LABOUR, NATURE AND EXPLOTAITON: SOCIAL METABOLISM AND INEQUALITY IN A FARMING COMMUNITY IN MID-NINTEENTH CENTURY CATALONIA

INÉS MARCO[1]
ROC PADRÓ[2]
ENRIC TELLO[1]

ACKNOWLEDGEMENTS

This work springs from the international research project on Sustainable Farm Systems: Long-Term Socio-Ecological Metabolism in Western Agriculture funded by the Social Sciences and Humanities Research Council of Canada SFS 895-2011-1020. Some parts have been supported by the Spanish research project RTI2018-093970-B-C33 (MCIU/AEI/FEDER, UE). We also thank the help received from Maria Guàrdia (Municipal Archive of Sentmenat). We are grateful to Manolo González de Molina and Inma Villa (University Pablo de Olavide, Sevilla), Eduardo Aguilera (Polytechnic University of Madrid) and David Soto (University of Santiago de Compostela) for stimulating discussions and helpful comments. Suggestions and comments from the anonymous peer-review are thankfully acknowledged. Remaining shortcomings are the authors' responsibility.

[1] Department of Economic History, Institutions and Policy and World Economy, Faculty of Economics and Business, University of Barcelona. Av. Diagonal, 690 - 08034 Barcelona, Spain.
[2] Roc Padró, Barcelona Institute of Regional and Metropolitan Studies, Autonomous University of Barcelona, Bellaterra Campus, Plaça del Coneixement, MRA building, 2nd floor - 08193 Bellaterra, Spain.
Correspondence
Inés Marco, Department of Economic History, Institutions and Policy and World Economy, Faculty of Economics and Business, University of Barcelona. Av. Diagonal, 690 - 08034 Barcelona, Spain
E-mails: ines.marco@ub.edu; Roc.Padro@uab.cat; tello@ub.edu

LABOUR, NATURE AND EXPLOITATION: SOCIAL METABOLISM AND INEQUALITY IN A FARMING COMMUNITY IN MID-NINTEENTH CENTURY CATALONIA

Abstract

Exploiting the labour of other people has historically been one of the main strategies to tackle the biophysical tension that always exists between the satisfaction of human needs and the labour required to fulfil them. Based on the insights of ecological, feminist and marxist economics, we disentangle the exploitation of the labour of women and labouring poor through a novel methodology that integrates energy, material, time and cash balances. We apply it to the sociometabolic flows between household units endowed with different land and livestock resources in a traditional rural community in Catalonia (Spain) in the mid-19th century. The results show that land and livestock hoarding led to a process of accumulation through dispossession that increased the exploitative relationships through the labour market, which in turn relied on the patriarchal division of labour between men and women at home. Our estimates of energy labour surplus reveal that male wages represented 88% of the equivalent consumption basket that would have been obtained by carrying out the same amount of labour on land of one's own. However, in the case of female wages the percentage was 54%. This shows that wage labour incorporated a significant amount of unpaid domestic family labour.

Keywords: Land-Time Budgets, Pre-industrial Organic Agricultures, Social Organization of Labour, Domestic and Care Labour, Energy-Labour Surplus.

INTRODUCTION

> 'Differences between individuals or between groups of individuals are not only normal but also unavoidable phenomena in the biological world. But only within the human species do we find, from the dawn of history on, inequalities of a different nature – social inequalities which have little, if anything, to do with the biological differences'. (Georgescu-Roegen 1977, 361)

Many studies of past and present rural communities have shown how the accumulation of land and livestock in fewer hands creates the need for landowners to hire wage labour and the dispossessed family units that need to accept this wage labour to survive. Yet, only very few researchers such as Bayliss-Smith (1982), Scheidel et al. (2013, 2014, 2018), Gizicki-Neundlinger et al. (2017a, 2017b) and Güldner and Krausmann (2017) have so far attempted to link the sociometabolic patterns of the biophyisical flows that sustain the economic reproduction of these rural communities with the social and gender inequalities that prevail both within and outside of them. In this article we advance a multidimensional analysis to link the biophysical, money and time flows to show how exploitative relationships based on patriarchal and social divisions of labour took place through the market exchange of labour time, money flows and the final consumption baskets of staple goods.

The exploration of these analytical links between the sociometabolic approach to farm reproduction and social and gender inequalities in a small pre-industrial farming community has the advantage of dealing with a much simpler unit of analysis than in the case of larger urban-industrial societies. Furthermore, it is important to gain a deeper understanding of the role that social and gender inequalities have played as driving forces in the historical socioecological transitions from past organic economies to the capitalist-industrial ones of the present day. González de Molina and Toledo (2014) argue that inequality often entailed an increase in exosomatic consumption by a small social group.[3] If this was not compensated by an equivalent reduction in the exosomatic consumption of other social classes, the total metabolic pressure increased the social demands on a territory beyond the size of its population. Thus, inequality might have been a powerful driver of the historical evolution of societies towards increasingly unsustainable sociometabolic regimes. Although the present work cannot enter deeply into this debate, this is the fundamental question within which our research is framed.

Despite being limited to a small-scale historical case study (Sentmenat, Catalonia, in the mid-19th century), our research seeks to contribute to the ample literature that sees technological advances as a process in which time and/or space are saved for some at the expense of time and space taken from someone and elsewhere through a process of appropriation based on accumulation by dispossession (Wilkinson 1973; Hornborg 2003; Harvey 2003). In the same vein, this approach helps us understand why the sociometabolic transition has entailed a change from a regime with greater pressure on internal inequality towards a regime that shifts social pressures towards external and intergenerational inequalities (González de Molina and Toledo 2014).

Empirical validation of these approaches requires research on the complex articulations between land endowment, labour performance and energy turnover in processes of social reproduction. This line of research is developed here in the study of traditional organic farming where land-labour-energy nexuses are clearer and easier to map and analyze. Nonetheless, the novel multi-budget accounting developed in this study has the potential to be enlarged and adapted to tackle wider cases in future research. The ultimate aim is to develop new methods of analysis and empirical evidence to inform a new sociometabolic transition towards more sustainable societies in what has been called the 'Third Great Transformation' (Haberl et al. 2010).

Our multi-budget analysis highlights two elements that have not been worked out in depth so far from a sociometabolic perspective: (*i*) the role of the human labour performed by different individuals belonging to different

[3] The distinction between endosomatic and exosomatic energy flows was first introduced by Lotka (1956) and later developed by Georgescu-Roegen (1975). Endosomatic energy flows refer to the use of energy needed to maintain the internal metabolism of a human being, while exosomatic flows refer to the use of energy sources for energy conversion outside the human body, but still operated under human control (Ramos-Martín, 2006).

social and gender groups in socio-ecological reproduction processes; and (*ii*) the unequal distribution of the final product among these different genders and social groups that results from the reproductive processess that take place through the market. Until now, the emphasis in sustainability analyses of agrarian systems has been on the reproduction of two agroecosystem funds: soil fertility and livestock (Burke et al. 2002; Cunfer 2004, 2005; Billen et al. 2009; García-Ruiz et al. 2012; Tello et al. 2012; Gingrich et al. 2015; Cunfer and Krausmann 2013, 2015; Delgadillo-Vargas et al. 2016). Less attention has been paid to the third fund; that is, household peasant units and their annual reproduction (Scheidel 2013). The role of these farming communities as suppliers of labour, the consideration of time as a key resource (Fischer-Kowalski et al. 2010) and the exploitative relationships established among different social groups have been analyzed in less detail, if at all.

Our study addresses four essential questions posed by agrarian political economy (Bernstein 2010): Who owns what? Who does what? Who gets what? What do they do with it? Although these questions have frequently been addressed in the study of social inequalities in many agrarian societies, including the Catalan one analyzed here (Tello and Badia-Miró 2018; Tello et al. 2018; Colomé et al. 2002; Garrabou et al. 2014; González de Molina et al. 2014; Parcerisas 2014), answering them from the perspective of the contributions made by social metabolism and political ecology research remains a pending task (Gerber and Scheidel 2018). The objective is to contribute to the development of a sociometabolic analysis of the historical forms of exploitation in traditional organic societies, in particular those that arose immediately after the Spanish liberal agrarian reforms of the 19th century as a result of unequal access to two key funds of agroecosystems: land and livestock. In the first section we outline the theoretical framework from which we understand the links between the prevailing biophysical constraints and the role of labour as a fundamental element that drives social metabolism. The second section summarizes the multi-budget method of calculation developed for our biophysical analysis of social inequality in traditional organic farming communities and presents the main hypothesis of this research. We then describe the main features of the case study – Sentmenat, Catalonia, in 1850 – and explain the choice of the households selected for analysis. In the third section we present the results, which we discuss in the conclusion. A methodological annex details the main criteria and data on which the empirical exercise is based.

THEORETICAL FRAMEWORK: NATURE, LABOUR AND EXPLOITATION

> 'The problem of "unequal exchange" is a paradigmatically Marxian topic in that *our difficulties in conceptualizing it can be seen as part of the conditions for its existence'* (Hornborg 2003, 4, emphasis in original).
>
> .

Can social inequality be analyzed from a sociometabolic perspective? What original contributions could this new perspective provide? Starting with the notions of the social organization of labour, the social distribution of product and the underlying exploitative relationships, we offer a first proposal for a new multi-budget accounting that interlinks the different flows (labour time, biomass and money) that were exchanged in markets by different types of household unit.

The concept of labour is integral to understanding the biophysical, cognitive and social links that economic activity establishes between society and nature. We are aware of its complex multidimensionality, but for the purposes of this research we start with a narrow definition that considers labour power, or labour capacity, as the set of physical and mental capabilities acquired by human beings at a certain point of their development as individuals (Marx 1996 [1867]). In biophysical terms, the specific implementation of this labour capacity is the fundamental process through which human societies are able to appropriate, transform, distribute, consume and produce a set of energy and material flows taken from nature in order to have enough energy and materials available for their annual reproduction. Therefore, labour is what drives the entire biophysical sphere of a society, and what the labouring households obtain from their labour determines the social distribution and consumption of what society produces.

Analogously, the existence of basic human needs requiring satisfaction is rooted in the belonging of the human species to the biosphere, which implies that its fulfilment is as much linked to thermodynamics as to the deployment of energy and materials by human labour. However, the socially produced satisfiers that fulfill these needs, although rooted in the nature of the human species and its biophysical environment, also become socially determined cultural constructs.[4] Acknowledging the multiple and relational nature of labour as biophysically, cognitively and socially determined has always been part of the basic core in the long conformation of a substantive economics, historically opposed to the mainstream of liberal neoclassical economics, which only operates with exchange values expressed in monetary terms (Gerber and Scheidel 2018). From the world-view of substantive economics, the primordial aim of

[4] Manfred Max-Neef (1991) has established the distinction between 'needs' and their 'satisfiers'. One of the key aspects that determines a sociometabolic regime is the choice of the specific *satisfiers* of the fundamental human *needs*, which are always culturally and economically determined by the prevailing societal rules.

human labour is the production of use values for the reproduction of workers and their offspring (Polanyi 1957a, 1957b[1944]). Accounting for this in energy and material terms is an analytical advance, but one that remains in its infancy due to the long history of misunderstandings between energy analysis, political ecology and Marxism (Martínez-Alier and Naredo 1982; Hornborg 1998; Foster and Holleman 2014; Tello 2016).

The relationship of every human being with their own labour power is also Janus-faced. On the one hand, labour is the process through which the goods and services that are necessary for life (food, fuel, fibres, housing, transportation) are obtained. On the other hand, a human being's own capabilities, both physical and mental, are their first means of production. As a means of production that develops physical labour in a world that is subordinated to the principle of entropy, all labour requires an 'effort' to overcome a resistance. As Karl Marx described it in *Capital*: '(man) *opposes himself to nature as one of her forces, setting in motion arms and legs, head and hands, the natural forces of his body, in order to appropriate Nature's productions in a form adapted to his wants*' (Marx 1996 [1867], Chapter 7). Therefore, the human body produces use value, which at the same time it needs to consume (Mies 1986). It is the integration of the human species in its biophysical context that defines both sides of this cycle: the inevitability of processes of appropriation and distribution to enable the consumption of the materials and energy needed for human reproduction and the inevitability of labour as a means to obtain them.

Given that human beings organize labour as well as consumption in a social manner, individual decision-making capabilities are extensively framed by the social structures in which both labour and consumption occur. As a mental experiment, we could start by placing this decision-making process in egalitarian societies defined as '*one* (community) *in which those who produce something are also—in an intergenerational sense—its consumers*' (Mies 1986, 46). In that case, and in the absence of technical innovation, any increase in consumption must be met by an increase in labouring time (Chayanov 1986 [1925]; Van der Ploeg 2014). When the social groups that benefit from the increase in consumption are the same as those that assume the efforts associated with that labour process, there will be no inherent tendency towards indefinitely increasing consumption levels, thus creating a certain stability in the sociometabolic regime.

