has been pushed by irrigation, high inputs of fertilizers, and other agrochemicals and heavy mechanization (Vila-Traver et al., 2021). The unsustainable management of natural resources has fostered environmental degradations such as the salinization and loss of soil fertility ultimately leading to desertification of land (Guzmán and González de Molina, 2015). Under climate change conditions, the invasion of pests and diseases and the reduction of water availability are likely to accelerate, putting additional pressures on the Mediterranean farming systems (Aguilera et al., 2020). Under these circumstances farmer's income is increasingly unpredictable, and societal access to healthy and nutritious food is at risk.

This contrasts with previous organic Mediterranean agricultural systems, which used to be more energy efficient from a systemic perspective (Campos and Naredo, 1980; Marull et al., 2010), as food was consumed in the vicinity of cultivation areas and waste was reincorporated into production to recycle nutrients and replenish soil fertility (Marco et al., 2018). To ensure the continuity of production, farmers relayed on the diversification of the agroecosystem through crop rotations, intercropping, and the integration of livestock farming with agricultural and forestry activities (Güldner and Krausmann, 2017), increasing the functional complexity of agricultural landscapes and strengthening its adaptive capacity to external stressors. Shifting away from these traditional agricultural practices has had negative effects for both farmers and local communities, and the environment. Reversing these side effects requires creating new agroecosystems more resilient and economically sustainable, while restoring and updating traditional ecological and agricultural knowledges and practices suited to Mediterranean conditions (Migliorini and Wezel, 2017).

We hypothesised that the efficient use of energy is a key element for improving sustainability in farming, as energy provision strongly influences the agroecosystem functioning (Tello et al., 2016; Gingrich et al., 2018). In the face of fossil fuels depletion and climate change, there is a need to shift towards agri-food systems that are based on renewable energies, lower energy intensity, and higher energy returns (Pérez-Neira et al., 2018). In this regard, efficient agroecosystems require a decreasing dependence on external inputs, a high reuse of biomass within the system, and an adequate integrated management of livestock in agroecology landscapes to perform physical labour and provide organic fertilizers (Marull et al., 2016). However, there is still an insufficient understanding of the influence that agroecological practices have in enhancing farm-level efficiency and resilience of agroecosystems under climate change. To support decision-making processes towards a sustainable agroecological transition requires methodologies and indicators based on an integrative systemic approach.

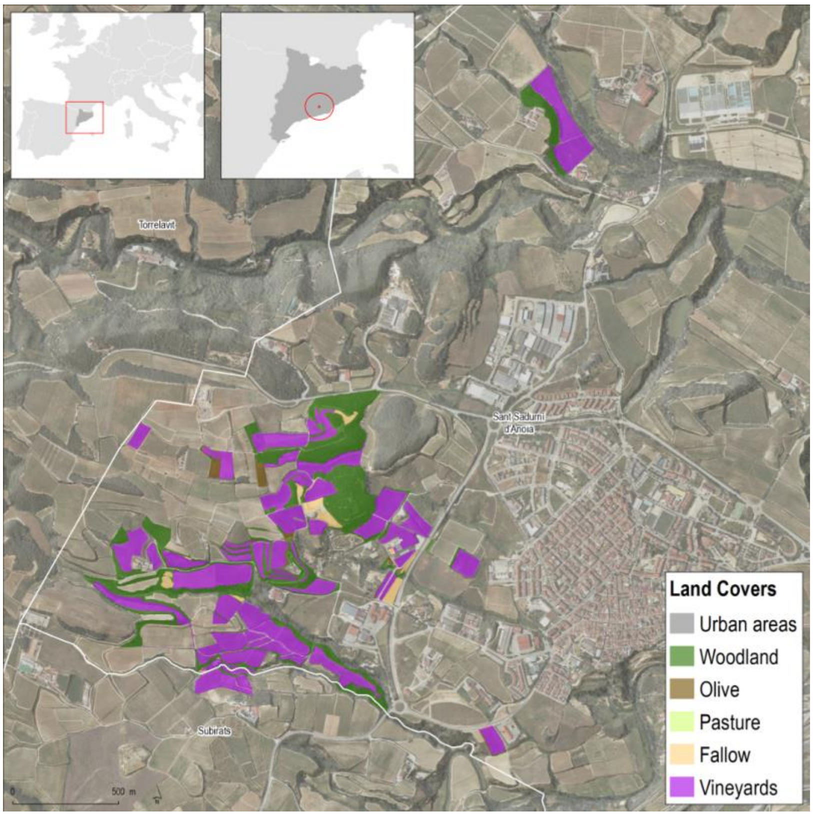
This paper analyses the energy efficiency of a farm system located in the Alt Penedès County (Spain) by applying Energy Return on Investment (multi-EROI) indicators. This analysis of the energy flow pattern is combined with an economic assessment of the farm, by accounting its financial profitability, the labour costs, and the distribution of the price paid by wholesalers among the different links in the added value chain of this winemaking sector, to consider the private and public benefits and costs of the organic vine-growing management adopted. The objectives of this paper are threefold: *i*) carry out a biophysical and value-added analysis of an agroecosystem at the farm-level to shed light on the energy and economic efficiency as well as agroecological circularity attained; *ii*) assess the level of the agroecological transition at which the farm system is, based on its energy and socioeconomic performance, making apparent how the biophysical circularity and the profitability of the farm can be enhanced, reducing environmental impacts by taking further agroecological innovations; *iii*) discuss the policy implications of this case study for helping advance these types of farm-level efficiency measures. The aim is to provide socioecological methods and indicators of agroecosystem sustainability useful as benchmarks for the energy and economic efficiency gains of specific farm-level agroecological practices in the Mediterranean. We also aim to discuss the usefulness of these indicators to inform public policy directed to scale up best practices to agroecologically integrated territories.

2. Methodology

2.1. Case study

The case study is the company ‘Gramona’, a biodynamic farm specialised in viticulture but with an aspiration to advance in the process of transition towards agroecology. The Gramona farm system is located in the municipality of Sant Sadurní d’Anoia at the heart of the Mediterranean region of the Alt Penedès County, 30 km from Barcelona (Catalonia, Spain) (figure 1). The farm has a total area of 80 ha, from which 65 ha comprise vineyards, some associated with olive and almond trees, and 15 ha of forest. Figure 1 shows the Gramona's landscape mosaic resulting from the diverse agricultural and forestry areas within this viticultural terroir where 40% of cultivated land is already organic.

Figure 1. Land covers of the Gramona farm system



The Gramona farm system applies organic management practices following the European Union standards for ecological agriculture (CCPAE, 2019). The combination of vineyards with forests, olive and almond trees creates a more diversified mosaic aimed at enhancing landscape heterogeneity and the biodiversity associated to this agroecosystem. The farm also has flocks of horses, cows and sheep, which provide a share of the manure needed to fertilize the vineyards and other crops. Additionally, livestock supports other farm management tasks and services such as some soil tillage (horses), forest wildfire control through cow grazing, and cover crop and soil maintenance through sheep grazing. They aim to prevent soil erosion, contribute to weed control, and fertilise the vines and other tree crops. Other soil treatments are intended to increase the belowground biodiversity by applying green manure. Further management practices include biological pest control, hand-harvesting of grapes, and intercropping.

