Dialogues between Nature, Class and Gender: Revisiting Socio-Ecological Reproduction from Past Advanced Organic to Industrial Agricultures (Sentmenat, Catalonia, 1860-1999)

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PhD in Economic History

Thesis title:

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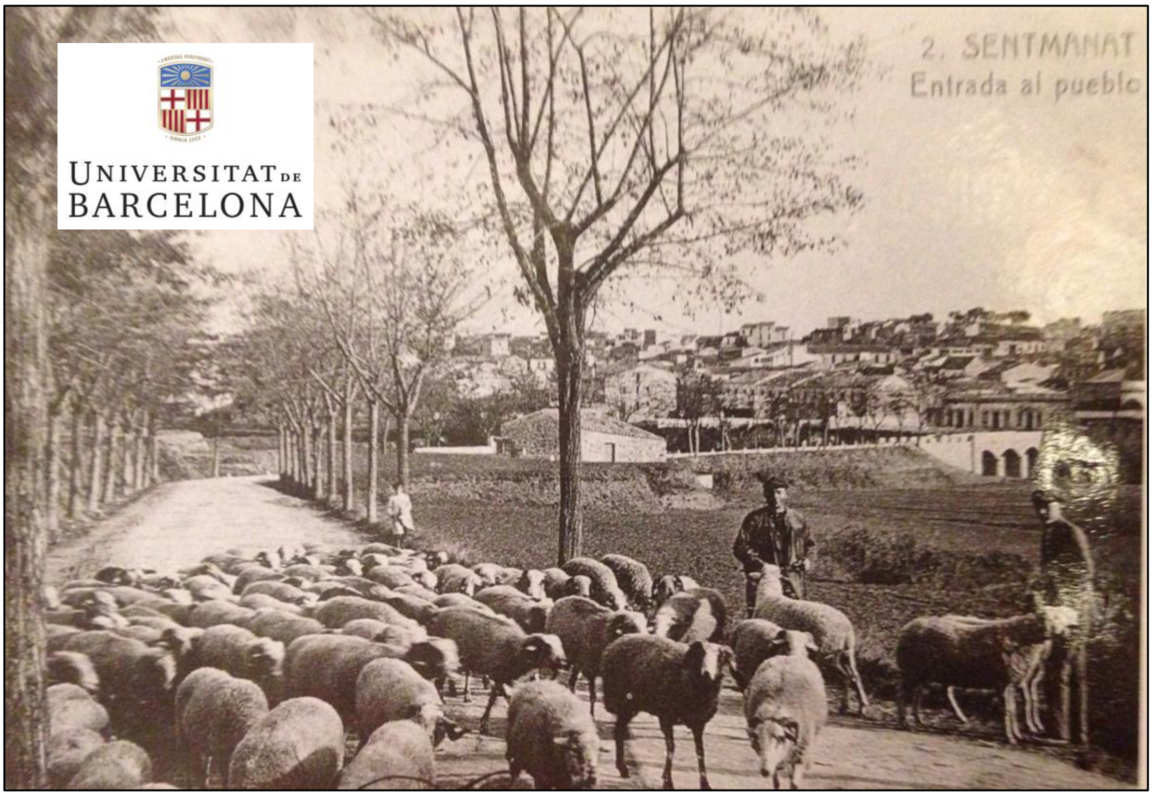
Date: **December 2017**



UNIVERSITAT DE BARCELONA

"La dificultad hoy en día no estriba en expresar libremente nuestra opinión,
sino en generar espacios libres de soledad y silencio en los que encontremos algo que decir.
Fuerzas represivas ya no nos impiden expresar nuestra opinión.
Por el contrario, nos coaccionan a ello.
Qué liberación es por una vez no tener que decir nada y poder callar,
pues solo entonces tenemos la posibilidad de crear algo singular: algo que realmente vale la pena ser dicho"
Gilles Deleuze, *Política del Silencio* (1995)

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a las campesinas y campesinos
del pasado y del presente
que mientras alimenta(ro)n al mundo
han pasado hambre

AGRADECIMIENTOS [ACKNOWLEDGMENTS]