Despite the above, even in societies based in relatively small and egalitarian human groups, a latent biophysical tension may exist. This may lead to the potential pursuit of an increase in consumption flows (desirable goal) while avoiding an increase in the applied labour required (undesirable goal). Different strategies have been formulated to deal with this biophysical tension, among which we can emphasize (*i*) the incentive for technological innovations, particularly those that facilitate the control of labour and the products of others; (*ii*) the overexploitation of natural resources (either renewable, e.g. soil fertility, or non-renewable, e.g. fossil fuels; and (*iii*) the establishment of exploitative inter-personal relationships. Given the characteristics of our case study, which is focused on a pre-industrial rural community that practised an advanced form of organic agriculture with a still low incidence of industrial technical innovations and non-renewable energy sources, the present work will focus on the third aspect.

The capacity to appropriate part of the products generated by the labour of others – that is, the prospect of 'using' the endosomatic organs of 'others' (Georgescu-Roegen 1977) – presupposes the breaking of a direct link between the producer and consumer of a given consumption basket. In this way, the original biophysical tension could also become an incentive for the establishment of exploitative social relationships, understood as 'those in which non-producers are able to appropriate and consume (or invest) products and services of actual producers' (Mies 1986, 46; also Luxemburg 1985[1925]). From the understanding of power as based on consent (Godelier 1998), the maintenance of permanent exploitative relationships also requires several processes of legitimation. For the purposes of our case study, located within a traditional Catalan form of organic agriculture in the aftermath of the Spanish liberal reforms, we identify two main sorts of exploitative relationship: (*i*) patriarchy, through the sexual division of labour; and (*ii*) the agrarian class structure, through land and livestock being treated as private property.

It seems incontrovertible that one of the first forms of exploitation that appeared within human communities originated with the sexual division of labour: 'The imbalance of production meant that women, through their labour, were giving men both time and surplus' (Mellor 1992, 133). Domestic labour and care labour were both assigned exclusively to women, partially denying their role in production outside the home and ensuring (re)productive labour for the preservation of the family and society's labour force. Even though the total amount of labour hours of men and women might be similar within the domestic economy, some research suggests that food redistribution was unequal within the household (Ryan-Johansson 1977; Humphries 1991; Nicholas and Oxley 1993; Horrell and Oxley 2013). A feature common to all these female tasks was that they also included the biological process of intergenerational reproduction, thus ensuring the (re)production of the labour force (Firestone 1970) in order to sustain its current 'active' members, as well as future workers. The importance of female domestic and care work, which ensures social reproduction, went hand in hand with its devaluation, which helped to legitimize the exploitation of women from the outset.

Once human gender inequality had been socio-symbolically legitimized, it led the way to establishing other forms of social hierarchy within communities or societies (Bookchin 1982). This allowed the unequal distribution of labour and the appropriation of surplus production on the part of dominant classes of non-producers (Bernstein 2010, 21). Starting with John Locke (1963[1690]), the line of thought that led from the Age of Enlightenment to Liberalism has continued to assume that property is the result of one's own labour. However, it had to face the fact that this criterion ceases to apply when dissociation occurs between the producer (labourer) and the means of production (proprieter). In this case, Locke argued that the landowner was also entitled to appropriate the results of the labour performed by the bodies of other people when these bodies belonged to him. From that point on, it could also be admitted that only a fraction of product had to be directed at recompensing the labourer, thus justifying the owner of any means of production (including the time of human labour) to appropriate all the resulting product. Only through a previous 'competitive exclusion', defined as the 'appropriation by a group of humans of a territory and thus of the use of its services and resources' (González de Molina and Toledo 2014, 278), exerted by a minority against the rest of society, was it possible to develop and later legitimize a more stable process of '*parasitism*' dependent on the exploitation of labour and resources.

The processes just described allow us to observe how biophysical limits raised a series of tensions inherently linked to the social organization of labour and the resulting allocation of rights in the distribution of production. Exploitative relationships that lead to a process of the asymmetrical performance of roles and the appropriation of production regarding labour distribution can therefore also be understood from a biophysical perspective. This allows the consideration of 'inequality' to be widened by referring to 'exploitation' between human beings, thereby bringing to light the underlying links between the different social groups that are opposed in this process of the appropriation, transformation, circulation, consumption and production of energy and materials taken from nature by labour. The maintenance of this kind of parasitic relationship requires symbolic and institutional mechanisms to be legitimized. In this study we will focus on two of them: the sexual division of labour, and private property in land and livestock. Our goal is to advance a substantive ecological economics that, from accounting for social metabolism, goes on to examine inequality, exploitation and the socioecological mechanisms that enforce them (Gerber and Scheidel 2018). For this purpose, we need to examine ideological veils and the institutional mechanisms that justify and preserve them, such as the market exchanges that, from a sociometabolic standpoint, are seen as the 'converters' of biophysical flows into monetary flows and vice versa.

METHODOLOGY, HYPOTHESIS AND FEATURES OF THE CASE STUDY (SENTMENAT, 1850)

Labour, land and livestock: A new methodological approach to their flow accounting

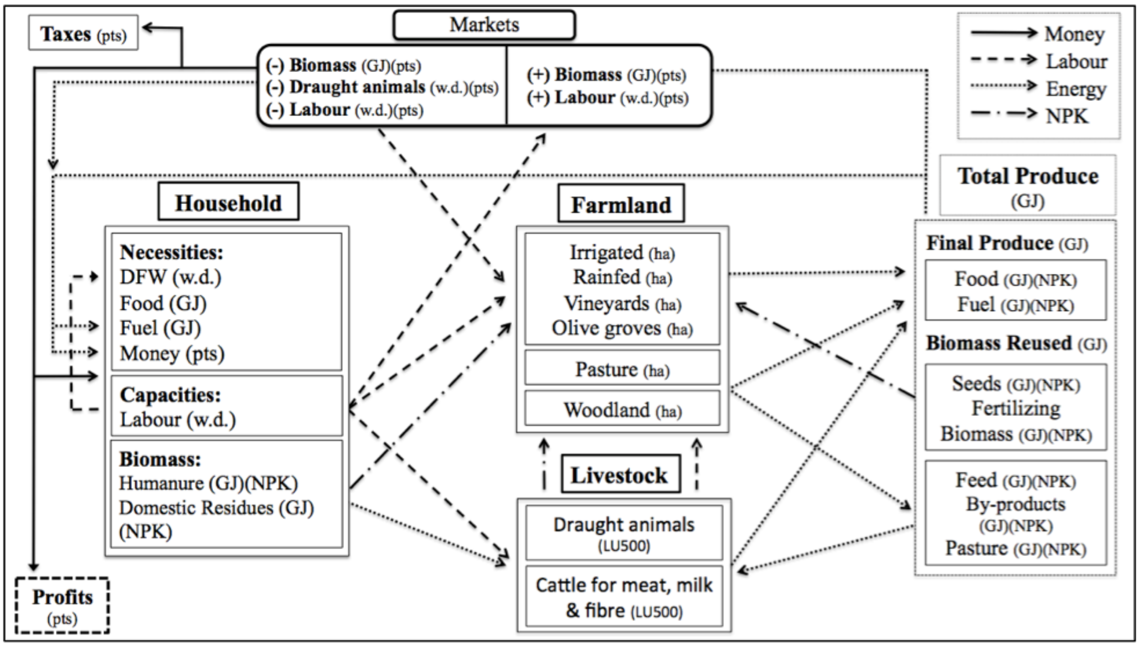
In order to assess exploitative relationships within pre-industrial organic farming communities, our starting point is the fact that, through the hoarding of farmland and livestock, the larger landowners established their capacity to control large shares of the agricultural product that resulted. However, without the ability to mobilize a labour force, the management of any farmland estate that exceeded the labour capacity of a family household unit would not have been possible. Hence, a requirement for the availability of external labour was the existence of social groups that had been 'dispossessed' of the land and other means of production and whose reproduction required the sale of their labour in the market. Although the imbalances between those with a 'farmland surplus' and a 'labour surplus' were also adjusted through land tenure, here we will focus only on the hiring of labour. We will present a methodology for sociometabolic accounting that visualizes and characterizes the functioning of the exploitative relationships that arose through the labour market between different social groups within the agrarian class structure we are examining.

This kind of approach requires the elaboration of biophysical balances on the scale of the domestic unit, a quite unusual perspective except for some very recent studies (Nawn 2016; Gizicki-Neundlinger et al. 2017a, 2017b). So far each of these sociometabolic explorations of social inequality uses its own methodology, which makes comparative analyses difficult. The accounting method we propose is a hybrid that combines methodologies used in other lines of research. First, we use Material and Energy Flow Accounting (MEFA) to estimate the different energy and biophysical flows that connected the key fund elements being considered: farmland, livestock and the agricultural community (Tello et al. 2016; Galán et al. 2016; Guzmán and González de Molina 2017; Gingrich et al. 2018). Secondly, we apply Land-Time Budget Analysis (LTBA), a methodology used in many case studies of traditional or transitional farming (Pastore et al. 1999; Gomiero and Giampietro 2001; Grunbuhel and Schandl 2005). Lastly, we link material-energy flows and labour time with family cash flows through a circular-reproductive connection that allows us to observe where these biophysical flows came from and where they finally ended up. In doing so, for every domestic unit we can specify the flows that connected the distinct funds (household, farmland and livestock) expressed in terms of energy, materials, soil nutrients, labour and money (Figure 1).

Every fund has reproductive needs and capacities. In this work we will mainly focus on the yearly needs and capacities of households (HH). Every HH had needs in terms of (*i*) domestic and care work, (*ii*) food consumption, (*iii*) fuel and (*iv*) money (details can be found in the annex). In turn, certain capacities were available for every HH that in this approach we narrow down to labour capacity, even though they are a lot more diverse in human terms. All these variables will be defined by the size and composition of every HH (gender and age), except the need for cash flows that also depended on their farmland and livestock endowments.

Total Produce (TP) obtained will, at first, be distributed according to the capacity of every HH to reproduce their funds every year. We proceed under the assumption that agricultural processes did not pursue social reproduction alone, but also the reproduction of all the other funds that made farmland labour possible (livestock and soil fertility). In a sequential process, we first compare food and fuel availability for human consumption with the requirements of every HH. This will show the self-sufficiency ratios, as well as the resulting surpluses or deficits for every product. A second group of products were allocated to the reproduction of soil fertility, from which we can estimate the quantity and quality of available fertilizing biomass and the outcome of nutrient balances. A third group of products was devoted to reproducing livestock. These last two flows are grouped as Biomass Reused (BR), and the criteria for the drafting of these two processes are detailed in Marco et al. (2018) and Padró et al. (2019). The implicit assumption is that in normal conditions these three reproduction processes had to be met every year, and that the flows that could not be obtained from HHs' own internal provisions would be acquired in the market (thus increasing cash requirements).

Figure 1. Sociometabolic Fund-Flow structure of traditional organic agricultures



Notes: 'pts' refers to the Spanish monetary unit, '*pesetas*'; 'w.d.' refers to 'working days' and 'LU500' refers to Livestock Units of a standardized weight of 500 kg. The boxes on the left represent the three funds (Household, Farmland and Livestock). Labour that is directly incorporated from the HH towards the same HH is Domestic and Family Work (DFW). Although the material flows have an equivalent in energy as well as in nutrients, we will define every flow according to its main role (i.e. fertilizing biomass in Nitrogen equivalents; food, fuel and feed in energy units). Source: Our own.

Time balances are calculated next. To that end we start deducting from the total amount of available labouring time the quantity of Domestic and Family Work (DFW) required, defined by HH size and composition (gender and age). Secondly, we estimated the quantity of farming labour required by each HH according to (*i*) farmland extent and uses, and (*ii*) livestock size and composition (see annex). From this comparison we can determine whether labour requirements were greater or lower than the HH's labour capacity, that is, whether there was a surplus of or a deficit in family labour capacity. In the case of the latter, the HH had to hire external labour. If there was a surplus, we estimated what part of that surplus would be effectively transformed into wage labour according to the family's need for a cash income. To that end, we estimated the income from the surplus of agricultural products and deducted the expenses resulting from purchases of products (including food intake, fuel, animal feed or fertilizer). We also included housing rent, clothing and other HH expenses. If the cash balance was negative, a part of the extra labour force needed would have had to be hired in the market. Only the wages necessary to close cash deficits in basic subsistence have been considered, a conservative assumption that does not include coverage of other needs or the effects of unemployment. In so doing, we are linking five consecutive balances: (*i*) human consumption, (*ii*), livestock feed, (*iii*) soil nutrients, (*iv*) labour and (*v*) money. This does not mean that all balances could always be closed. Although the household types that we are examining here do not reflect these situations, there might be two sorts of barrier. First, the availability of labour for sale in the market could not be enough to earn enough money to buy the products needed to achieve the HH's reproduction (e.g. food, housing, manure). Second, the ability to transform available labour into hired labour depended on unemployment rates and seasonality. In neither case can we determine which balances would not be finally closed. These questions should be addressed in further research.