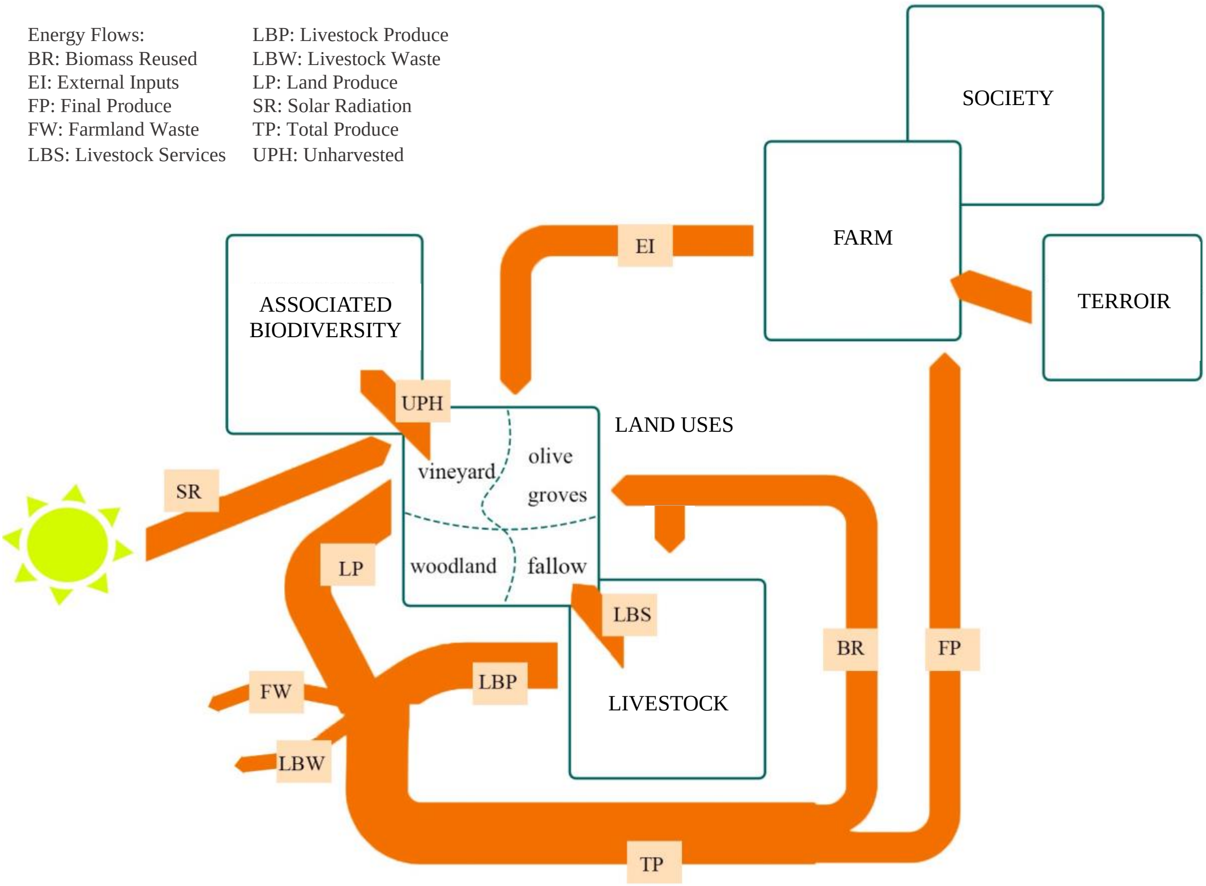
Gramona is a family-run business including the farm and cellar dedicated to producing and exporting high-quality wine and sparkling wine. Since the 2000s, Gramona began a transition towards organic production targeting the growing demand in European and American markets. Currently, all the bottles produced and sold are organic, vinified entirely on the winery. The grapes produced on the farm account for about 25% of the vintage quantity needed to produce the company's wines. The remaining 75% of organic grapes are purchased through an 'alliance for the terroir' association (called *Aliances per la Terra*) with small organic winegrowers from the Penedès. Together, they cultivate over 300 hectares of wines, and through this alliance Gramona is promoting organic farming, disseminating agroecological landscapes and practices in the region, and improving the income of smallholder peasants by offering them stable and higher prices than those of the large agro-industrial sparkling wine producers in the region. Their annual production is 638,000 bottles, most of which sold on the national market. However, they export around 12% of their production to the USA, Nordic countries and central Europe (Francàs, 2020). Together with eight other producers of organic sparkling wine in the region, Gramona created the EU quality label called CORPINNAT to differentiate together their family business model of making organic sparkling wines.

2.2 Methodological approach

This research is based on a socio-metabolic accounting of the farm system that analyses the matter and energy flows taking place in the territory (Marull et al., 2010). To account for the energy throughputs, we compare the inputs invested into the farm with the final energy outputs obtained to satisfy societal needs (Tello et al., 2016). Conceptually, this research adopts a fund-flow approach (Georgescu-Roegen, 1971) that understands sustainability as the system's capacity to ensuring the reproduction of the agroecosystem fund elements (i.e., soil biota, livestock, landscape, associated biodiversity) by means of the flow of matter and energy recirculated either in the form of biomass reused through farmers' labour, or through the uptake of unharvested biomass by wildlife. Further, the reproduction of fund elements involves external entries in form of rainwater and solar energy. Once the reproduction of these live funds is ensured by the internal matter-energy flows of the agroecosystems, they can keep providing a final produce and other ecosystem services essential to farmers and the society.

To set the boundaries of this system within the theoretical framework of social metabolism, we apply a farm-operator standpoint (figure 2), distinguishing the different energy subsystems and energy carriers flowing internally among them, or exiting outside the system to meet the needs of the broader societal system to which the farm belongs. See a detailed description of the fund-flow energy approach in table A1. The functional unit for the biophysical and economic analyses is the Gramona farm system, including its land uses and agricultural production, plus the grape production coming from the alliance with the smallholder vine-growers' association. In figure 2, boxes refer to energy sub-systems, where agricultural activity transforms energy from one form to another through various conversion processes. These boxes can be identified as fund elements, and their reproduction over time is key to the sustainable functioning of the agroecosystem. The arrows indicate the energy-carrying material flows that move from one subsystem to another.

Figure 2. Biophysical fund-flow conceptual model of the Gramona farm system



2.3 Biophysical analysis

To construct the accounting flowchart of Gramona's biophysical metabolism (figure 2), the agroecosystem's fund-flow model put forward by Tello et al. (2016) was adapted to the case study at the farm level. This study considers five fund elements: *i*) the Gramona farm; *ii*) the society; *iii*) the land uses; *iv*) the livestock; and *v*) the associated biodiversity. Society refers to the consumers of the final product and the providers of external inputs to the agricultural system managed by the Gramona farm. In addition to receiving matter-energy flows as a final produce from the agricultural system, both the farm and the broader society it belongs feeds energy carriers back into the system, especially in the form of labour, machinery, animal feed and manure. The land uses refer to the different spaces where agricultural activities are carried out. Livestock refers to the size of different flocks, and their internal nourishment and manure recovery either in the barnyard or on the land. Associated biodiversity is understood as the fauna and flora maintained in the agricultural landscape.

The energy flows used in the balance for Gramona's farm management and wine production are detailed in table A2. Data for the external inputs were collected through primary sources from Gramona's yearbooks reporting seasonal production and cultivated surface, as well as the daily costs generated by the viticultural production, such as labour (hours), machinery use (hours of work and operators), and manure produced and purchased. To perform the energy-balance all flows reported for 2018 in mass (kg) or time (hours) were converted to energy (MJ) following Guzmán et al., 2014 (see conversion factors in table A3). The energy performance of the agroecosystem was then calculated by using three energy efficiency indicators:

Final EROI: indicates the energy return on all the energy investment made by farmers and society to get a given amount of human consumable Final Produce (FP) (Marco et al., 2018). It indicates the amount of energy required to obtain a unit of energy in the form of must, olives, and livestock products. High values denote greater resource efficiency than low values.

$$FEROI = \frac{Final\ Produce}{Total\ Inputs\ Consumed} = \frac{FP}{BR + EI}$$

Internal Final EROI: assesses the portion of production reinvested in the agroecosystem as Biomass Reused (BR) to get a unit of FP that exits the farmgate. It indicates the investment made in the reproduction of the agroecosystem live funds such as soil, livestock, and farm-associated biodiversity. Notice that increasing IFEROI by reducing BR per unit of FP may involve a lack of care in the reproduction of these agroecosystem live funds, leading to a greater dependence on External Inputs (EI), mainly coming from fossil fuels, that is the hallmark of industrial agriculture. On the contrary, comparatively lower IFEROI values may involve a greater effort for a healthy reproduction of the agroecosystem, which becomes an agroecology hallmark.

$$IFEROI = \frac{FP}{BR}$$

External Final EROI: indicates the degree of dependence of the analysed agroecosystem from outside (EI), and it assesses whether the agroecosystem is a net supplier to the society or a consumer of energy from the society. Again, lower EFEROI values use to be the hallmark of industrial farming compared to organic and agroecology management, although this also depends on the type of crop and FP.

$$EFEROI = \frac{FP}{EI}$$

Based on this energy flow accounting, we will assess two hypothetical management scenarios and recalculate the EROIs to explore possible efficiency improvements of the farm system considering ways to internally reuse the grape pomace and other by-products currently lost through a compulsory external delivery as wastes.