Esta tesis doctoral ha podido iniciarse y completarse gracias a muchísimas personas. La mayor parte de las condiciones gracias las cuales ha podido desarrollarse no han estado bajo mi control. Esta tesis ha sido un proyecto de vida durante cuatro años y medio. Están incorporadas muchas horas, muchos esfuerzos, muchas alegrías, muchas dudas. El compromiso con esta tesis ha supuesto poder dar menos (atención-cariño-tiempo) a mucha gente, y aun así he seguido recibiendo mucho. He recibido tanto que espero que lo que yo devuelvo pueda servir a otras personas. Por todo lo que significa para mi cerrar esta etapa, voy a permitirme agradecer sin prisa.

El soporte financiero de esta tesis tengo que agradecerlo al proyecto de investigación *Sustainable Farm Systems: Long-Term Socio-Ecological Metabolism in Western Agriculture*, financiado por el Social Sciences and Humanities Research Council of Canada (SFS 895-2011-1020). Este trabajo se ha beneficiado tambien del proyecto *¿Sistemas Agrarios Sustentables? Una interpretación histórica de la agricultura en España desde la perspectiva biofísica*, financiado por el Ministerio de Economía, Industria y Competitividad (HAR2015-69620-C2-1-P). Por lo tanto, quiero agradecer a todas las personas que, indirectamente, han permitido que yo me dedicara a la investigación durante este tiempo.

Junto al soporte financiero, querría agradecer a todas las personas que me ayudaron a tomar este camino, y a las que me han apoyado y animado en estos años.

En primer lugar quiero agradecer a mi familia, porque me ha regalado muchas de las cosas fundamentales. En especial a mi madre y a mi padre, pero también a mi hermana y a mi hermano, que me han dado el apoyo fundamental para que tuviera confianza en mi misma. Me han educado para valorar la justicia, la honestidad y el respeto, y han tenido mucha paciencia conmigo. A pesar de que quizás no siempre han sabido en qué andaba metida, han respetado y apoyado mis decisiones. Gracias a ellxs he podido dedicar una buena etapa de mi vida a aprender, a pensar. Es uno de los mejores regalos que nunca podré recibir. Sin todo su trabajo y su amor esto no hubiera sido posible. Quiero agradecer especialmente a mi madre, por el esfuerzo físico, mental y emocional que ha hecho por criarnos. Por las renuncias a lo que ella hubiera querido. Eso nunca podré devolvérselo. A mi hermano, que me ha acogido y cuidado esta última-intensa semana de tesis. Porque tiene que ir en este párrafo, gracias a Laia Pedrós, una amiga incondicional por la que no pasa el tiempo (y al Cris, Aleix y Biel).

Por otro lado, quiero agradecer a la gran familia que ha ido creciendo en los últimos tiempos. Esta tesis nunca hubiera existido si no hubiera tenido la suerte de encontrarme en el camino con muchas personas de las que he aprendido. Son las personas que encontré después de muchos años de soledad en la facultad de economía, y con las que de verdad he compartido procesos de trabajo y aprendizaje que me han servido mucho para intentar comprender la realidad. Javier Martínez Peinado me introdujo prácticamente en todos los ámbitos en los que luego me he nutrido. Me abrió las puertas de la Asociación de Economía Crítica, con la que luego colaboré durante varios años en la secretaría de la Revista de Economía Crítica, pero también las puertas del Observatori del Deute en la Globalització (ODG). La colaboración con el ODG me dio la oportunidad de implicarme en campañas como Stop Corporate Power, del Transnational Institute, donde estuve en contacto con organizaciones de afectadas y afectados por las actividades de las empresas transnacionales en todo el mundo. Aprendí mucho durante esos años junto con las compañeras con las que luego formamos el Colectivo RETS. Hoy todavía puedo disfrutar de la compañía y el aprendizaje de personas como Iolanda Fresnillo, Jesús Carrión, Fernando Fernández y Albert Sales.