Hence, we consider that exchanges among HHs with different imbalances (surplus of labour or surplus of agricultural product) were conducted through markets, which operated as key elements in redistributing the necessary production and labour flows for the sociometabolic reproduction of funds. Using the data obtained through historical sources, this multi-budget methodology allows us to understand the different roles of use value and exchange value flows within each HH, along with their ability or inability to obtain the monetary flows they needed to close their annual reproduction. Applied to a larger number of farm units, it would be worth assessing whether, as proposed by Amit Bhaduri (1983), there existed a polarization among the different farming HHs in their degree of insertion into the market. In any case, we would expect medium-size farms to be able to focus more on the production of use value, while the smallest and largest farms were more deeply involved in exchange value—either voluntarily (the richer ones) or forcibly (the poorer ones).

In order to analyze land and labour productivity indicators, we have to convert the energy content of Final Produce through some homogenization procedure. However, in doing so we seek to avoid conflating the different energy qualities carried by food and fuel with meaningless numbers (Giampietro et al. 2013). To this end, we have created a basic consumption basket which includes the average annual consumption of food and fuel for the selected household model. Then we estimate its energy content (15 GJ for food and 42 GJ for fuel) and its cash cost (400 pesetas for food and 96 pesetas for fuel). As can be seen, one food GJ (26 pesetas) was much more expensive than a fuel GJ (2.3 pesetas). Weighted by their proportions, we arrive at a price for the whole basic consumption basket (9 pesetas·GJ^{-1}). This common ratio will be used to convert the heterogeneous composition of Final Produce into a homogeneous one, which consists of the same proportion of food and fuel energy that we found in the historical sources on family consumption baskets. This allows us to compare the Final Produce of different HHs in terms of their

Equivalent Consumption Baskets (ECB) calculated in energy units. This procedure facilitates the comparison between hired labour productivity and the labour productivity of autonomous labour by converting the money earnt through wage labour into the same energy ECB ratios as those that can be calculated for a family farm.

We use different energy productivity indicators, depending on the inputs and outputs analyzed. Although the productivities are all measured in energy terms (mainly GJ of ECB, or GJ_{ECB}; we will not indicate this on every occasion in order to avoid repetition). First, we analyze the productivities with respect to the Final Produce in the Equivalent Consumption Baskets (FP_{ECB}). Final Produce comprises all biomass products from the regional agroecosystem that were used by the local community or sold to markets, including crops and firewood derived from the land (land final product) and livestock products (livestock final product). We relate it to two major inputs, land (measured in hectares of farmland) and labour (measured in agricultural working days) to provide us with the average *Final Productivity of Land* (FP_{Lan}) and the *Final Productivity of Labour* (FP_{Lab}). Secondly, we calculate an indicator to assess the whole labour effort required to maintain the productive capacity of the agroecosystem, which would include not only the agricultural tasks needed to maintain soil fertility and livestock, but also the labour needed to reproduce the human workforce within HHs. In this case, we maintain FP_{ECB} as the output and include both agricultural as well as Domestic and Family Work (DFW) as inputs to produce what we call the *Total Productivity of Labour* (TP_{Lab}).

Case study and household selection

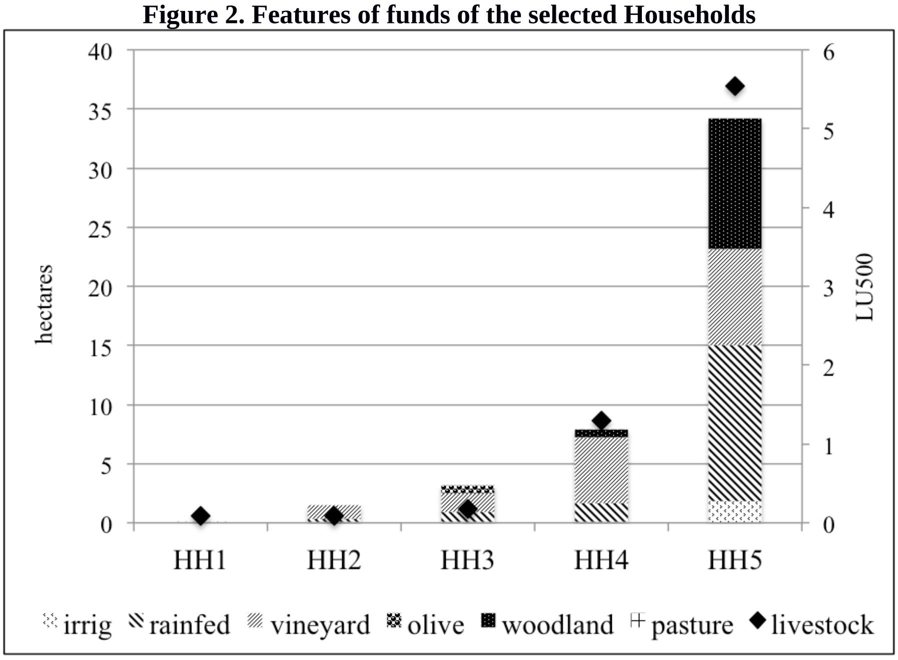
Given the complexity of the methodology just presented, in this initial attempt we propose to apply it first to five representative households of a local case study located in the province of Barcelona (Sentmenat municipality, Vallès County, Catalonia, c.1850). Thanks to the availability of historical sources and cadastral maps, and to the long-term historical research conducted on these four municipalities of the Vallès County (Serra 1988; Cussó et al. 2006a and 2006b; Garrabou et al. 2001, 2010, 2012; Olarieta et al. 2011; Tello et al., 2016; Marull et al. 2010, Galán et al. 2016), our research project has been using them as a test case in developing and applying a sociometabolic analysis of farm systems before and after the Green Revolution. The Vallès is a small plain between the littoral and pre-littoral mountain ranges of Catalonia, and the municipalities in the study area are located 30-40 km away from Barcelona city, but within its metropolitan region. This is a transect area going from the hilltops in the pre-littoral mountains to the centre of the plain that includes different types of soils and slopes, with typical Mediterranean rainfall ranging from 600 mm in the plain up to 800 mm a year in the hills. Previous research has analyzed land-use (Olarieta et al. 2011) and calculated energy balances (Marco et al. 2018; Padró et al. 2017; Galán et al. 2016; Tello et al. 2016) and nutrient balances (Tello et al. 2012, 2013). In the present article we apply our proposed methodology to just one of these municipalities (Sentmenat).

On the basis of the sources detailed in the methodological annex (the Cadastre of 1841, the Municipal Census of 1855, and the *Amillaramiento* of 1850, a list of plots and their ownership), we have resampled the size and composition of the funds (farmland and livestock) owned by 193 agricultural HHs, which means 86% of those listed as farm labourers in the Municipal Census of 1857. To those numbers we added 51 registered agricultural HHs with no access to land or livestock. Our sample therefore comprises 244 HHs covering 63% of the total area, as it excludes land in this municipality owned by residents of other municipalities (more is detailed in the annex). Although we will generally refer to the year 1850, given that the main historical sources used to account for landownership and land uses are closest to this date, other historical records provide us with other types of data for later dates ranging from 1850 to 1870. This is especially relevant for cash flows, as most of the sources referring to them date from 1870. Despite this, only deep changes in relative prices, which did not take place throughout that period in this area, would strongly affect our results, especially those between the wages and prices of agricultural products. Indeed, the prices and wages used are coherent throughout the sample, as they all refer to the mid-1870s. In doing so, we are assuming that landownership distribution and farmland uses had a high inertia after the main Spanish agrarian liberal reforms (1836-1845), with only small and slow changes from the 1850s to the 1870s. This also means that the results refer to this whole period. However, they are aimed at revealing the basic structural functioning of this epoch, rather than at addressing short-term historical changes. The following quantitative estimates need to be understood as an initial test of the application of the multi-budget methodology, and not only as an exercise in local history.

To establish the different subgroups in the sample, we start within the limits related to area and land use that are necessary for the annual reproduction of this agroecosystem, defined by Padró et al. (2019). By means of an agro-ecological and socioeconomic linear programming model, the present work simulates the dynamics established between the household composition of fund elements (needs/capabilities) and the biophysical conditions. Through technical coefficients and consumption standards, we have established that the average household c.1850 in this case study (five people; two dependent persons) needed 4.36 hectares of total surface (including crops, grassland and forest) to cover the family's basic needs, replenish soil fertility and provide enough animal feed. From this reference to a reproducible farmland area, we have categorised HHs into a five-part typology: (*i*) those without land (21% of the total); (*ii*) those with up to 2.18 ha (26%); (*iii*) those between 2.18 and 4.36 ha (23%); (*iv*) those between 4.36 and 8.72 (18 %); and (*v*) those with more than 8.72 ha (12 %). The choice of these five types of household will be used as a test for the application of the multi-budget accounting methodology. We aim to find different types of pattern in terms of labour/land ratios, and their consequences in terms of the exploitative relationships thereby established. The limits of these initial empirical results imply that more research is needed using this method.

Given that HH size and composition affected many of the main flows analyzed (domestic care and family work, availability of labour, food consumption and clothing expenses), we isolated the effect by standardizing the different HH models so as to be able to focus our analysis on the impact of inequality in terms of access to farmland. To that end, we defined a representative HH model and selected actual HHs with those characteristics for each group (see the annex). All the chosen HHs (Figure 2) had four members—a bit less than the average—, with two of them active and two dependents, except HH5 because in this subgroup there was no HH with those characteristics. For this category we selected the HH with the most similar size and dependency ratio. The existence of two very different HH sizes was another consequence of the unequal social polarization between the wealthy farms and the rest. The former lodged servants hired as farmhands by the year and were also interested in retaining some family members labouring on the farm (e.g. singles and widowers who were not heirs) to avoid hiring journeymen and journeywomen. The latter ones, conversely, could not afford to house more relatives, nor even some of their young sons and daughters, who became the formers' servants. The different HHs owned respectively 0, 1.5, 3.2, 7.9 and 34.2 hectares of farmland (Figure 2). Vine cultivation prevailed in HH2 and HH3, while the share of rain-fed and/or irrigated cereals and woodland increased in the larger HHs. In a similar way, livestock density increased with the size of the land possessed: 0.09, 0.09, 0.17, 1.34 and 5.54 Livestock Units of a standardized live weight of 500 kg (LU500) respectively.

Figure 2. Features of funds of the selected Households



Source: Our own, from the sources mentioned in the text.

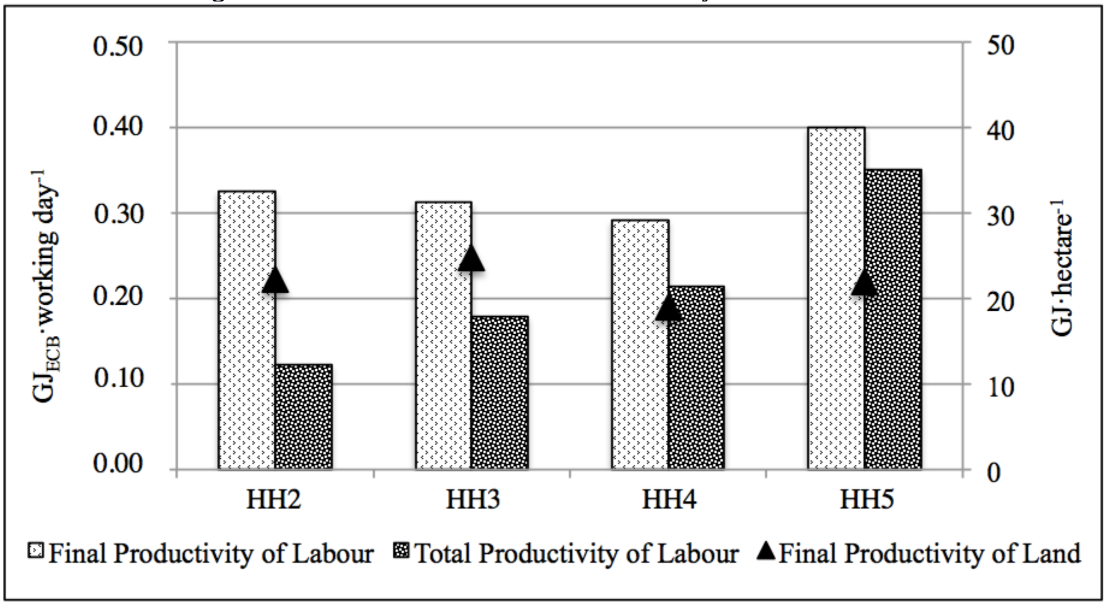
RESULTS

Total Produce and factor productivity (labour and land)

From the results obtained, we observe how the Total Produce (TP) of energy increased with the size of the farm, from 61 GJ for HH2 up to 1,710 GJ for HH5. In relative terms, Final Productivity of Land (FP_{Lan}) (Figure 3) is one of the indicators with the greatest stability, ranging between 19 and 25 GJ_{ECB} of FP in ECB terms (FP_{ECB}) per hectare, irrespective of the size of the farm. Putting the data into context, these results corresponded to 33% and 45% of an Equivalent Consumption Basket (ECB) respectively. Final Productivity of Labour (FP_{Lab}) varied between 0.31 and 0.40 GJ_{ECB} per working day, which also showed a certain stability among the different farms. Therefore, we find no relevant differences among the farms in terms of land or labour productivity. Unfortunately, the available sources do not allow inclusion of the effect of the likely existence of more extensive agricultural practices (and labour time-saving) on the larger farms, which means that our results can only take into consideration the different composition of land uses among the HH types compared, as well as the effects of hoarding cropland of best quality or irrigated lands by the richer HHs.