2.4. Economic analysis

The economic activity assessed was made in 2018 up of three different firms: La Solana del Cava (cultivation and management of the farm vineyards), Gramona SA (vinification and sparkling wine production from its own grapes and those of the *Aliances per la Terra*), and Gramona Stock (distribution and sales). Profitability indicators are presented to assess the profitability of the company in the years 2016-2019, obtained from the Iberian Balance Analysis System that collects the official accounts of Spanish firms in a standardised and homogenous format. The indicators selected are: *i*) economic profitability (%, ordinary profit before taxes on total assets); *ii*) financial profitability (%, ordinary profit before taxes on own funds); *iii*) overall liquidity (current assets over liquid liabilities); *iv*) indebtedness (%, total liabilities plus own capital minus own funds over total liabilities and own capital); *v*) return on equity (%, ordinary profit before taxes on equity); *vi*) return on capital employed (%); *vii*) ordinary profit before taxes plus financial expenses on equity plus fixed liabilities; *viii*) return on total assets (%, ordinary profit before taxes on total assets).

The cost of the labour inputs necessary to exploit the land is assessed. As to execute the economic analysis we used the following sources provided by the company: economic accounting of the company, accounting data of all the daily costs generated by production of the La Solana del Cava estate; cadastral data for La Solana del Cava.

3. Results

3.1 Biophysical analysis

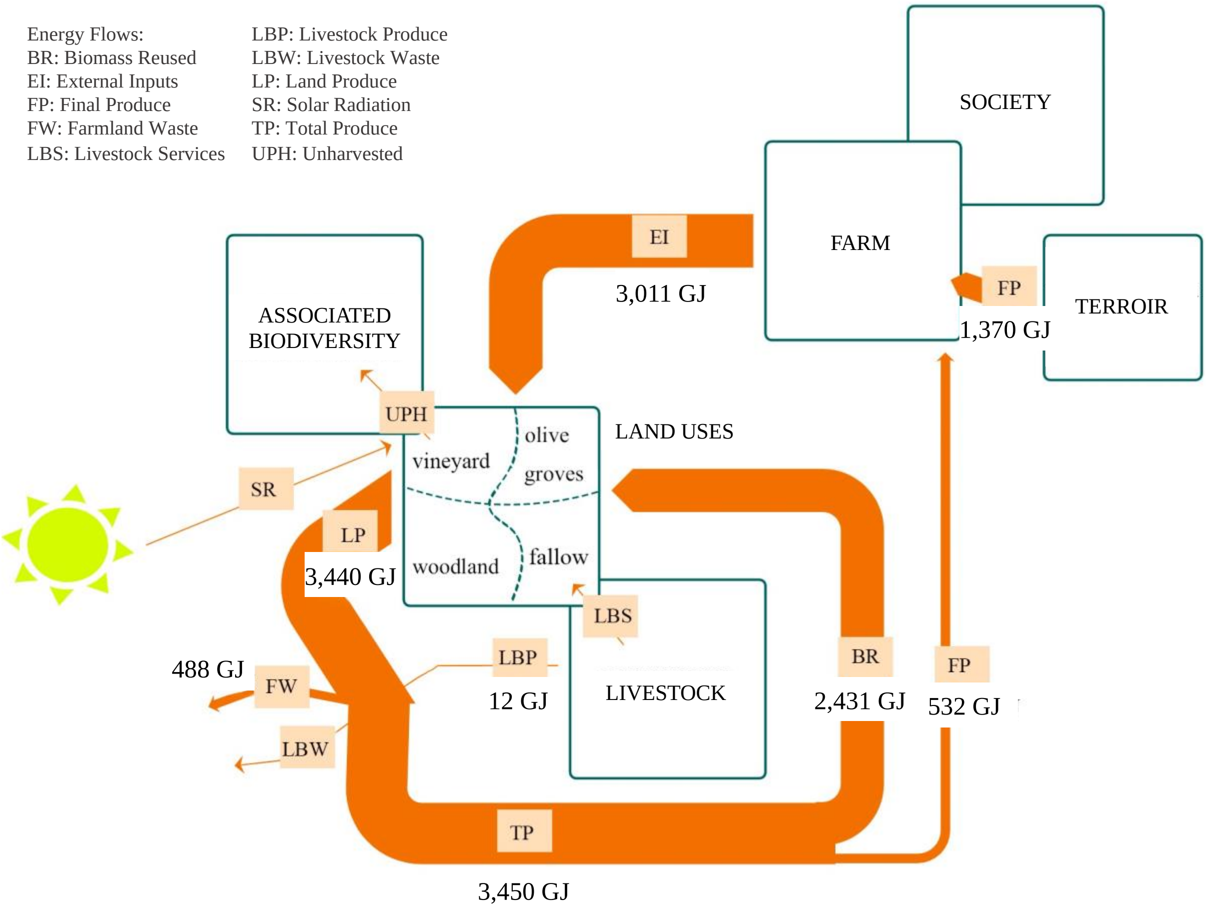
3.1.1. Current energy efficiency

The Gramona analysis flows for 2018 (table 1) indicate that FP flow was 532 GJ (6 GJ/ha), EI 3,011 GJ (34 GJ/ha), and BR 2,431 GJ (27 GJ/ha). Based on these flows, the FEROI, EFEROI and IFEROI were 0.10, 0.18 and 0.22, respectively. A complete picture of the agroecosystem's situation is presented in figure 3. EFEROI –which indicates the relationship between inputs (EI) coming from outside Gramona farm and its final produce (FP) sold outside— indicates that only 18% of the total energy coming from the society is returned as the energy content of wines and sparkling wine. IFEROI –an indicator for high energy investments in the internal circulation of biomass flow to reproduce the agroecosystem live funds— has a value of 0.22, meaning a great reproductive effort compared to the energy content of the produce extracted to be sold and consumed outside. Finally, FEROI is 0.10, again pointing to small returns on the total energy investment made to obtain the FP.

Table 1. Energy balance of the Gramona farm system. The main flows (GJ/year) are External Inputs (EI), Biomass Reused (BR), and Final Produce (FP), used to obtain the external, internal, and final Energy Return on Investment (EROI) indicators

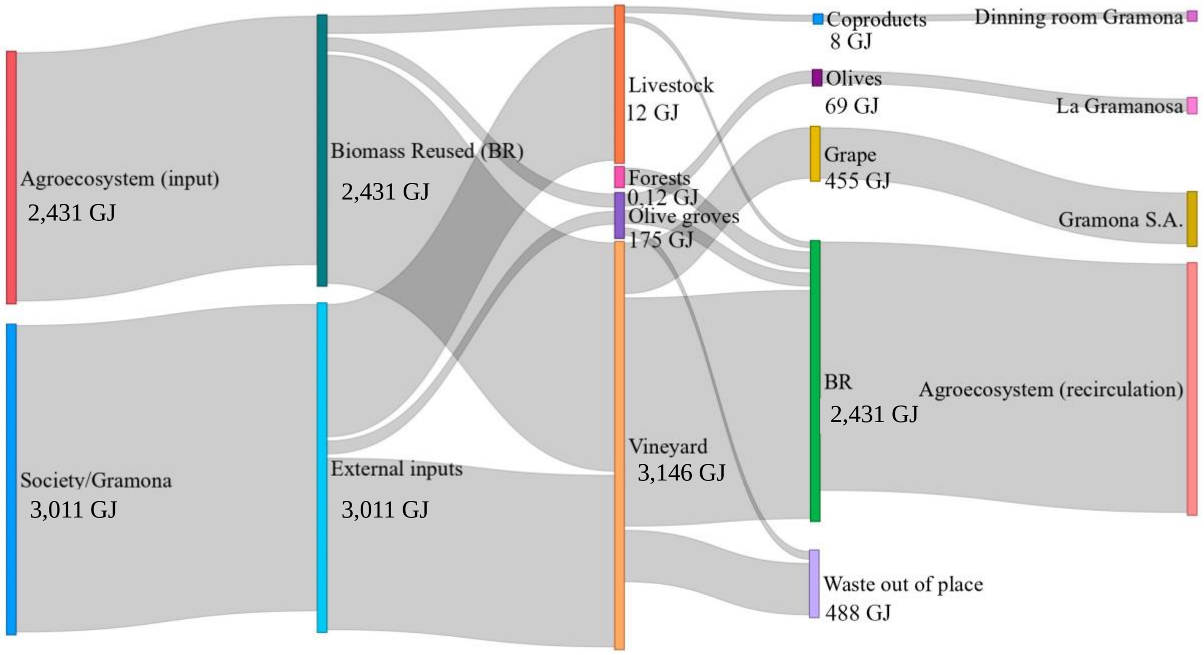
External Inputs		Biomass Reused		Final Product		Wastes		EROIs	
Manure	744.92	Grape leaves	568.00	Must (Grape juice)	455	Grape pomace	462.16	EFEROI (FP/EI)	0.18
Machinery	741.49	Vine shoot tips	1,276.86	Olive trees	69	Olive waste	26.29	IFEROI (FP/BR)	0.22
Biodynamic treatments	0.06	Old vines (wood)	384.99	Livestock	8			FEROI (FP/(BR+EI))	0.10
Organic treatments	265.73	Olive-tree branches (wood)	62.85						
Human labour	8.19	Olive-tree twigs	17.91						
Animal feed	1,251.35	Pasture – Forest	116.76						
		Manure	4.10						
Total (GJ)	3,011.74		2,431.47		532		488.45		
(GJ/ha)	33.9		27.4		6.0				