Given both factor productivities, we observe that, in order to obtain one ECB of final consumption, between 2.3 and 3.03 hectares were required, as well as between 144 and 185 agricultural working days a year. These results suggest that the limiting factor was land availability, as 50% of the farms in our sample were below this threshold, while a single agricultural active worker was enough to meet the corresponding labour requirements. We must note here that these results only refer to this HH model and cannot be extrapolated to the whole sample.

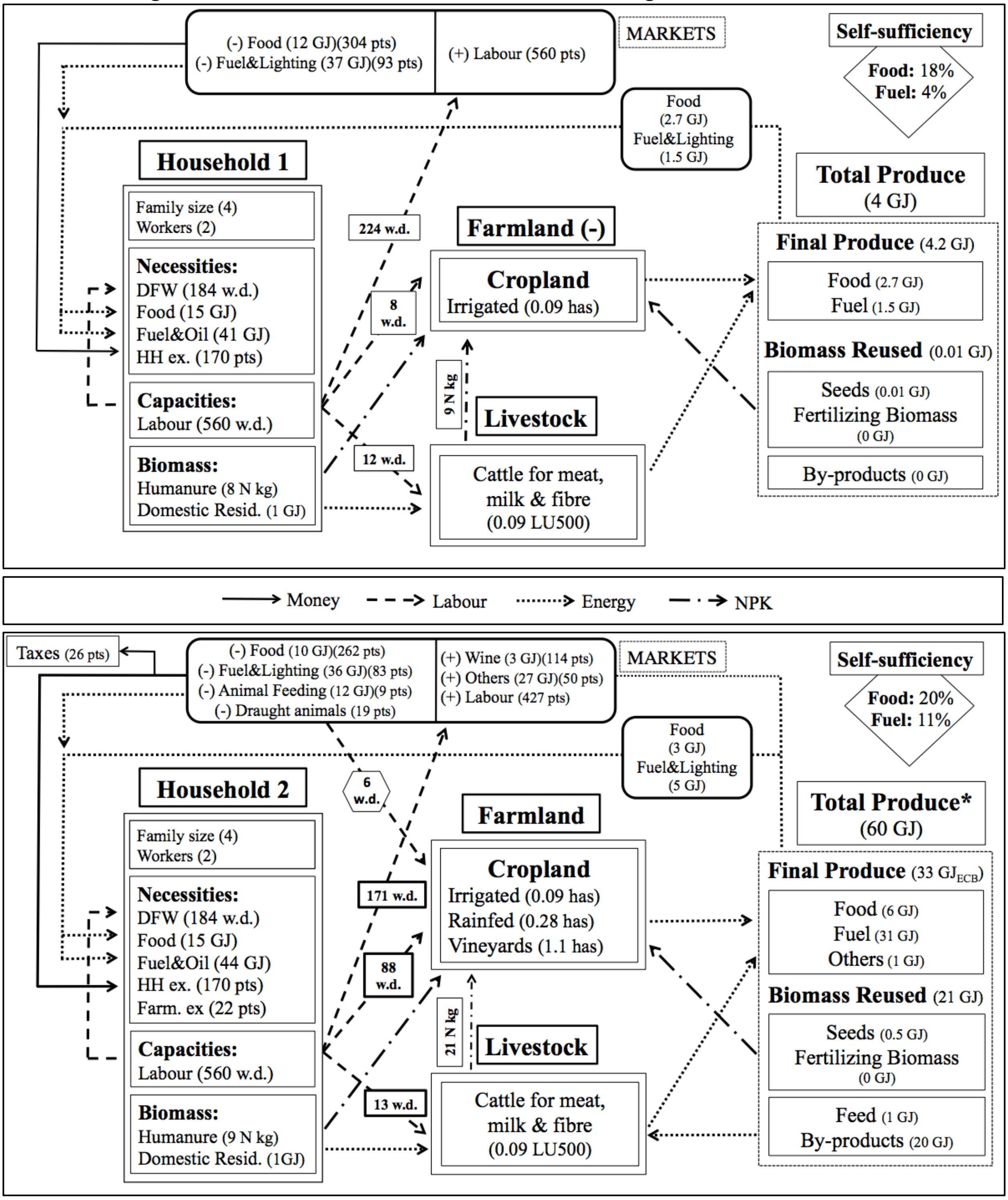
Figure 3. Final Labour and Land Productivity in terms of FP_{ECB}

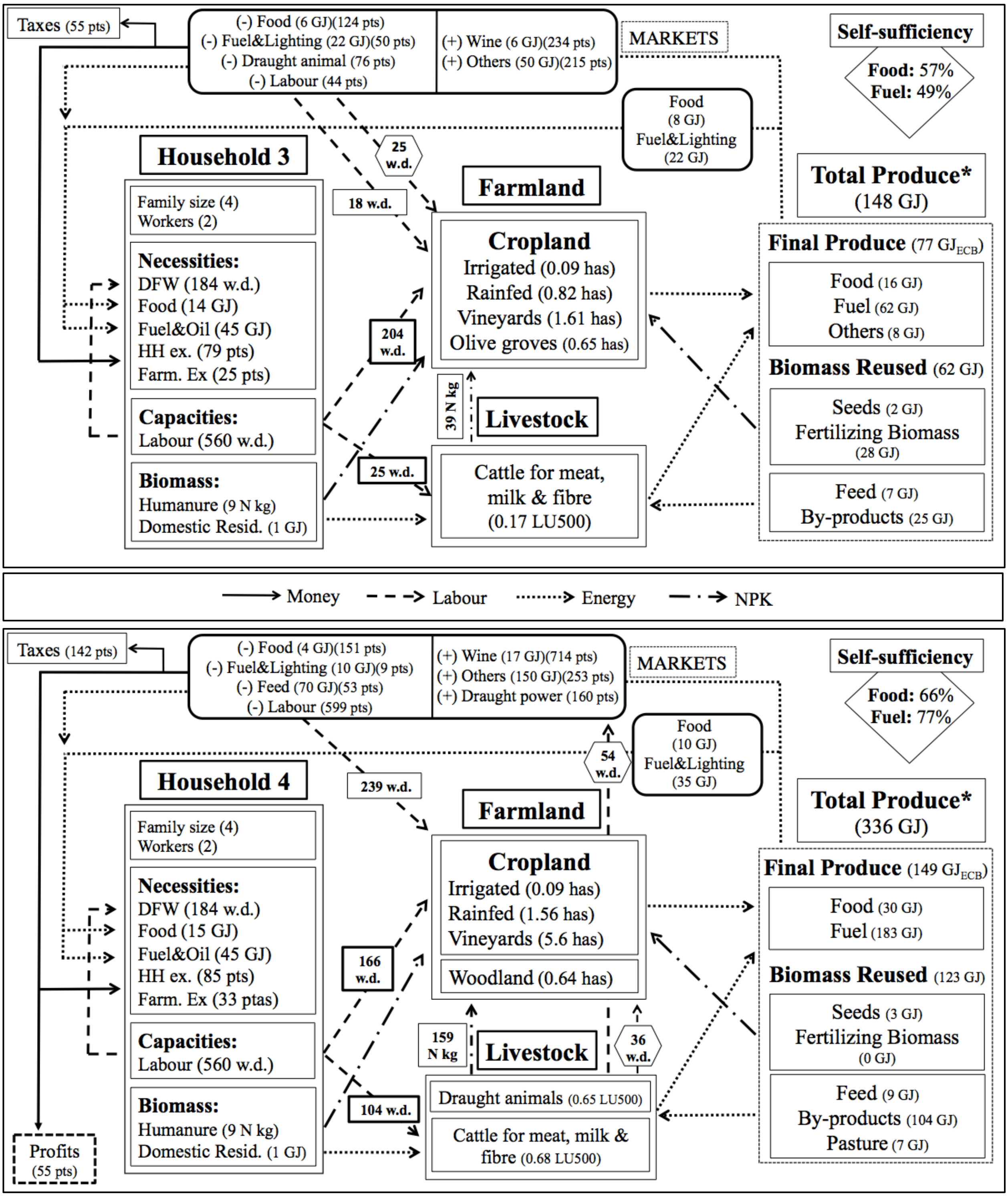


Source: Our own, from the sources mentioned in the text. Note: HH1 is not included in this figure, as it did not own land.

We notice a rise in the Total Productivity of Labour (TP_{Lab}) as the farm size increased (Figure 3). The reason for this growth trend is that the DFW of the smaller farms (HH1 and HH2) was useful not just to reproduce the labour force required to cultivate their own land, but also to sustain the share of family labour that would eventually be sold in the labour market for use on the larger farms. This increase in total energy productivity regarding farm size reveals that agricultural labour hired by the larger farms embodied 'invisible working days' carried out by women in the HHs of hired farmhands. We estimated an average of 46 annual working days of DFW per person, meaning that each hired working day had 0.16 DFW embodied working days if we consider the hired worker as an isolated element. Calculating the full 'life-cycle' of the labour force means recognizing that workers' reproduction depended on the existence and reproduction of those women performing DFW, who also took care of the sustenance of dependent HH members, thus ensuring intergenerational reproduction. Then each hired working day would have had a total of 0.66 DFW working days incorporated. When DFW is included in the analysis, and assuming that one agricultural working day required 0.66 DFW working days for its reproduction, we observe how the average required working days per ECB increased. Now, to obtain one ECB, between 164 and 468 working days were needed, with an average productivity of 0.22 GJ per working day. When hired labour was contracted, Total Labour Productivity would be increased through the appropriation of external DFW that remained unpaid. These results show that gender inequality based on the sexual division of labour was not just a remote source of other types of inequality and exploitation among human beings: the daily functioning and social reproduction of this agrarian class structure continued to be based on the invisible and unpaid labour of women.

Figure 4. Multidimensional balance of the HHs according to their access to funds





Our proposed methodology allows to estimate how many working days should be offered or hired in the market to even out the three balances (i.e. when a surplus of labour capacity was combined with cash needs to close the corresponding flows in some HHs, and in other HHs with a lack of internal labour force combined with sufficient cash capacities to hire the former in the labour market). Thus, HH1, without access to the two fund elements (land and livestock) and only endowed with the third one (labour), needed to sell 224 working days per year to be able to access basic subsistence needs (12 GJ of food products and 37 GJ of fuel, representing an annual expense of 397 pesetas), as well as to cover other monetary needs (85 pesetas for housing rent and 85 for footwear and clothing) (Figure 4). This was the representation of a 'proletarian' HH. HH2 needed to sell only 171 working days thanks to the income obtained through the sale of wine (114 pesetas) and other products, and thanks to a certain production capacity for self-consumption that reduced its purchase needs (10 GJ of food products, 36 GJ of fuel and 12 GJ to feed the animals). This was the case for a 'semi-proletarian' HH. In the case of farms with access to land, expenses increased (taxes, tool expenses and those derived from hiring draught power). HH3 represents a peasant typology with a certain degree of self-sufficiency. Its needs for external labour were very low (18 working days), although it needed to go to market to exchange wine and fuel surpluses for food products, fuel and draught power.

HH4 and HH5 had a large labour force deficit, this being the reason why they hired 239 and 1,603 working days a year respectively (46% and 75% of their total required agricultural labour). Wages became a fundamental cost for them (62% and 56% of the gross income for HH4 and HH5, respectively). Despite that, both HHs acquired net profits of 55 and 1,726 pesetas respectively, surpluses that entailed the equivalent of 11% and 347% of a basic consumption basket (ECB).

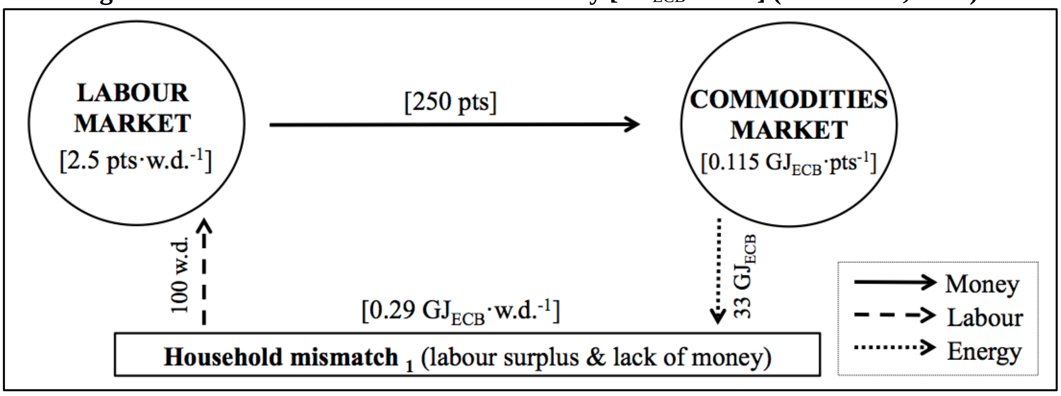
On the basis of these examples, we can establish dependency rates beween those farms that needed to hire labour in the market and those that needed to sell it. For instance, the dependency ratio between HH5 and HH1 was 1:7, and between HH4 and HH1 1:1. Thus, every HH with the same characteristics as HH5 needed 7 HHs similar to those of HH1 to be able to cover their external labour needs.

Markets as converters of energy labour surpluses

Our results confirm that an important part of the agricultural production had to be redistributed through the labour and commodity markets, where labour had to be exchanged for staple products (for HH1 and HH2), or in reverse (HH4 and HH5), in order to be able to close their sociometabolic balances. The results also confirm the polarization pattern proposed by Bhaduri (1983) through the assessment of the share of agricultural product used for self-consumption and the share diverted to markets. HH3, which is representative of a medium-size farmstead, presented the highest percentage of Final Produce devoted to self-consumption (38%). HH2 (24%), HH3 (30%) and HH5 (14%) devoted smaller parts, although HH4 and HH5 had the highest self-sufficiency ratios (respectively 66-77% and 90-100% for food and fuel).

To estimate the energy productivity of wage labour, we have first to define what the products and inputs were and how we should measure them. Our multi-budget method includes the endosomatic (food intake) and exosomatic (fuel) consumption needs of each HH, and accounts for a consumption basket composed of both. A key element in this reproductive calculation is the transformation of cash flows into energy flows and vice versa. The conversion factor for food products was 26 pesetas·GJ^{-1}, and for fuel 2.3 pesetas·GJ^{-1}. The whole consumption basket comprised 57.5 GJ_{ECB} and cost 498 pesetas, with an interchange coefficient of 0.115 GJ_{ECB}·$peseta^{-1}$. Thus, as shown in Figure 5, for every wage earned during a working day, the acquisition capacity was equivalent to 0.29 GJ_{ECB}. If we compare this figure with the energy productivity of labour in a property regime whose average value was 0.33 GJ_{ECB} per working day, we conclude that market-hired working days obtained as energy content of the wage pay 88% of the labour earnings when performing the same labour in a in a land of its own. The difference between the two (12% of FP_{Lab}) would be the rent for land ownership. In the case of female wage labour, the surplus value would be much greater. Given the lower wage compensation (half of a male salary), female earnings would be reduced to 0.17 GJ_{ECB} per working day, equating to 52% of the labour pay in a property regime and a corresponding extration ratio of 48%. These extraction ratios, which need to be understood as a first quantitative estimate, may be compared with the percentage of product that landowners retained in the land tenancy arrangements in this area and period, which was around 25% of the harvest. If we consider the distribution of the total product and the inclusion of female labour, the two percentages (12 and 25%, respectively) would be closer. In fact, both would depend on the difference between actual labour productivity and the reproduction cost of labour (i.e. the potential surplus).

Figure 5. Effect on Hired Labour Productivity [GJ_{ECB}·$w.d.^{-1}$] (Sentmenat, 1850)



Source: Our own, from the sources mentioned in the text.

CONCLUDING REMARKS

This article represents an initial exploration of the sociometabolic links between biophysical capabilities and limits with the kind of exploitative relationships that prevailed in traditional organic farming societies. Our starting point is the existence of a biophysical tension between the appropriation and consumption of energy and material flows taken from agroecosystems, and the labour required to do so. This sociometabolic tension set in motion a contingent tendency towards the establishment of exploitative relationships instituted throughout history. This would affect gender relationships, as well as those established among social classes. Although these relationships started off from situations of inequality regarding access to natural resources and were widely reproduced in space and time, they should be defined as relationships involving the exploitation of some human beings by others. Only in this way can we visualize the interdependence generated among social classes, given that the existence of privileged groups based on the concentration of land and livestock ownership would not have been possible without their domination of others who provided the required labour force to work for them. From the outset the most basic legitimation in the maintenance of this kind of exploitative relationship was rooted in the sexual division of labour. To this an unequal distribution of the ownership of the fund elements of the agroecosystems was added, structured and legitimized. Land and livestock hoarding by a few, and the dispossession of the rest, led to the creation of labour markets where a redistribution of income, production and consumption flows between workers and owners operated through price converters in a way that ensured the appropriation of surplus value by the latter. These different types of exploitation were articulated with one another, establishing social relationships that were parasitic of some human groups by others and that were rooted, in turn, in previous situations of competitive exclusion (González de Molina and Toledo 2014).

We have ascertained how in the village of Sentmenat in the mid-19th century unequal access to the ownership of two basic fund elements of the agroecosystem established a clear distinction between self-employed and wage labour, and determined that wage incomes were 88 percent of self-employed labour product. This difference became a rent income for the landowner, swelling his capacity to accumulate surpluses. The inclusion of Domestic and Family Work (DFW) in the analysis brings to light its importance not just in the social organization of labour, but also for the maintenance of other hidden exploitative relationships that supported the hired agricultural labour. We have estimated that DFW represented about half the entirety of socially necessary human work time, clearly demonstrating its importance in any reproductive analysis of traditional organic farming societies. We have also seen how commodified labour-hiring processes implied an indirect appropriation of part of the DFW carried out within families. Although we do not yet have enough data to analyse the effects of the sexual division of labour on the quality of life of these women, and also taking into account the fact that our analysis still has many limitations in estimating the weight of female agricultural labour, the explicit omission of women as subjects from the ownership of the means of production becomes apparent, rescuing them from the oblivion (at least in historical sources) of their participation in the (re)productive processes of these communities.

This study is a contribution to debates on the role of exploitative relationships within traditional organic farming societies and on the sociometabolic transition towards agrarian capitalism and industrial agriculture. The tension these exploitative interrelations implied, not only in social terms but also in economic (given the weight of wage costs in the accounts of large farms) and socio-ecological terms (given the ‘agroecosystemic diseases’ stemming from the impossibility to balance all the budgets by the impoverished household units), created a conflictual scenario that could lead, among other outcomes, towards the mechanization of agricultural labour.

The multi-budget sociometabolic analysis here applied to a small rural community of Catalonia in mid-19th century has brought to light the unequal exchanges through which time and space were appropriated by a ruling class and gender at the expense of the others. This becomes a revelant subject at present, when opening the ways towards more sustainable economies that are not based on unequal exchanges (social, sexual, ecological and territorial) means taking into account the implications of the internalization of costs in time and space (Guzmán and González de Molina 2009), and the consequent impact on potential social conflicts. Exploring in depth the links between biophysical limits, social reproduction processes and the social organization of labour allows us to identify the potentially antagonisms that have to be tackled in any change towards fairer sustainable societies.

Methodological Annex

In this methodological annex we summarize the most relevant data and the main decisions taken in the accounting of the socio-metabolic balances presented in this article. Much of the basic information used in this case study is detailed in Padró et al. (2017) and Marco et al. (2018). In particular, the calculation of Biomass Reused (BR) flows, both for livestock feeding and soil nutrient replenishment, is specified in Marco et al. (2018). Here we focus on decisions and data that have not been thoroughly presented previously. First, we describe the main historical sources used. Second, we explain the decisions of what type of households (size and dependency ratio) we choose to analyze. Third, we present the assumptions made regarding the reproduction of households and the consumption of food and fuel. Fourth, we show the labour ratios applied for Domestic and Family Work (DFW), and agricultural and livestock labour, as well as the draught power requirements per crop. Finally, we include a summary of the prices of the products used..

HISTORICAL SOURCES

Funds estimation: Household, farmland and livestock

Information on the number of households (HH) and their features (size, gender, age) is available in the municipal population censuses available for 1855 and 1857, which also indicate the occupation of household heads as well as of other members. Both register 333 families, and a population of around 1,700 people. Of these families, 73% can be considered agricultural, since this was the profession associated with the head of the household.

Information on the farmland area and livestock of each household comes from the Cadastre of 1841, the Cadastral Map of 1853 (Moreno Ramírez 1856), and the land tax registry called *Amillaramiento* of 1850 which was a municipal record of all the plots, their land use and ownership. To account for the extent of farmland we mainly used the *Amillaramiento* (1850), resorting to the Cadastral map (1853) for those HHs that did not appear in *Amillaramiento* (11 cases). In order to account for the livestock of each HH, we completed the information of *Amillaramiento* with the livestock registered in the Cadastre of 1841. This was due to the apparent underestimation of livestock densities in *Amillaramiento* of 1850, where only 2 mules, 22 head of cattle, 210 swines, 75 sheeps and 20 goats were recorded (i.e. 55.8 LU500 in total). The Cadastre of 1842 counted instead 138 mules, 36 head of cattle, 286 swines, 557 sheeps and 135 goats (203.3 LU500 in total). It is apparent that these the differences cannot respond to a decrease in livestock density in just nine years. We cross-checked these three historical sources (*Amillaramiento* [1850], Cadastral map [1853] and Cadastre [1841]) using the name and surname of the owner, and sometimes also the name of the farm.

HOUSEHOLD SELECTION

Our analysis is based on a selection of one HH for each of the five typological subgroups established according to the size of the farms: (*i*) the ones that had no land (21% of the total); (*ii*) the ones that had up to 2.18 ha (26 %); (*iii*) between 2.18 and 4.36 ha (23%); (*iv*) between 4.36 and 8.72 (18%) and (*v*) more than 8.72 ha (12%). Although we maintain access to land as a constant, there appear significant variations throughout the family life cycle. We see that among farms with similar access to land, both HH size and dependency ratio affected time, material and cash flows. Therefore, we calcualted dependency ratios relating the number of children (0-14 years old) to the working-age population as a percentage ($Dependency\ ratio = \frac{0-14\text{ years old population}}{\text{total population}}$ *100). They are indicated in the tables as '(Dependents:Total)' –e.g. '(5:2)'—, and used to isolate the effect of HH size from each dependency ratio when we analyse the effect of HH size variation on the land uses of each farm.

To choose the HH model that will be the basis to compare, we firstly analysed the general characteristics of all the HHs in the sample. The average sample size was 5 people per HH and 2 dependent (2:5), which means a dependency ratio of 40%. However, the highest frequency was 3 and 4 members, and the dependency ratio between 0-10 % and 50-60%. Indeed, these variations could mean either a different stage of the life cycle of the same model of HH, or different HH models (mainly according to the number of children and the coexistence or not of different generations). Among the 4-member HHs, those with two dependents predominated (48%), although there was an important presence of models that included one of the two grandparents (4:1) or families in which two generations lived (4:0). We therefore decided to work on the basis of simple HHs, and amongst them, we consider that the (4:2) structure is more balanced with respect to the sample, since they represent a subsequent stage to the growing HHs represented by the (3:1), and prior to stages (4:1), (4:0) (4-member families), or (5:3), (5:2), (5:1) (5-member families). The selected HHs model respond to the one defined before, except for HH5. In this fifth section with more than 8.72 ha there is no HH with these characteristics. Thus, the most similar one has been selected (7:3).

HOUSEHOLD REPRODUCTION: FOOD AND FUEL CONSUMPTION

Food consumption

Human diets have been considered according to the available historical sources at the local and national level (Table A). From these sources we estimated a basket of average daily food consumption for an adult male between 18 and 30 years, with intense physical activity (Table B). The diet means a caloric intake of 2,797 kcal per day, a similar value to that proposed by Cussó and Garrabou (2007) and by Cussó and Garrabou (2012) for similar regions.

Table B. Estimation of a daily food basket for an adult-male (18-30) with intense physical activity

Food per person and day	Weight (kg f.m.)	Metabolizable Energy (kcal/kg)	Ditto ME total (kcal)	Water content (%)	Weight (kg d.m.)	Gross Calorific Values (MJ/kg)	Ditto GCV total (MJ)	Ditto (MJ/ person a day)
Bread	0.700	2,630	1,841	30	0.489	17.05	8.30	3,042
Olive oil	0.018	8,990	165	0	0.018	39.70	0.70	266
Wine	0.132	610	81	83	0.022	17.20	0.40	140
Legumes	0.035	509	18	15	0.029	18.00	0.50	193
Potatoes	0.460	710	327	78	0.101	16.80	1.70	621
Vegetables	0.250	256	64	91	0.023	18.90	0.40	162
Fresh fruits	0.040	447	18	85	0.006	20.10	0.10	45
Nuts	0.020	6,243	125	4	0.019	25.00	0.50	175
Fish	0.007	1,150	8	80	0.001	22.28	0.03	11
Meat, bacon & sausage	0.050	3,032	152	50	0.025	22.00	0.60	201
TOTAL	**1.710**		**2,797**		**0.740**		**13.30**	**4,854**

Source: Our own, sources are detailed in Marco et al. (2018).