Figure 3. Sankey flowchart of the main energy flows and returns of the Gramona farm system



To help compare these biophysical flows of the agroecosystem with the distribution of monetary value-added flows of the company from the wholesale selling of wine bottles back to the winemaking and agricultural activities (later in 3.2.), we have drawn an input-output flowchart (figure 4). It differentiates from the grapes, the products obtained from livestock farming to supply the Gramona canteen, and the olives processed by an external company (La Gramanosa) into oil also used for the staff lunch (about 1,000 litres of oil per year). Again, the share of what is extracted from the soil and reused (BR) into it is much higher than the final production (must, olives and meat). Disaggregating from EI the external purchase of animal fodder (1,251 GJ) and manure (745 GJ), they represent an energy flow of 1,996 GJ per year, which is more than three times the energy content of the FP generated yearly by the agroecosystem (532 GJ).

Figure 4. Input-output flowchart of energy flows (GJ) in the Gramona farm system



3.1.2. *Hypothetical management scenarios*

Given the energetic lower relevance of grape pomace (455 GJ) compared to the residues obtained (488 GJ) pressing it (figure 4), we calculated two hypothetical scenarios for improving the energy returns of the farm. The first scenario assumes that the pomace residues could be used to obtain FP, such as flour and oil from the seeds, or liquor from the peel. The second scenario incorporates the grape pomace as BR either as animal feed or in the compost piles used to fertilize the land (which helps aerate the piles, reduce stir work, and shorten the composting process). The results are presented in table 2, where we observe in the first scenario considerable improvements, as almost twice as much energy would be obtained from the final production considered so far. In the second scenario, the energy returns become even smaller as Gramona would increase an already high amount of biomass reused. However, if the use of pomace were considered for animal feed, it could potentially reduce the purchase of manure that currently flows into the system as EI.

Table 2. Energy Return on Investment (EROI) of the Gramona farm system under two hypothetical scenarios

Scenarios	Description	EFEROI	IFEROI	FEROI
Scenario 0 Current state	Gramona farm system (2018)	0.18	0.22	0.1
Scenario 1 Grape pomace as FP	Grape pomace would be used as grape seeds for flour and oil or peel for liquor	0.31	0.41	0.18
Scenario 2 Grape pomace as BR	Grape pomace would be used as compost	0.17	0.18	0.09

Final EROI (FEROI), Internal Final EROI (IFEROI), External Final EROI (EFEROI)

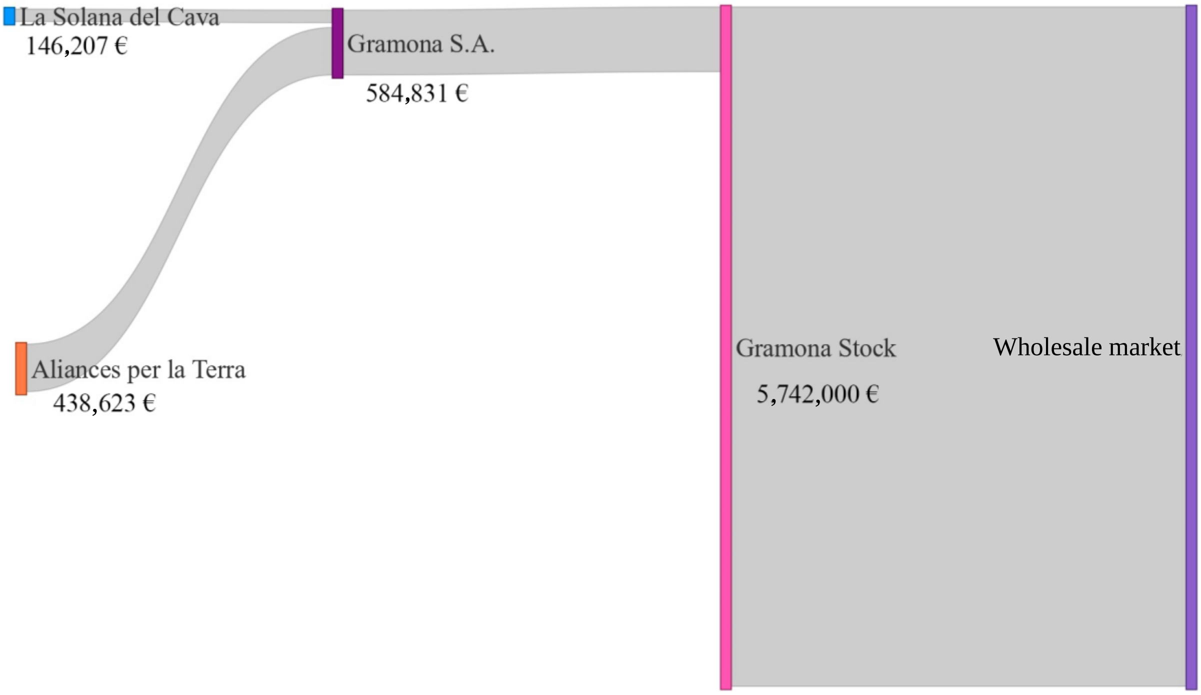
3.2 Economic analysis

3.2.1. Financial state

Looking at the profitability indicators shown in the Supplementary Material (tables A4, A5 and A6), this family businesses can be described as financially sound. The business model has been kept profitable in economic and financial terms in the years considered, outperforming the indicators of the big corporations of the area and of other family organic wineries of the CORPINNAT label. Although debt increased and liquidity decreased due to the Gramona investments mainly made in land acquisition, its indebtedness rate (see 2.4 section) remained lower than the two biggest corporations and like other CORPINNAT family business of the Penedès area.

The flowchart of figure 5 compares the cash flow of the organic grapes sold by the Solana del Cava farm to the cellar of Gramona Ltd., together with the ones sold by the smallholder vine-growers of the *Aliances per la Terra*, compared with the one obtained by selling the bottles of wine and sparkling wine in the wholesale market by Gramona Stock. The industrial production and commercial sale of wine and sparkling wine increases nearly ten times the value-added flow of the organic grapes along this agro-industrial chain. The Gramona's business model has a strong commitment to its organic vineyards in the Penedès terroir to keep up the willingness of its customers to pay for these organic and biodynamic labelled bottles of wines and sparkling wines. As a result, the company is helping to make organic farming economically profitable for many small vine-growers in the area that sell grapes to Gramona. This business model help explain why organic viticulture currently covers 40% of the cultivated area in the Penedès, after having been adopted by family cellars like Gramona and others assembled in the organic CORPINNAT and Classic Penedès Protected Designations of Origin (PDO).

Figure 5. Operating cash flows of grape primary production and industrial production of wines and sparkling wines sold in the wholesale market through the three firms of the Gramona group



3.2.3. Labour and Other Input Costs

Human labour represents 55% and ecological treatments 31% of the total input costs, due to their intensive use rather than their cost per hour or per kg. The high external labour inputs are due to the specific production of the Gramona farm system, which entails the hand-harvesting of grapes and the biological treatments that allow to obtain a higher quality of the primary product. The company has permanent and temporary employees, the latter for occasional labour-intensive activities such as tillage, harvesting and destemming that account for 47% of total labour costs and 49% of total hours. In the period studied the company's employment increased 20%, and profit per worker was 14% lower in 2019 than in 2016. However, average labour costs remained quite stable, with only a slight downward trend, while incomes increased, meaning that the operating income per employee was significantly higher than their average costs.

4. Discussion

4.1. The biophysical efficiency

Since Pimentel and Pimentel (1979) we know that food production and consumption in an industrial agricultural system requires a considerable amount of energy provided by external inputs, due to an increasing dependence on fossil fuels and agrochemicals that lead to a lack of energy efficiency (Carpintero and Naredo, 2006; Infante-Amate et al., 2018). At the same time, the internal energy cycles of agricultural systems were disrupted by the separation of crop and livestock production, as well as from woodland uses, increasing the need of specialised farms to import either feed for livestock or industrial fertilizers (Cattaneo et al., 2018).