Table B. Estimation of a daily food basket for an adult-male (18-30) with intense physical activity

Food per person and day	Weight (kg f.m.)	Metabolizable Energy (kcal/kg)	Ditto ME total (kcal)	Water content (%)	Weight (kg d.m.)	Gross Calorific Values (MJ/kg)	Ditto GCV total (MJ)	Ditto (MJ/ person a day)
Bread	0.700	2,630	1,841	30	0.489	17.05	8.30	3,042
Olive oil	0.018	8,990	165	0	0.018	39.70	0.70	266
Wine	0.132	610	81	83	0.022	17.20	0.40	140
Legumes	0.035	509	18	15	0.029	18.00	0.50	193
Potatoes	0.460	710	327	78	0.101	16.80	1.70	621
Vegetables	0.250	256	64	91	0.023	18.90	0.40	162
Fresh fruits	0.040	447	18	85	0.006	20.10	0.10	45
Nuts	0.020	6,243	125	4	0.019	25.00	0.50	175
Fish	0.007	1,150	8	80	0.001	22.28	0.03	11
Meat, bacon & sausage	0.050	3,032	152	50	0.025	22.00	0.60	201
TOTAL	**1.710**		**2,797**		**0.740**		**13.30**	**4,854**

Source: Our own, sources are detailed in Marco et al. (2018).

From this reference diet, and from the ratios extracted from the caloric intake proposed by FAO (2001) (Table C), we have adapted the diet for each of the subgroups (sex-age).

Table C. Estimation from FAO of the energy intake requirement depending on the sex-age

	Energy Requirements (kcal/day) FAO				**Male-adult comparison of Energy Requirement**			
sex	**Women**		**Men**		**Women**		**Men**	
activity / age	**moderate**	**intense**	**moderate**	**intense**	**moderate**	**intense**	**moderate**	**intense**
00-05	1,412		1,534		0.41		0.44	
05-10	1,818		2,050		0.53		0.59	
10-15	2,090		2,456		0.60		0.71	
15-18	2,135		2,835		0.62		0.82	
18-30	2,529	2,744	3,174	3,460	0.73	0.79	0.92	1.00
30-60	2,410	2,601	3,031	3,293	0.70	0.75	0.88	0.95
≥ 60	2,171		2,458		0.63		0.71	

Source: Our own, from the sources mentioned in the text.

Fuel consumption

According to a Medical Topography of the village of Sentmenat, 'private rooms are mostly heated by the traditional Catalan fireplace, fed by firewood of all kinds; the least by braziers, with charcoal of oak or pine' (Pujadas-Serratosa 1889, 55). To estimate the amount of consumed fuel, we have reviewed both historical and contemporary sources. A reference of 1885 quoted by Colomé (1996) refers to a daily consumption of 4 pounds of charcoal per household for cooking and heating in Vilanova i la Geltrú (Catalonia), a town with similar climatic conditions. According to the conversion factors proposed by FAO (1983), this means a daily per capita consumption of 0.32 kg of charcoal, 3.2 kg of firewood (fresh matter [f.m.]), or 2.24 kg of firewood (dry matter [d.m.]). In countries where charcoal and firewood are still used as the main sources of energy research has found out lower fuel consumption for cooking and heating. Bhatt and Sachan (2004) estimate an average daily firewood consumption of 1.07 kg [f.m.] per capita (for the lowest altitudes) and 2.8 kg [f.m.] (for the highest altitudes) in Garhwal (Himalaya). Reddy (1981) and Wijesinghe (1984) estimate it around 2 kg [f.m.] per capita in South India and Sri Lanka.

Bhatt and Sachan (2004) also consider a seasonal variation of fuel consumption, so that consumption would double approximately during the winter. This coincides with a 1885 reference in a vine-growing village of Catalonia according to which half of domesitc consumption was related to cooking (1.12 kg [d.m.]) and the other half for heating needs during winter, which made Colomé (1996) to assume that fuel expenditure was lower than the average for at least seven months a year. Giampietro and Pimentel (1990) proposed a ratio of 1:2 between the metabolic energy of a daily food intake and the energy required to cook it, a proportion that applied to our case study would increase daily consumption per capita up to 1.23 kg [d.m.]. All of the above allowed us to assume a daily consumption of firewood per inhabitant of 2.24 kg [d.m.] for 5 months, and 1.12 kg [m.s.] during the rest of the year (which leads to an average daily consumption of 1.56 kg [d.m] or 2.35 kg [f.m.]). We imposed a restriction on the consumption of vineyard by-products (strain replacement and prunning) as a source of fuel, which in our budgets can represent a maximum of 10% of total fuel consumption [f.m.].

LABOUR: AVAILABILITY AND REQUIREMENTS

Availability of human labour

To calculate the number of yearly working days, we start with an annual potential availability of 280 working days per capita. According to Garrabou et al. (2014), the number of working days per annum in La Segarra County, in inner Catalonia, would be around 291 in 1886-1890. García-Zúñiga (2011) proposes 281 for the middle of the 19th century, and Jover and Pons (2013) estimated 280 working days in Mallorca. We established the agricultural working population considering people over 14 years old. Despite of this, there is evidence that children below the age of 14 also formed part of the workforce, working mainly as shepherds or swine keepers. We do not include as 'dependents' the population of elderly people, since historical sources show how this people continued to work until a strong physical impediment occurred. We introduced coefficients that reduce the working capacity (w.c.) of people of some ages: 14-18 (80% of w.c.), 60-70 (60%) and 70-80 (40%).

Domestic, care and family work

In order to estimate the amount of working days needed to carry out domestic and family work, we based upon the data collected by Wall (1994), on the basis of the European studies of Frédéric Le Play (1877-79). Le Play data shows a great similarity between the annual working days of men (320) and women (317) both outdoor and indoor of the household. On average, women would spend 120 days of domestic work and 80 days for the family economy, the rest being external labour. In order to contrast these data, and since we do not have more historical sources that quantified domestic and care work, we compared the data of Le Play with some contemporary studies in rural settings (Pastore et al. 1999; Gomiero and Giampietro 2001; Grünbühel and Schandl 2005; Fischer-Kowalski et al. 2010). Given that these studies are not homogeneous in terms of naming and grouping domestic, care and family work, we tried to homogenize and compare the available data (Table D).

Table D. Compilation of data on the quantification of domestic and family work in traditional agriculture

Female labour								
Researches consulted	Domestic		Familiar		External		Total	
	hours/day	hours/year	hours/day	hours/year	hours/day	hours/year	hours/day	hours/year
Le Play (1877) in Wall (1994)	2.9	1,060	1.6	590	1.8	672	6.8	2,490
Pastore et al. (1999)	2.6	967	n.a.	n.a.	n.a.	n.a.	2.6	967
Gomiero and Giampietro (2001)	6.3	2,286	n.a	n.a	n.a	n.a	6.3	2,286
Grünhubel and Schandl (2005)	2.7	986	2.5	913	3.9	1,424	9.1	3,322
Fischer-Kowalski et al. (2010)	7.6	2,774	1.2	420	1.2	420	9.9	3,614

Source: Our own.

From the results shown in Table D, we conclude that the Le Play data (1877-79) collected by Wall (1994) match with contemporary studies in traditional agricultural societies. Therefore, based on the information of Wall (1994, 194), we estimate the weight of Domestic and Family work (DFW) by the number of children in the household: 132 fixed-work days, with an increase of 26 annual working days for every son or daughter.

Agricultural labour and work requirements

Human labour and animal work requirements for the different land and livestock uses have been obtained from an Agricultural Study of the Vallès County written in 1874 (EAV from now on; Garrabou and Planas 1998[1874]), and from IACSI (1879). Given the strong seasonality, it is necessary that monthly labour requirements be taken into account to accurately capture the surpluses and deficits of workforce. Table E and F show human labour required for each type of crop and livestock, including wages for livestock management since they are lower than the average agricultural wage (2.5 pesetas). Table G presents the data for draught power required by type of crop.

Table E. Total and monthly labour requirements per land use and small livestock unit

crops			Cropland												
			working days per hectare												
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
Vegetable garden			6	6	9	14	15	15	19	19	17	10	7	6	**142**
Fresh fruits			0	3	0	0	0	2	2	5	5	0	0	0	**18**
Nuts			0	3	0	0	0	2	2	5	5	0	0	0	**18**
irrigated	Wheat		0	5	9	2	0	5	14	4	2	5	3	0	**49**
	Corn		0	4	7	1	9	7	0	4	2	8	0	9	**52**
	Hemp		18	0	26	5	3	3	3	3	14	14	40	63	**194**
	Beans		9	9	0	9	0	11	5	0	13	0	8	2	**65**
rainfed rotations according to soil quality	1st	Wheat	0	5	9	2	0	5	14	4	2	5	3	0	**49**
		Beans	9	9	0	9	0	11	5	0	13	0	8	2	**65**
		Potatoes	0	0	15	0	6	6	0	0	36	11	5	0	**79**
	2nd	Fodder	5	5	6	0	9	4	7	6	4	4	0	0	**50**
		Wheat	0	5	9	2	0	5	14	4	2	5	3	0	**49**
		Potatoes	0	0	15	0	6	6	0	0	36	11	5	0	**79**
	3rd	Vetches	9	9	0	9	0	11	5	0	13	0	8	2	**65**
		Rye & wheat	0	6	0	4	0	4	10	3	3	5	4	0	**48**
Vineyard			0	0	7	18	6	7	1	0	2	16	1	0	**59**
associated olive groves rotations according to soil quality	Olive groves		7	0	15	15	12	5	0	0	0	0	0	27	**81**
	1st	Wheat	0	5	9	2	0	5	14	4	2	5	3	0	**49**
		Potatoes	0	0	15	0	6	6	0	0	36	11	5	0	**79**
	2nd	Corn	0	4	7	1	9	7	0	4	2	8	0	9	**52**
		Rye & wheat	0	6	0	4	0	4	10	3	3	5	4	0	**48**
	3rd	Barley	0	2	4	2	0	5	14	15	3	3	0	0	**48**
		Lupins	9	9	0	9	0	11	5	0	13	0	8	2	**65**
Woodland															
Woodland			0	0	0	0	0	0	0	0	0	3.6	3.6	3.6	**11**
Swine, poultry, rabbits															
Swine			2	2	2	2	2	2	2	2	2	2	2	2	**25**
Poultry and rabbits			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	**0.013**

Source: Our own, from the sources mentioned in the text.

Table F. Annual labour requirements per livestock types

type of livestock	animal feeding and care		manure management	
	working days (w.d.)	pts/w.d.	working days (w.d.)	pts/w.d.
Flock of sheep (90 units)	365	1.3	22	2.3
Herd of goats (30 units)	365	1.8	6	2.3
Horses	190	0.3	7	2.3
Mules	173	0.3	7	2.3
Bovine	--	0.3	7	2.3

Source: Our own, from the sources mentioned in the text.

Table G. Draught power requirements per crop

Crops		Animal working days/ha		
		1st quality soil	2nd quality soil	3rd quality soil
irrigated	Wheat	21	20	20
	Corn	7	6	5
	Hemp	15	15	15
	Beans	9	8	8
rainfed	Wheat	22	21	--
	Beans	7	--	--
	Potatoes	5	5	--
	Fodder	--	3	--
	Vetches	--	--	12
	Rye & wheat mixture	--	--	17
Vineyards		3	3	2
Olive groves associated with annual crops	Olive groves	11	11	11
	Wheat	13	--	--
	Potatoes	5	--	--
	Corn	--	15	--
	Rye & wheat mixture	--	17	--
	Barley	--	--	15
	Lupins	--	--	12

Source: Our own, from the sources mentioned in the text.

CASH BALANCE

Paid labour and estimates of daily wages

From the comparison between the monthly agricultural labour required in the family farm and the availability of agricultural family workforce (after deducting DFW), we estimate a monthly agricultural surplus or deficit. In the event of work deficit, we estimate the number of annual working days needed to be hired. Its cash cost is calculated through a daily wage of 2.5 pesetas from the EAV (Garrabou and Planas 1998[1874]). In the case of agricultural labour surplus, a more complex process is carried out to determine which was the need for an additional income. First, we estimated the HH cash balance after obtaining the income from the sale of agricultural products, and deducting the biomass expenses (food, fuel, feed and fertilizing biomass). To this, we added: (*i*) the HHs clothing and footwear expenses, for which Colomé (1996) proposes an average expenditure of 0.32 pesetas for people between 0-4 years, of 0.52 for 5-9 years, of 0.82 for 10-14 years, of 1 between 15 and 59 years and 0.80 in the Catalan Penedès County of that time; as well as the house rent, which has been set on 85 pesetas at that time in Catalonia by Vicedo et al. (2002); and (*ii*) other external acquisitions such as farm implements, for which we applied the average cost of amortization of the farm tools in a Catalan village of the Penedès County, estimated at 2.04 pesetas/ha at that time by a study quoted in Colomé (1996). We also estimated tax payments from the direct data appearing in the *Amillaramiento* (1850). Only if the cash income was not enough to cover all the expenses, part of the labour surplus should be hired in the market. We assumed that the labour offered in the market was the minimum required to fill de money gap. Thus, we do not consider that there would be savings or the need for additional cash expenses as debts or social expenses (i.e. marriages or funerals).