Our results show that it is a crucial endeavour to reverse these dependencies and overcome the agroecological inefficiencies of monocultures. With the energy efficiency assessment of the Gramona farm we can highlight the following key findings. First, the three EROIs accounted are small (table 1), which must be considered in the context of a winegrowing specialized area. Wine has always been a commercial crop produced as a stimulant, not a staple ingredient of food nutrition. After being exported and consumed over long distances, the energy content of wine will never return to the vineyards. The high water and low energy content of wine implies that most of the carbon and nutrients harvested or pruned from the vines remain local and may return to the vineyard soils, helping to make these exports agroecologically sustainable. In this case, the low energy return is indeed a sign of energy inefficiency, however, it has positive environmental side effects as it allows a higher degree of biomass circularity from the production back to soil nutrients’ replenishment.

Second, despite the organic production of the farm that limits the use of fossil-fuelled external inputs (suppressing synthetic fertilizers, pesticides, and herbicides, only keeping farming machinery), the low EFEROI rate (0.18) is also due to the large amount of imported fodder to feed its herds, and the animal manure bought for soil fertilization (table 1). From an energetic point of view, this animal husbandry is doubly inefficient. On the one hand, Gramona does not produce feed grain due to its specialisation in viticulture, while the forests, pastures, and fallow strips in between rows of vines does not provide enough grazing resources to cover the livestock's feed requirements. On the other hand, there are too few animals to generate enough manure for fertilising the fields (4.10 GJ), which must be supplemented with imported manure (744.92 GJ).

Third, the low IFEROI of 0.22 can be interpreted in two ways. On the one hand, it signals low partial yields obtained per unit of internal biomass spent, again due to the low energy content of the FP. On the other hand, it also highlights a great investment of internal biomass reuses to preserve the live funds of the agroecosystem, such as soil regeneration and biodiversity (figure 3), contributing to the maintenance of ecosystem services (Ellis et al., 2019). In the Penedès these investments in soil regeneration are important to reverse the low soil organic matter content and high erosion rates, commonly observed after a century of agro-industrial land management (Martínez-Casasnova and Ramos, 2006).

Finally, the FEROI indicates an overall low return on the total energy invested to obtain the FP, which is again a result of keeping a high dependence on organic EI combined with a high investment in internal BR and a low energy FP. As explained, the grape must contains 80-85% water, and only a small proportion of other energy-dense products. Only other small components of FP such as olives help increase the energy content of FP. However, Gramona's organic farming is also making initial efforts to increase the complexity and self-sufficiency of the agroecosystem by including livestock and internal products to supply the Gramona's canteen.

As to improve the closure of internal biophysical cycles, hypothetical scenarios demonstrate that Gramona's farm energy efficiency could be remarkably increased with a wiser use of the organic 'waste' (table 3). For example, by recycling the discarded grape and olive pomaces as animal feed. The current organic wine production regulations (2000/532/CE) require separation and delivery of grape pomace out of the cellar facilities to prevent wine adulterations, setting a barrier to sustainability improvements. Despite this, on 2015 a decree of the Catalan government (198/2015 of 8th September) has opened the door to the agricultural reuse of grape and oil pomaces under certain conditions.

Against the backdrop of historical EROI data, Gramona's results are particularly remarkable in terms of biomass reuses (IFEROI), as they match the same patterns of BR flows in traditional Mediterranean organic ways of farming that relied on BR to keep biophysical cycles as closed as possible (Marco et al., 2018; Guzmán et al., 2018). Indeed, contrasting our results of this best practice at the farm-level (table 1) with previous regional-level analyses (Cattaneo et al. 2018), we observe significant differences: in 2009, due to the high dependence on non-renewable EI such as synthetic fertilisers and pesticides used by the larger conventional companies of the sector, FP, BR and EI per hectare of the Alt Penedès averaged 17.27, 6.35 and 92.42 GJ/ha, respectively, and EFEROI, IFEROI, FEROI were 0.19, 2.72 and 0.17, respectively. In comparison, Gramona had a higher BR/ha and a much lower IFEROI values, while its energy inflows were mainly renewable imported livestock feed (1251.35 GJ, 42% of the total EI) and animal manure (744.92 GJ, an amount equivalent to the energy cost of machinery, which accounts for 25% of the EI). If these biomass flows could be supplied directly from the farm, the EFEROI would triple (from 0.18 to 0.52). Meanwhile, the energy value of FP/ha in Gramona is almost three times below that of the region due to the less intensive use of the land through an organic viticulture. Despite this major structural difference of the Gramona farm system, its EFEROI value is similar to the average of the Alt Penedès.

4.2. The economic efficiency

In financial terms, the company was in a good position (tables A4, A5 and A6), with a balanced structure, as well as returns above the winegrowing average in the area. The high-quality organic and biodynamic production requires the company to employ more workers than agro-industrial wineries. Due to the hand harvest and pruning, and lesser machinery use, labour is a major expense for the company and a key element in guaranteeing access to its market segment. This is another differentiating feature of its business model of organic viticulture. During the years studied, average labour costs remained stable while revenues from the high-quality products sold increased. Thus, production system generated an operating income per worker significantly higher than their average costs, creating positive economic benefits for the company. Together with human labour, ecological treatments also had greatest weight in the external input costs. Based on the profitability obtained, we conclude that Gramona's allocation of more resources to human labour and organic treatments is economically efficient.

The *Aliances per la Terra* is an important strategic partnership essential for the company to guarantee the volume, quality, and stability of the organic grape production needed to meet the demand for its biodynamic sparkling wines, while the supplying farmers obtain a price for their organic product significantly higher than the regional average. These contracts clearly favour the socioeconomic development of the territory through an agroecological transition path.

The company operates in a niche market with buyers affluent enough to be willing to pay a higher price for a quality product endowed with a label that certifies the environmental benefits of the organic production model (9 € of average price per bottle of Gramona sparkling wines in the wholesale market, when the Penedès sector's average was 3 € in 2020). The leap in the added value obtained remunerates the Gramona winery and farm, and the small family vine-growers associated in the *Aliances per la Terra*, with a higher price for the organic grapes (0.7 €/kg compared to the 0.35 €/kg of conventional ones in 2020) that helped cover their higher labour, land and livestock costs and improve the Alt Penedès landscape and soils.

Compared to larger agro-industrial winemaking companies of the Penedès, we found that Gramona has a higher profitability (table A5). These agro-industrial corporations (e.g, Codorniu, Freixenet) have much higher leverage and lower liquidity than the organic

CORPINNAT label companies (table A6), because they need a higher energy investment in fossil-based inputs and a higher allocation of financial resources. Gramona has 14% less working capital per employee and approximately 70% less assets per employee than these big corporations. Nevertheless, Gramona can generate a slightly higher profit per employee. The results show that organic wine production, combined with efficient management, can achieve similar returns with a lower use of agroecologically unsustainable resources (Antonini and Argilés-Bosch, 2017).

4.3. The agroecological transition

Within the five levels of agroecological transition (Gliessman, 2015), Gramona stands between level 3 ‘Redesigning whole agroecosystem’ and level 4 ‘Re-establishing connections between growers and eaters, developing alternative food networks’. Gramona farm is making a particular effort to close internal loops by recycling biomass flows, which account for 45% of the total energy inputs used (table 1). It also intends to gradually reduce its external dependence by on-farm producing and consuming, and by recovering traditional methods such as hand-harvesting and horse ploughing. This involves considerable investments in diversifying the farm system to create a landscape mosaic intermingled with the vineyards.

Therefore, beyond suppressing the use of agrochemicals to get the organic label, Gramona, has begun to incorporate central elements of the agroecology concept, including an autonomous resource-base and farm-internal cycles by gradually diversifying production, and establishing synergies between the different compartments of the agroecosystem (Migliorini and Wezel, 2017). Despite these efforts, the company is currently a net energy consumer, due to the low energy content of the must and the large volume of imported organic animal feed and manure. As a result, Gramona’s energy profile can be improved by turning grape pomaces, currently treated as residues to elaborate industrial alcohols, into an internal resource for soil regeneration through animal feeding. More agroecology synergies can be activated by increasing mixed farming with more livestock, intercropping grains and legumes in rotations between rows of vines and olive trees, or grazing wood pastures with agroforestry.

The results show that organic wine production can achieve similar economic returns than agro-industrial conventional farming with a lower use of resources. Indeed, this profitability success is achieved despite the investment made in less-productive land and livestock uses, as well as in biodiversity improvements, assuming production costs about 20% higher than the conventional sector (Sánchez-Silva, 2018) without being yet paid for the non-provisioning ecosystem services. Gramona is actively engaged in local farmers/distribution networks (i.e., *Aliances per la Terra*, CORPINNAT label) creating incentives for advancing the agroecology transition, and generating economic benefits for local, small-scale family farmers.

The economic success of Gramona and other family organic winegrowing business remains closely linked to the willingness to pay higher prices for eco-labelled sparkling wines by consumers that can afford them. This makes it difficult to take Gramona as a showcase for more advanced agroecological transition levels in this sector, let alone in other staple sectors with no such close trademark link to the producing landscapes that endure larger price squeezing of their commodities in wholesale markets. However, avoiding further progress in level 4 would involve a clear risk of conventionalizing the organic farming in the Penedès, which has so far been a success story (Darnhofer et al., 2010). Further research is needed to assess whether a Gramona-like business model can be scaled up to landscape scales and the entire Penedès PDO area, what this would entail for the communities inhabiting this territory, what environmental impacts could result from such a transition for the mitigation and sequestration of carbon in regenerated soils at landscape, regional and ultimately global scales, and which public policies and regulations would be required.

4.4 Policy implications

Increasing resource-use efficiency in farming to minimize environmental damage and farmers' reliance on external inputs are decisive challenges in the transition towards agroecology (FAO, 2018; HLPE, 2019), which require public policies supporting farmers efforts to engage and persevere in them (González de Molina et al., 2020). These public policies for agroecology transition must: *i*) be based on scientific insights, *ii*) take into account farmers' experiences and knowledge, and *iii*) consider social movements demands and actions as an important counterweight to corporate vested interests giving democratic space for less powerful actors (Gaitán-Cremaschi et al., 2019).

On the one hand, applying such a holistic approach to agri-food system policies is important to prevent law-making focused only on sectoral policies. On the other hand, incremental improvements in different areas are also needed (i.e., payment scheme for ecosystem services) to kick off change (Van de Ploeg et al., 2019). In Europe, the Farm to Fork strategy has lately provided a more holistic vision to reduce 50% chemical pesticides and 20% fertilisers by 2030; increase organic farming up to 25% of agricultural land, andsetting aside at least 10% for high-diversity landscape features for biodiversity enhancement by 2030 (European Commission, 2020). At the same time, the Common Agricultural Policy (CAP) is the most influential economic framework. Both, the vision and the subsidies should necessarily go hand in hand, but so far has scarcely been the case (Schebesta and Candel, 2020).

Our combined sociometabolic and socioeconomic approach helps to see both interacting sides and gain a more holistic view of the agroecological transition to generate concrete strategies and policies based on scientific research and farmers' local knowledge. This bioeconomic analysis has shown the importance of different practices related to biomass recycling that reduce dependence on external inputs, and the positive economic returns to the higher role of human labour and renewable inputs in sustainable agriculture. They are important insights when it comes to implement eco-schemes under the new attempts of greening the CAP (European Commission, 2021), as they reveal a continuum of efficiency, substitution and redesign measures for whose implementation farmers must be rewarded (Agroecology Europe, 2021).

Moreover, our farm energy balance reveals that it is a combination of different practices what may increase efficiency and resilience at farm level by enabling synergistic outcomes, which would require multidimensional eco-schemes whereby farmers adopt them in ways that also improve the functioning of agroecology landscapes (Nyssens et al., 2021). This will help overcome the geographical isolation of pioneering organic farms, and to achieve its uptake on a larger scale (Mier y Terán Giménez Cacho et al., 2018)

The pivotal role of human labour in agroecological farming (Van der Ploeg et al., 2019), highlights the urgent need to reorient EU direct payments to overcome income distribution inequalities among farmers preventing that the lion's share of these CAP Pillar 1 subsidies be taken by the largest 20% of European farms (Kay et al., 2015). Instead of paying direct payments per hectare, they could be based on a full-time equivalent worker basis which would reward farmers who use less machinery and agrochemicals and seek to strengthen local economies and rural development by employing local people, and counteracting the emptying of rural areas, which is a problem particularly acute in the Mediterranean (Pinilla and Sáez, 2017).

5 Conclusions

The transformations of the agri-food system during the 20th century have generated multiple negative environmental and social impacts which endanger food sustainability and security, making a change of model necessary. The transition to agroecology is a solution that addresses the main problems of the current system, although it still faces major challenges of scaling up best farming practices. The Gramona farm system is an interesting ‘best practice’ case in an advanced level of transitioning towards agroecology in the Mediterranean viticulture. Our study shows that the energy efficiency of the Gramona agroecosystem is greater to conventional vine-growing farms in the region, while generating similar economic returns more equally distributed than other big agro-industrial companies of the sector. It also brings to light some possibilities and barriers to attain further advances in the agroecology transition, avoiding the risk of organic conventionalisation.

This best practice case study provides specific methodological and practical insights for the forthcoming agroecological transition. The latter refer to the need of carrying out both energy and value-added balances that link farm systems with their business models. The former methodological results highlight the need of multifactorial analyses and indicators that contribute to a systemic perspective on the synergic drivers of the agroecological transition. Further research should address other questions raised by our results: How, and to what extent, this agroecological production model is improving biodiversity and increasing ecosystem services at the landscape scale, helping to cope with climate change mitigation and adaptation. How, and to what extent, is this organic winegrowing business model contributing to getting fairer prices and incomes for those who farm the land. And how can these positive outcomes be scaled up towards higher levels of agroecological transition.

References

Agroecology Europe. (2021). *Integrating agroecology into European agricultural policies. Position paper and recommendations to the European Commission on Eco-schemes*. https://www.agroecology-europe.org/integrating-agroecology-into-european-agricultural-policies-new-aeeu-position-paper-on-eco-schemes/

Aguilera, E., Díaz-Gaona, C., García-Laureano, et al. (2020). Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. *Agricultural Systems*, *181*, 102809. https://doi.org/10.1016/j.agsy.2020.102809

Antonini, C., Argilés-Bosch, J. M. (2017). Productivity and environmental costs from intensification of farming. A panel data analysis across EU regions. *Journal of Cleaner Production*, *140*, 796–803. https://doi.org/10.1016/j.jclepro.2016.04.009

Campos, P., Naredo, J.M. (1980): La energía en los sistemas agrarios. *Agricultura y sociedad*, 15, 17-113. https://digital.csic.es/handle/10261/20594

Carpintero, O., Naredo, J.M. (2006): Sobre la evolución de los balances energéticos de la agricultura española, 1950-2000. *Historia Agraria*, 40, 531-554. https://www.historiaagraria.com/FILE/articulos/oscarsobre.pdf

Cattaneo, C., Marull, J., Tello, E. (2018). Landscape Agroecology. The Dysfunctionalities of Industrial Agriculture and the Loss of the Circular Bioeconomy in the Barcelona Region, 1956–2009. *Sustainability*, *10*(12), 4722. https://doi.org/10.3390/su10124722

CCPAE. (2019). *Recull d'estadístiques del sector ecològic a Catalunya.*

Clark, M.A., Domingo, N.G.G., Colgan, K., et al. (2020). Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science*, *370*(6517), 705–708. https://doi.org/10.1126/science.aba7357

Crippa, M., Solazzo, E., Guizzardi, D., et al. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198–209. https://doi.org/10.1038/s43016-021-00225-9

Darnhofer, I., Lindenthal, T., Bartel-Kratochvil, R., et al. (2010). Conventionalisation of organic farming practices: From structural criteria towards an assessment based on organic principles. A review. *Agronomy for Sustainable Development*, *30*(1), 67–81. https://doi.org/10.1051/agro/2009011

Ellis, E.C., Pascual, U., Mertz, O. (2019). Ecosystem services and nature's contribution to people: Negotiating diverse values and trade-offs in land systems. *Current Opinion in Environmental Sustainability*, *38*, 86–94. https://doi.org/10.1016/j.cosust.2019.05.001

European Commission. (2020). *Communication—A Farm to Fork strategy for a fair, healthy and environmentally-friendly food system (+Annex)*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381

European Commission. (2021). *List of potential agricultural practices that Eco-Schemes could support.* https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/key_policies/documents/factsheet-agri-practices-under-ecoscheme_en.pdf

FAO. (2018). *The 10 Elements of Agroecology. Guiding the Transition to Sustainable Food and Agricultural Systems*. http://www.fao.org/3/i9037en/i9037en.pdf

FAO. (2021). World Food and Agriculture – Statistical Yearbook 2021. Rome.