In order to estimate how many day wages were needed to cover the money gap, we need to take into account that male and female wages were different (2.5 and 1.25 pesetas respectively). We assumed that women wages were required only when male wages were not enough to cover the money gap. This is a risky assumption, since the choice of selling labour surplus depended not only on the potential income (for which the family would seek to maximize income from the higher wage), but also on the type of work performed, the incentives of those who contracted it (who would seek to minimize wage expenditure, given equal productivity of women and men) and the recruitment opportunities, given the seasonality of agricultural work, among others factors. On the other hand, some researchers suggests 'that married women with children were not thought (…) to be in a position to undertake regular wage labor' (Humphries 1990, 37). This was compatible with the statement that 'before mechanization, at haymaking and harvest the farmers' requirements could not be met from the local pool of day labor, and the wives and children of the laborers constituted an essential labor reserve' (Humphries 1990, 29). In spite of this, for the moment we maintain the assumption that male labour surplus was prioritized, as any other criterion would be equally random. This would be better assessed at municipal level including seasonal wage labour demand and supply. As a result, this assumption implies that the number of hired working days estimated is the minimum one.

Other external Inputs

In case that it became necessary to obtain food for animals, we assume that pastureland was rented. When fertilizing biomass was not enough to close the nutrients cycle, we assume they bought biomass to bury into the soil (mainly from woodland).

Commodities and fuel prices

Table H shows the prices applied for each of the products and the sources used.

Table H. Summary of the prices of the main products

Product	Price (pts/kg f.m.)	Sources	Comments
Wheat	0.37	EAV 1874 & 1879 Sentmenat cadastre complaint	0.30 pts/kg in 1874 & 0.32 in 1878 in a period of decreasing trend
Corn	0.29		0.21 pts/kg in 1878 during a period of decreasing trend of prices
Hemp	0.96	EAV 1874	
Barley	0.20	Sentmenat cadastre complaint	0.17 pts/kg according to EAV in 1874
Rye & wheat	0.25	Sentmenat cadastre complaint	0.27 pts/kg according to EAV in 1874
Fodder	0.08	EAV 1874	
Olive oil	1.24 (l)	Sentmenat cadastre complaint	1.02 pts/litre according to EAV in 1874
Wine	0.12 (l)	Sentmenat cadastre complaint	0.13 pts/litre according to EAV in 1874
Green beans	0.42	Sentmenat cadastre complaint	0.372 pts/kg irrigated and 0.335 rainfed according to EAV in 1874
Vetches	0.15	EAV 1874	
Lupins	0.15	EAV 1874	
Potatoes	0.11	Sentmenat cadastre complaint	Great variability and a decreasing trend also shown in EAV 1874
Fish	0.89	PROYECTONISAL UAB	http://www.proyectonisal.org/index.php/en/
Meat	0.82	EAV 1874	2.5 for capons (3.5 kg), 2.25 for hens (2.5), 1.5 for chicken (1.5)
Firewood	0.03	IACSI (1879)	We took this since the price at EAV 1874 seemed too high
Pasture	0.01	EAV 1874	8 pts/ha for grazing from 1 June to 31 December & 1,523 kg f.m.

Source: Our own, from the EAV 1874 (facsimile reproduction in Planas and Garrabou 1998[1874]; IACSI (1879); and the 1879 Sentmenat cadastre complaint (Treasury Records, Aragon Crown Archive, Barcelona).

References

Ballesteros, E. (1997). *Niveles de vida en España, s. XIX y XX*. Madrid: Universidad Complutense de Madrid.

Bayliss-Smith, T. P. (1982). *The ecology of agricultural systems*. Cambridge: Cambridge University Press.

Bennassar, B. & Goy, J. (1975). Contribution à l'histoire de la consommation alimentaire du XIVe au XIXe siècle. *Annales. Histoire, Sciences Sociales*, *30*(2/3), 402-430.

Bernstein, H. (2010). *Class dynamics of agrarian change*. Sterling (VA): Kumarian Press.

Bhaduri, A. (1983). *Economic Structure of Backward Agriculture*. London: Academic Press.

Bhatt, B. P. & Sachan, M. S. (2004). Firewood consumption along an altitudinal gradient in mountain villages of India. *Biomass and Bioenergy*, *27*(1), 69-75.

Billen, G., Barles, S., Garnier, J., Rouillard, J., & Benoit, P. (2009). The food-print of Paris: long-term reconstruction of the nitrogen flows imported into the city from its rural hinterland. *Regional Environmental Change*, *9*(1), 13-24.

Bookchin, M. (1982). *The ecology of freedom: the emergence and dissolution of hierarchy*. Palo Alto (CA): Cheshire Books.

Burke, I. C., Lauenroth, W. K., Cunfer, G., Barrett, J. E., Mosier, A., Lowe, P. (2002). Nitrogen in the Central Grasslands Region of the United States: Current anthropogenic additions of nitrogen to ecosystems of the US central grasslands far outweigh loss of nitrogen through crop removal, resulting in increased nitrogen fluxes with the potential to alter regional-scale biogeochemical cycling. *BioScience*, *52*(9), 813–823.

Cascón, J. (1931). *Agricultura Española*. Madrid: Dirección General de Agricultura.

Cerdà, I. (1968[1867]). *Teoría general de la urbanización, y aplicación de sus principios y doctrinas a la reforma y ensanche de Barcelona*. *Vol. II. La urbanización considerada como un hecho concreto. Estadística urbana de Barcelona* (pp. 656-660). Madrid: Instituto de Estudios Fiscales.

Chayanov, A. V. (1986 [1925]). *The Theory of Peasant Economy*. Madison: Wisconsin University Press.

Colomé, J. (1996). *L'especialització vitícola a la Catalunya del segle XIX. La comarca del Penedés*. Doctoral Thesis, Universitat de Barcelona.

Colomé, J. (1997). Los amillaramientos como fuente documental histórica. Algunas reflexiones a partir del grado de ocultación detectado en las comarcas vitícolas catalanas. In Comunicación presentada al VI Congreso de la Asociación de Historia Económica (Girona).

Colomé, J., Saguer, E., & Vicedo, E. (2002). Las condiciones de reproducción económicas en las unidades familiares campesinas en Cataluña a mediados del siglo XIX. In J. M. Martínez Carrión (Ed.), *El nivel de vida en la España rural, siglos XVIII-XX* (pp. 233-260). San Vicente del Raspeig: Ediciones de la Universidad de Alicante.

Cunfer, G. (2004). Manure matters on the Great Plains frontier. *The Journal of Interdisciplinary History*, *34*(4), 539-567.

Cunfer, G. (2005). *On the Great Plains: Agriculture and Environment*. College Station: Texas A and M University Press.

Cunfer, G., & Krausmann, F. (2013). Sustaining agricultural systems in the old and new worlds: a long term socio-ecological comparison. In S. Singh, H. Haberl, M. Chertow, M. Mirt, & Schmid, M. (Eds.), *Long-Term Socio-Ecological Research: Human-Environment Interactions*, vol 2., (pp. 269-296). Dordrecht: Springer.

Cunfer, G., & Krausmann, F. (2015). Adaptation on an Agricultural Frontier: Socio-Ecological Profiles of Great Plains Settlement, 1870–1940. *Journal of Interdisciplinary History*, *46*(3), 355-392.

Cussó, X., Garrabou, R., & Tello, E. (2006a). Social metabolism in an agrarian region of Catalonia (Spain) in 1860–70: flows, energy balance and land use. *Ecological Economics*, *58*, 49–65.

Cussó, X., Garrabou, R., Olarieta, J.R., & Tello, E. (2006b). Balances energéticos y usos del suelo en la agricultura catalana: una comparación entre mediados del siglo XIX y finales del siglo XX'. *Historia Agraria*, 40: 471–500.

Cussó, X., & Garrabou, R. (2007). Mediterranean Diet Changes during the Nutritional Transition in Spain. UHE Working papers 2007-09, Universitat Autònoma de Barcelona, Departament d'Economia i Història Econòmica, Unitat d'Història Econòmica. Available at: http://www.recercat.cat//handle/2072/5369 (Accessed 25th February 2017).

Cussó, X., & Garrabou, R. (2012). Alimentació i nutrició al Vallès Occidental. Un segle i mig de canvis i permanències: 1787-1936. Working Paper of the Unitat d'Història Econòmica de la Universitat Autónoma de Barcelona.Available at: https://recercat.cat/bitstream/handle/2072/213662/uhe2012_05.pdf?sequence=1 (Accessed 25th February 2017).

Delgadillo-Vargas, O., Garcia-Ruiz, R., and J. Forero-Álvarez, 2016. 'Fertilising techniques and nutrient balances in the agriculture industrialization transition: the case of sugarcane in the Cauca river valley (Colombia), 1943–2010. *Agriculture, Ecosystems and Environment*, *218*, 150-162.

FAO (1983). Métodos simples para fabricar carbón vegetal. Roma. Estudio Montes. FAO Available at: http://www.fao.org/docrep/X5328S/X5328S00.htm (Accessed 25th February 2017).

FAO (2001). Human energy requirements. In FAO Food and nutrition technical report series. Report of a Joint FAO/WHO/UNU Expert Consultation. Rome, 17–24 October 2001. Availabe at: ftp://ftp.fao.org/docrep/fao/007/y5686e/y5686e00.pdf (Accessed 25th February 2017).

Firestone, S. (1970). *The Dialectic of Sex: The Case for Feminist Revolution*. New York: William Morrow and Co.

Fischer-Kowalski, M., Singh, S. J., Ringhofer, L., Grünbühel, C. M., Lauk, C., & Remesch, A. (2010). *Sociometabolic regimes in indigenous communities and the crucial role of working time: a comparison of case studies*. Social Ecology Working Paper 121, Institute of Social Ecology, Alpen Adria Klagenfurt University, Vienna. https://is.muni.cz/el/1423/jaro2013/HEN633/um/Fischer-Kowalski_et_al_Sociometabolic_regimes.pdf (accessed 01-01-2019)

Foster, J. B., & Holleman, (2014). The theory of unequal ecological exchange: a Marx-Odum dialectic. *Journal of Peasant Studies*, *41*(2), 199–233.

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). *Ecological Modeling*, *336*, 13-25.

García-Ruiz, R., González de Molina, M., Guzmán, G., Soto, D., & Infante-Amate, J. (2012). Guidelines for Constructing Nitrogen, Phosphorus, and Potassium Balances in Historical Agricultural Systems. *Journal of Sustainable Agriculture*, *36*(6), 650–682.

García-Zúñiga, M. (2011). La evolución de los días de trabajo en España, 1250-1918. In comunicación presentada en el X Congreso Internacional de la Asociación Española de Historia Económica, Carmona.

Garrabou R. & Planas, J. (Eds.) (1998[1874]). *Estudio Agrícola del Vallés (1874)*. Granollers: Museu de Granollers.

Garrabou, R., Planas, J., & Saguer, E. (2001). *Un capitalisme impossible? La gestió de la gran propietat agrària a la Catalunya contemporània*. Vic: Eumo Editorial & Universitat de Vic.

Garrabou, R., Tello, E. & Cussó, X. (2010). Ecological and socio-economic functioning in the middle of the nineteenth century: a Catalan case study (the Vallès county, 1850-1870). In, Landsteiner, E. & Langthaler, E. (Eds.), *Agrosystems and Labour Relations in European Rural Societies (Middle Ages-Twentieth Century)* (pp. 119-154). Turnhout: Brepols Publishers.

Garrabou, R., Planas, J., & Saguer, E. (2012). The management of agricultural estates in Catalonia in the nineteenth and early twentieth century. *Agricultural History Review*, *60*(2), 173-190.

Garrabou, R., Planas, J., Saguer, E. & E. Vicedo, D. (2014). Propiedad de la tierra y desigualdad social en el mundo rural catalán de mediados del siglo XIX. *Historia Agraria*, *63*, 47-82.

Georgescu-Roegen, N. (1977). Inequality, limits and growth from a bioeconomic viewpoint. *Review of Social Economy*, *35*(3), 361-375.

Gerber, J. F., & E. Scheidel, E. (2018). In Search of Substantive Economics: Comparing Today's Two Major Socio-metabolic Approaches to the Economy–MEFA and MuSIASEM. *Ecological Economics*, *144*, 186-194.