Francàs, R. (2020). Gramona atura l'hotel del Penedès però continua a la Cerdanya. *La Vanguardia*. http://hemeroteca.lavanguardia.com/preview/2010/07/12/pagina-50/322566266/pdf.html?search=gramona exportaciones

Gaitán-Cremaschi, D., Klerkx, L., Duncan, J., et al. (2019). Characterizing diversity of food systems in view of sustainability transitions. A review. *Agronomy for Sustainable Development*, *39*(1), 1. https://doi.org/10.1007/s13593-018-0550-2

Georgescu-Roegen, N. (1971). *The entropy law and the economic process*. Harvard University Press.

Gingrich, S., Marco, I., Aguilera, E., et al. (2018). Agroecosystem energy transitions in the old and new worlds: Trajectories and determinants at the regional scale. *Regional Environmental Change*, 18, 1089–1101. https://doi.org/10.1007/s10113-017-1261-y

Gliessman, S. R. (2015). *Agroecology: The ecology of sustainable food systems* (3. ed). CRC Press.

González de Molina, M., Petersen, P.F., Garrido Peña, F., et al. (2020). *Political agroecology: Advancing the transition to sustainable food systems*. CRC Press.

Güldner, D., Krausmann, F. (2017). Nutrient recycling and soil fertility management in the course of the industrial transition of traditional, organic agriculture: The case of Bruck estate, 1787–1906. *Agriculture, Ecosystems & Environment*, *249*, 80–90. https://doi.org/10.1016/j.agee.2017.07.038

Guzmán, G.I., González de Molina, M. (2015). Energy Efficiency in Agrarian Systems From an Agroecological Perspective. *Agroecology and Sustainable Food Systems*, *39*(8), 924–952. https://doi.org/10.1080/21683565.2015.1053587

Guzmán, G.I., González de Molina, M., Soto-Fernández, D., et al. (2018). Spanish agriculture from 1900 to 2008: A long-term perspective on agroecosystem energy from an agroecological approach. *Regional Environmental Change*, *18*(4), 995–1008. https://doi.org/10.1007/s10113-017-1136-2

Guzmán, G.I. Soto-Fernandez, D., García, R. (2014). *Methodology and conversión factors to estimate the net primary productivity of historical and contemporary agroecosystems*.

HLPE. (2019). *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*.

IFAD. (2021). *Stock-take report on agroecology in IFAD operations: An integrated approach to sustainable food systems.* https://www.ifad. org/en/web/knowledge/-/stock-take-report-on-agroecology

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. (2018). *Breaking away from industrial food and farming systems: Seven case studies of agroecological transition.* https://www.ipes-food.org/_img/upload/files/CS2_web.pdf

Kay, S., Peuch, J., Franco, J.C. (2015). *Extent of Farmland Grabbing in the EU (Study for Directorate-General for Internal Policies, Agriculture and Rural Development).* Transnational Institute.

Marco, I., Padró, R., Cattaneo, C., et al. (2018). From vineyards to feedlots: A fund-flow scanning of sociometabolic transition in the Vallès County (Catalonia) 1860–1956–1999. *Regional Environmental Change*, *18*(4), 981–993. https://doi.org/10.1007/s10113-017-1172-y

Martínez-Casasnovas, J.A., Ramos, M.C. (2006). The cost of soil erosion in vineyard fields in the Penedès–Anoia Region (NE Spain). *CATENA*, *68*(2–3), 194–199. https://doi.org/10.1016/j.catena.2006.04.007

Marull, J., Pino, J., Tello, E., et al. (2010). Social metabolism, landscape change and land-use planning in the Barcelona Metropolitan Region. *Land Use Policy*, *27*(2), 497–510. https://doi.org/10.1016/j.landusepol.2009.07.004

Marull, J., Font, C., Padró, R., et al. (2016). Energy–Landscape Integrated Analysis: A proposal for measuring complexity in internal agroecosystem processes (Barcelona Metropolitan Region, 1860–2000). *Ecological Indicators*, *66*, 30–46. https://doi.org/10.1016/j.ecolind.2016.01.015

Mier y Terán Giménez Cacho, M., Giraldo, O.F., Aldasoro, M., et al. (2018). Bringing agroecology to scale: Key drivers and emblematic cases. *Agroecology and Sustainable Food Systems*, *42*(6), 637–665. https://doi.org/10.1080/21683565.2018.1443313

Migliorini, P., Wezel, A. (2017). Converging and diverging principles and practices of organic agriculture regulations and agroecology. A review. *Agronomy for Sustainable Development*, *37*(6), 63. https://doi.org/10.1007/s13593-017-0472-4

Millennium Institute. (2018). *The Impact of Agroecology on the Achievement of the Sustainable Development Goals (SDGs)—An Integrated Scenario Analysis.* https://www.agroecology-pool.org/download/1321/

Nyssens, C., Ruiz, J., Nemcová, T. (2021). *Will CAP ecoschemes be worth their name? An assessment of draft ecoschemes proposed by Member States.* WWF, EEB, Bird Life International.

Padró, R., Tello, E., Marco, I., et al. (2020). Modelling the scaling up of sustainable farming into Agroecology Territories: Potentials and bottlenecks at the landscape level in a Mediterranean case study. *Journal of Cleaner Production*, *275*, 124043. https://doi.org/10.1016/j.jclepro.2020.124043

Pérez-Neira, D., Soler-Montiel, M., Gutiérrez-Peña, R., et al. (2018). Energy Assessment of Pastoral Dairy Goat Husbandry from an Agroecological Economics Perspective. A Case Study in Andalusia (Spain). *Sustainability*, *10*(8), 2838. https://doi.org/10.3390/su10082838

Pimentel, P., Pimentel, M. (1979). *Food, Energy and Society*. Edward Arnold.

Pingali, P.L. (2012). Green Revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, *109*(31), 12302–12308. https://doi.org/10.1073/pnas.0912953109

Pinilla, V., Sáez, L. A. (2017). *Rural depopulation in Spain: Genesis of a problem and innovative policies*. https://sspa-network.eu/wp-content/uploads/Informe-CEDDAR-def-1_EN-GB-1.pdf

Sánchez-Silva, C. (2018). En las entrañas del imperio del cava. *El País*. https://elpais.com/elpais/2018/12/14/album/1544804527_104652.html#foto_gal_1

Schebesta, H., Candel, J.J.L. (2020). Game-changing potential of the EU’s Farm to Fork Strategy. *Nature Food*, *1*(10), 586–588. https://doi.org/10.1038/s43016-020-00166-9

Tello, E., Galán, E., Sacristán, V., et al. (2016). Opening the black box of energy throughputs in farm systems: A decomposition analysis between the energy returns to external inputs, internal biomass reuses and total inputs consumed (the Vallès County, Catalonia, c.1860 and 1999). *Ecological Economics*, *121*, 160–174. https://doi.org/10.1016/j.ecolecon.2015.11.012

van der Ploeg, J. D., Barjolle, D., Bruil, J., et al. (2019). The economic potential of agroecology: Empirical evidence from Europe. *Journal of Rural Studies*, *71*, 46–61. https://doi.org/10.1016/j.jrurstud.2019.09.003

Vila-Traver, J., Aguilera, E., Infante-Amate, J., et al. (2021). Climate change and industrialization as the main drivers of Spanish agriculture water stress. *Science of The Total Environment*, *760*, 143399. https://doi.org/10.1016/j.scitotenv.2020.143399

Wezel, A., Bellon, S., Doré, T., et al. (2011). Agroecology as a Science, a Movement and a Practice. In E. Lichtfouse, M. Hamelin, M. Navarrete, & P. Debaeke (Eds.), *Sustainable Agriculture Volume 2* (pp. 27–43). Springer Netherlands. https://doi.org/10.1007/978-94-007-0394-0_3

Supplementary Material

Table A1. Fund-flow energy approach of the agroecosystem accounted for a year

	Name	Description	Abbreviation
Energy Carriers	Farming Community Societal Inputs	This flow counts all inputs that the farm system uses from society	FCSI
	External Inputs	All the energy carriers coming from outside the system boundaries, including all organic and inorganic materials (machinery, fertilisers, animal feed, etc.), and the required human labour provided by the workers of the company.	EI
	Total Inputs Consumed	Includes all those elements that the agricultural system consumes, adding to the External Inputs (EI) all the biomass internally reused (BR).	TIC
	Solar Radiation	Energy from the sun that primary producers transform into plant biomass. As a gift of Nature, it is not accounted for as a cost.	SR
	Unharvested plant biomass	That part of the plant biomass production that is not harvested and remains available for feeding and self-reproduce the wildlife biodiversity associated with the agroecosystem.	UPH
	Land Produce	Total biomass harvested	LP
	Livestock-Barnyard Produce	All biomass produced and sold outside the farm by domestic animals (milk, meat, wool, hides and skins, etc.).	LBP
	Livestock-Barnyard Waste	Waste is defined as that part of animal production that is not allocated to a suitable destination to renew the live funds of the agroecosystem.	LBW
	Total Produce	It includes everything produced by vines, other crops and animals, before deducting reused biomass (and residues wasted, if any).	TP
	Biomass Reused	The agricultural part of all harvested biomass directly reused for agricultural purposes within the farm to maintain the live funds of the agroecosystem.	BR
	Farmland Waste	The portion of biomass production, both agricultural and animal, that does not contribute to the renewal of live agroecosystem funds. The only relevant waste in this case is the grape pomace.	FW
	Final Produce	That part of plant and animal biomass production which is available for human consumption, and which will not be used to maintain agroecosystem functions and to reproduce its live funds when it is released to the outside world beyond the agroecosystem boundaries.	FP
	Livestock-Barnyard Services	Those services that animals can perform, e.g., ploughing, grazing or manuring.	LBS
Fund Elements	Gramona	We separate the Gramona and society sub-systems to distinguish between them but considering the close relationship between them. We also consider that part of the final product that Gramona uses coming from small vine-growers associated to the firm.	
	Society		
	Associated Biodiversity	The vineyard refers to the space where agricultural activity is carried out to produce grapes. This, in turn, is affected by the ecosystem services provided by the associated biodiversity. Livestock also has effects on the vineyards through physical work or grazing, and the contribution of biomass reuses to the soil. Olive trees and woodland favour the creation of a heterogeneous landscape that benefits the farm-associated biodiversity in the territory.	
	Vineyard/Olive/Tree/Bush/Forest		
	Livestock		

Table A2. Energy flows considered for the biophysical accounting of the Gramona farm

	Energy flows	**Description**	**Unit**	**Flow**	**Source**	
Inputs	Manure	When manure is bought from outside the farm, including the straw to make it.	Kg	EI	Gramona report	
	Machinery	Reference is made to tractors used	Hours	EI	Gramona report	
	Biodynamic treatments	Soil treatments bought from outside the farm	Grams	EI	Gramona report	
	Organic treatments	Soil treatments bought from outside the farm	Kg	EI	Gramona report	
	Human labour	All types of human work used for the farm production	Hours	EI	Gramona report	
	Animal fodder	All types of fodder for the livestock being bought from external suppliers.	Kg	EI	Gramona report	
	Grape leaves	1,925 kg/ha	Kg	BR	AMB Database	
	Vine shoot tips pruned	2,442 kg/ha	Kg	BR	AMB Database	
	Old vines uprooted (wood)	Strains that are uprooted annually due to disease or lack of vigour. In an ideal theoretical situation, 2.5% of all Gramona vineyards are uprooted every year.	Kg	BR	Gramona report	
	Olive-tree branches pruned (wood)	Fresh production*10.02*Surface/5,42	Kg	BR	AMB Database	
	Olive-tree twigs grazed	Fresh production *4.42* Surface/5.42	Kg	BR	AMB Database	
	Pastures, forestland & fallows grazed	Natural forests, pastures and fallows foraged by livestock (cows and sheep)	Kg	BR	Gramona	
	Manure	Internally obtained from the farm herds, and uncollected livestock manure while grazing	Kg	BR	Gramona	
Wastes	Grape Pomace	25% of the production	Kg	Out-of-place waste[3]	AMB Database	
	Olive pomace (residue of the olive after it has been pressed to extract the oil).	Fresh production *2.92*Surface/5.42	Kg	Out-of-place waste[1]	AMB Database	
Outputs	Must (grape juice)	75% of the production	Kg	FP	AMB Database	
	Olives	Olive tree production	Kg	FP	Gramona	
	Livestock	Livestock products from the Gramona agroecosystem (i.e., eggs and lamb meat)	Kg	FP	Gramona	

Note: [1]Out of place wastes refer to agroecosystem flows that could be included as BR or FP but, because of legal regulations or company constrains, they are currently discarded as such.

Table A3. Conversion factors of the flows identified in La Solana del Cava in 2018

External Inputs					
Machinery	lifespan, years	kg	MJ/kg	fuel, MJ/h	**Source**
TRA-01 - Tractor 66 (without operator)	18	2,811.60	114.55	511.	kg: Parcerisas et al. (2012)
TRA-02 - Tractor 88 (without operator)	18	2,811.60	114.55	511	MJ/kg: Aguilera et al. (2015)
TRA-03 - Tractor 100 (without operator)	18	4,217.40	114.55	767	fuel, MJ/h: Marco et al. (2018)
Human labour	MJ/workday				Tello et al. (2015)
	7.50				
Biodynamic inputs	MJ/kg	**Font**			
AGR BIO 011 - Ponytail	24.00	https://biodinamica.es/preparados-biodinamicos/#			
AGR PRE 500 - preparation 500	9.10				
AGR PRE 501 - preparation 501	0.18				
AGR PRE MTH - preparation Maria Thun	8.99				
Organic inputs	MJ/kg	**Source**			
fungicides & insecticides	24.00	Aguilera et al. (2015)			
fertilizers	14.50				
Compost	MJ/kg	Humidity	**Source**		
	18.21	50%	IERMB Report		
Compost transport	MJ(t-km)	GJ	**Source**		
road trucks	1.40	32.73	Pérez Martínez, Monzón de Cáceres (2008)		
Animal feeding	MJ/kg	**Source**			
Wheat bran	18.00	IERMB Report			
By-products					
	MJ/kg	Humidity	**Source**		
Grape pomace	21.80	59%	IERMB Report		
Vine leaves	19.00	67%			
Vine shoot tips	18.80	41%			
Old vines uprooted	18.80	41%			
Olive-tree branches pruned	19.60	29%			
Olive pomace	22.00	40%			
Olive-tree twigs grazed	18.90	28%			
Pastures, forestland & fallows grazed	17.50	80%			
Manure produced in the farm	18.21	50%			
Final Produce					
	MJ/kg	Humidity			
Grape juice (must)	17.20	83%	IERMB Report		
Olives	39.70	0%			
Eggs	30.00	70%			
Lamb meat	22. 00	55%			

Table A4. Profitability indicators for the consolidated Gramona group of three Ltd. companies

Indicators	2016	2017	2018	2019	Average
Economic profitability	10%	11%	8%	8%	9%
Financial profitability	7%	8%	7%	6%	7%
Overall liquidity	4.32	5.06	6.53	3.49	4.85
Indebtedness	30%	25%	18%	40%	28%
Return on equity	9%	11%	8%	9%	9%
Return on capital	12%	13%	9%	9%	11%
Return on total assets	7%	8%	7%	6%	6%

Source: Our own from the Iberian Balance Analysis System (SABI).

Table A5. Profitability of leading companies in the sector located in Sant Sadurní d'Anoia, outside the CORPINNAT label.

Codorniu	Average (2016-2018)	Average Gramona (2016-2019)
Economic profitability	-1%	9%
Financial profitability	-3%	7%
General liquidity	1.06	4.85
Indebtedness	54%	28%
Freixenet	Average (2016-2019)	
Economic profitability	2%	
Financial profitability	4%	
General liquidity	1.53	
Indebtedness	194%	

Source: Prepared by the authors based on data from the Iberian Balance Analysis System (SABI).

Table A6. Average profitability of four CORPINNAT companies (excluding Gramona)

	2016	2017	2018	2019	Average Gramona (2016-2019)
Economic profitability	1%	2%	2%	2%	9%
Financial profitability	2%	3%	4%	4%	7%
Overall liquidity	4.61	4.15	4.91	4.32	4.85
General indebtedness	29%	31%	33%	33%	28%
Number of workers	15.8	16.2	19.0	18.6	66.75

Source: Prepared by the authors based on data from the Iberian Balance Analysis System (SABI).