Giampietro, M., Mayumi, K. & Şorman, A.H. (2013). *Energy analysis for a sustainable future: multi-scale integrated analysis of societal and ecosystem metabolism*. Abingdon: Routledge.

Gingrich, S., Haidvogl, G., Krausmann, F., Preis, S., & Garcia-Ruiz, R. (2015). Providing food while sustaining soil fertility in two pre-industrial Alpine agroecosystems. *Human Ecology*, *43*(3), 395-410.

Gingrich, S., Marco, I., Aguilera, E., Padró, E., Cattaneo, C., Cunfer, G., Guzmán, G.I., MacFadyen, J. & Watson, A. (2018). Agroecosystem energy transitions in the old and new worlds: trajectories and determinants at the regional scale. *Regional Environmental Change*, *18(*4), 1089–1101.

Giral, J. (1914). *Ración alimenticia desde los puntos de vista higiénico y social*. Madrid: Librería Internacional Adrián Romo.

Gizicki-Neundlinger, M., Gingrich, S., Güldner, D., Krausmann, F. & Tello, E. (2017a). Land, Food and Labour in Pre-Industrial Agro-Ecosystems: A Socio-Ecological Perspective on Early 19th Century Seigneurial Systems. *Historia Agraria*, *71*, 37-78.

Gizicki-Neundlinger, M. & Güldner, D. (2017b). Surplus, Scarcity and Soil Fertility in Pre-Industrial Austrian Agriculture: The Sustainability Costs of Inequality. *Sustainability*, *9*(2), 265.

Godelier, M. (1998). Deconstructions, changing perspectives and progress in understanding social phenomena: An anthropologist's point of view. *Folk*, *40*, 5-23.

Gomiero, T. & Giampietro, M. (2001). Multiple-scale integrated analysis of farming systems: the Thuong Lo Commune (Vietnamese Uplands) case study. *Population and Environment*, *22*(3), 315-352.

González de Molina, M. & Guzmán, G. I. (2007). *Tras los pasos de la insustentabilidad. Agricultura y medio ambiente en perspectiva histórica (s.XVIII-XX)*. Barcelona: Icaria

González de Molina, M. & Toledo, V. (2014). *The Social Metabolism: A Socio-Ecological Theory of Historical Change*. New York: Springer.

González de Molina, M., Infante Amate, J., & Herrero, A. (2014). Challenging the traditional story: inequality, liberal reform and agricultural growth in Southern Spain (1752-1901). *Historia Agraria*, *63*, 55-88.

Grünbühel, C. M., & Schandl, H. (2005). Using land-time-budgets to analyse farming systems and poverty alleviation policies in the Lao PDR. *International Journal of Global Environmental Issues*, *5*(3-4),142-180.

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*(1),80-90.

Guzmán, G. I., & M. González de Molina, 2009. 'Preindustrial agriculture versus organic agriculture: the land cost of sustainability'. *Land Use Policy*, 26(2): 502-510.

Guzmán, G. I., and González de Molina, M. Eds). (2017). *Energy in Agroecosystems: A Tool for Assessing Sustainability*. Boca Raton: CRC Press.

Haberl, H., Fischer-Kowalski, M., Krausmann, F., Martinez-Alier, J., & Winiwarter, V. (2010). A sociometabolic transition towards sustainability? Challenges for another Great Transformation. *Sustainable Development*, *19*(1), 1-14.

Harvey, D. (2003). *The new imperialism*. Oxford: Oxford University Press.

Hornborg, A. (1998). Towards an ecological theory of unequal exchange: articulating world system theory and ecological economics. *Ecological economics*, *25*(1), 127-136.

Hornborg, A. (2003). The unequal exchange of time and space: toward a non-normative ecological theory of exploitation. *Journal of Ecological Anthropology, 7*(1), 4-10.

Horrell, S., & Oxley, D. (2013). Bargaining for basics? Inferring decision making in nineteenth-century British households from expenditure, diet, stature, and death. *European Review of Economic History*, *17*(2), 147-170.

Humphries, J. (1990). Enclosures, Common Rights, and Women: The Proletarianization of Families in the Late Eighteenth and Early Nineteenth Centuries. *The Journal of Economic History*, *50*(1), 17-42.

Humphries, J. (1991). 'Bread and a pennyworth of treacle': excess female mortality in England in the 1840s. *Cambridge Journal of Economics*, *15*, 451–473.

IACSI (1879). *Amillaramientos y modelos de cartillas. Revista de agricultura práctica, economía rural, horticultura y jardinería*. Barcelona: Instituto Agrícola Catalán de San Isidro.

Jover, G., & Pons, J. (2013). Notes sobre resistència pagesa i paisatges agraris en els dominis de Lloseta-Aiamans i l'alqueria s' Estorell, 1428-1532. *Estudis d'Història Agrària, 25*, 125-160.

Locke, J. (1963[1690]). *Two Treatises of Government*. Cambridge: Cambridge Univeristy Press.

Lotka, A.K. (1956). *Elements of Mathematical Biology*. New York: Dover Publications.

Luxemburg, R. (1985[1925]). Einführung in die Nationalökonomie. In *Luxemburg, Gesammelte Werke*, vol. 5 (pp. 524–778). Berlin: Dietz Berlin. An English translation is available in section IV of Luxemburg, R.1(954). *What is Economics?* New York: Pioneer Publishers (pp. 39–44).

Marco, I., Padró, R., Cattaneo, C., Caravaca, J., & Tello, E. (2018). From vineyards to feedlots: A fund-flow scanning of socio-metabolic transitions in the Vallès County (Catalonia) (1860-1956-1999). *Regional Environmental Change*, *18*(4), 981–993.

Martínez-Alier, J. M. and J. M. Naredo, 1982. 'A Marxist precursor of energy economics: Podolinsky'. *Journal of Peasant Studies*, 9(2): 207-224.

Marull, J., Pino, J. Tello, E., & Cordobilla, M. J. (2010), Social metabolism, landscape change and land-use planning in the Barcelona Metropolitan Region. *Land Use Policy*, *27*(2), 497-510.
Marx, K. (1996 [1867]). *Capital: A Critique of Political Economy*, Vol. 1. In *Marx and Engels Collected Works*, Vol. 35. New York: International Publishers.
Max-Neef, M. (1991). *Human Scale Development. Conception, Application and Further Reflections*. New York: The Apex Press.
Mellor, M. (1992). *Breaking the Boundaries: Towards a Feminist, Green Socialism*. London: Virago Press.
Mies, M. (1986). *Patriarchy and accumulation on a world scale: Women in the international division of labour*. London: Zed Books.
Moreno Ramírez, P., 1856. *Plano geometrico del termino jurisdiccional de Senmanat, partido judicial de Tarrasa*. Cortoteca Digital de l'Institut Cartogràfic i Geológic de Catalunya. http://cartotecadigital.icgc.cat/cdm/compoundobject/collection/catalunya/id/3450/rec/1
Nawn, N. (2016). Sustaining the Farming Household to Sustain the Farming. *Journal of Agrarian Change*, *16*(1), 94-122.
Nicholas, S., & Oxley, D. (1993). Living standards of women during the Industrial Revolution'. *Economic History Review*, *46*, 723–49.
Nicolau, R. & Pujol, J. (2005). El consumo de proteínas animales en Barcelona entre las décadas de 1830 y 1930: evolución y factores condicionantes. *Investigaciones de Historia Económica*, *1*(3),101-134.
Olarieta, J. R., Padró, R., Masip, G., Rodríguez-Ochoa, R., & Tello, E. (2011). Formiguers', a historical system of soil fertilization (and biochar production?). *Agriculture, Ecosystem & Environment*, *140*,27–33.
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. J. (Eds.), *Socio-Metabolic Perspectives on the Sustainability of Local Food Systems* (133-164). Dodrecht: Springer.
Padró, R., Marco, I., Font, C. and Tello, E. (2019). Beyond Chayanov: A sustainable agroecological farm reproductive analysis of peasant domestic units and rural communities (Sentmenat; Catalonia, 1860). *Ecological Economics*, *160*, 227-239.
Parcerisas, L. (2014). Landownership Distribution, Socio‐Economic Precariousness and Empowerment: The Role of Small Peasants in Maresme County (Catalonia, Spain) from 1850 to the 1950s. *Journal of Agrarian Change*, *15*(2), 261-285.
Pastore, G., Giampietro, M. & Ji, L. (1999). Conventional and land-time budget analysis of rural villages in Hubei province, China. *Critical Reviews in Plant Sciences, 18*(3), 331-357.
Polanyi, K. (1957a). The economy as instituted process. In Arensberg, C., & Pearson, H. (Eds.), *Trade and markets in the early empires*. Glencoe, Ill.: Free Press.
Polanyi, K. (1957b[1944]). The Self-Regulating Market and the Fictitious Commodities: Labor, Land, and Money. In *The Great Transformation: The Political and Economic Origins of Our Time* (pp. 68–76). Boston: Beacon Press.
Pujadas-Serratosa, R. (1889). Recopilación de algunos apuntes para una memoria médico-topográfica de Sentmanat. Barcelona: Imprenta de J. Balmas Planas.
Ramos-Martín, J. (2006). *Complex systems and exosomatic energy metabolism of human societies*. PhD thesis. Universitat Autònoma de Barcelona.
Reddy, A. K. N. (1981). An Indian village agricultural ecosystem case study of Ungra village. Part II. Discussion'. *Biomass*, *1*, 77–88.
Ryan-Johansson, S. (1977). Sex and death in Victorian England: an examination of age- and sex- specific death rates, 1840–1910. In Vicinus, M. (Ed.), *A Widening Sphere: Changing Roles of Victorian Women* (pp. 163–181). London: Methuen & Co.
Serra, E. (1988). *Pagesos i senyors a la Catalunya del segle XVII: baronia de Sentmenat 1590-1729*. Barcelona: Crítica.
Scheidel, A. (2013). Flows, funds and the complexity of deprivation: using concepts from ecological economics for the study of poverty. *Ecological Economics 86*, 28–36.
Scheidel, A., Farrell, K.N., Ramos-Martín, J., Giampietro, M., & Mayumi, K. (2014). Land poverty and emerging ruralities in Cambodia: insights from Kampot province. *Environment, Development and Sustainability 16*(4),823–840.
Scheidel, A., Temper, L., Demaria, F., & Martínez-Alier, J. (2018). Ecological distribution conflicts as forces for sustainability: an overview and conceptual framework. *Sustainability Science*, *13*(3),585-598.
Simpson, J. (1989). La producción agraria y el consumo español en el siglo XIX. *Revista de Historia Económica/Journal of Iberian and Latin American Economic History*, *7*(2), 355-388.
Tello, E. (2016). Manuel Sacristán at the Onset of Ecological Marxism after Stalinism. *Capitalism, Nature, Socialism*, *27*(2), 32-50.

Tello, E. & Badia-Miró, M. (2018). Land-use and rural inequality profiles in the province of Barcelona in mid-nineteenth century. *Historia Agraria 76*,157-188.
Tello, E., Garrabou, R., Cussó, X., Olarieta, J. R., & Galán, E. (2012). Fertilizing methods and nutrient balance at the end of traditional organic agriculture in the Mediterranean bioregion: Catalonia (Spain) in the 1860s. *Human Ecology*, *40*(3), 369-383.
Tello, E., Galán, E., Sacristán, V., Cunfer, G., Guzmán, G.I., González de Molina, M., Krausmann, F., Gingrich, S., Padró, R., Marco, I., & Moreno-Delgado, D. (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.
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). Journal of Agrarian Change, *18*(3), 483-516.
Van der Ploeg, J. D. (2014). *Peasants and the Art of Farming: A Chayanovian Manifesto*. Rugby: Practical Action Publishing.
Vicedo, E., Colomé, J., & Saguer, E. (2002). Las condiciones de reproducción económica de las unidades familiares campesinas en Cataluña a mediados del siglo XIX. In Martínez Carrión, J.M. (Ed.), *El Nivel de Vida En La España Rural, Siglos XVIII- XX* (pp. 321–358). Alicante: Publicaciones de la Universidad de Alicante.
Vilar-y-Ferran, J. (1914). *Topografía médica de la Villa de Viella y en general del valle de Arán. 1914*. Barcelona: Manuscrito de la Real Academia de Medicina de Barcelona.
Wall, R. (1994). La contribución de las mujeres casadas a la economía familiar bajo distintos sistemas familiares: algunos ejemplos de mediados del siglo XIX a partir de los presupuestos familiares recogidos por Le Play. *Boletín de la Asociación de Demografía Histórica*, *2-3*, 183-197.
Wijesinghe, L. C. A. de S. (1984). A sample study of biomass fuel consumption in Srilanka households. *Biomass*, 5, 261–82.
Wilkinson, R.G. (1973). *Poverty and progress: an ecological model of economic development*. London: Methuen.