Esta tesis es muy pero que muy tributaria del compartir en estos años con mis amigas y compañeras del Seminario de Economía Feminista. Ha sido un placer y un regalo poder formarme junto a vosotras. He disfrutado emocional, mental y físicamente. El Seminario, así como la Economía Feminista, ya forman parte de mí. Ahora soy más fuerte y más libre. Gracias Karme Díaz Corral, Cristina Carrasco Bengoa, Marina Sánchez Cid y Rosa Ortiz Monera.

A las personas que forman parte del Departamento de Historia Económica de la UB, con las que ha sido un enorme placer compartir estos largos años. Por el esfuerzo que han hecho por comprender los temas que trabajamos, y por el respeto y cariño con el que han querido debatir y aportar a nuestra investigación. Quiero agradecer especialmente a Alfonso Herranz, que ha estado dispuesto permanentemente en estos cuatro años, y a Pep Colomé, del que he aprendido mucho, por compartir su tiempo conmigo siempre que lo he necesitado. También a Ricard Soto, con el que ha sido un placer compartir la experiencia lectiva.

También he tenido la suerte de compartir estos años con el equipo de investigación *Sustainable Farm Systems*, un grupo de una calidad profesional y humana que todavía hoy me impresiona. Esta tesis no hubiera sido posible sin el apoyo intelectual, emocional y material del equipo. Ha sido un gran placer y un honor formar parte de él. Además de la generosidad con la que se ha discutido y compartido las cuestiones académicas, el SFS me ha regalado grandes amigxs con lxs que estoy segura que compartiré en el futuro. A Geoff Cunfer, por ser el mejor coordinador posible de este equipo, una persona que te hace sentir alguien a pesar de que seas el último de la fila. A Andy Watson, Bea Corbacho, Biel Jover, Claudio Cattaneo, David Soto, Dino Güldner, Edu Aguilera, Elena Galán, Fridolin Krausmann, Guiomar Carranza, Inma Villa, Josh McCunfer, Juan Infante, Lucía Díaz, Manolo González de Molina, Michi Neundlinger, Patrick Chasse, Simone Gingrich, Stephania Gallini. Especialmente al equipo de Sevilla y de Viena, que me han acogido muy generosamente durante las estancias que he realizado en sus universidades. A las nuevas incorporaciones, como Marc Maynou y Alex Urrego, por su apoyo. Tanto Andy como Edu han dedicado mucho tiempo a revisar mi humilde inglés, y lo han hecho con mucho cariño. Simone ha estado disponible hasta el último momento con sus lecciones de Sankey, que ha mejorado esta tesis.

No va a haber forma de agradecer a las personas del equipo catalán del SFS el apoyo que me han dado en estos años. Para empezar, la culpable (en gran parte) de todo esto, Elena Galán, que me cameló con sus buenos tratos y su alegría. A partir de ahí, junto con Roc Padró y Enric Tello hemos funcionado como una unidad, en la que a día de hoy es muy difícil distinguir las costuras. Ha sido una bonita luna de miel intelectual y personal. Creo que como equipo hemos sido conscientes desde el principio de que nunca ha habido nada de nadie. Todxs sabemos que esta es de lxs tres. Quiero agradecer a Enric Tello su confianza en mi, a veces muy ciega, incluso en los momentos delicados. He aprendido mucho con él. Estoy inmensamente agradecida. A Roc Padró solo puedo decirle que le echaré de menos. En estos cuatro años hemos vivido un proceso de fusión, y a pesar de que lo productivamente importante es la buena combinación de nuestras perspectivas, sinérgicas (seguro), lo realmente importante es que nos hemos conocido mucho y nos hemos querido mucho. Sé perfectamente que no hubiera podido sin ti, y sé que a esta tesis has aportado lo mismo que yo. Ojalá nos volvamos a encontrar lxs tres o lxs cuatro en el camino.

Quería agradecer especialmente a Ramón Garrabou, porque de muchas formas él ha inspirado esta tesis. Siempre he sentido una profunda admiración por su trabajo, por las preguntas que han guiado su investigación, y por la forma que tiene de responderlas. Para mi ha sido un enorme placer poder compartir parte de esta tesis con él. Me hubiera gustado que fuera más, pero los tiempos modernos no me lo han permitido. También a Biel Jover, porque con su rigor intelectual y sus preguntas de investigación, que he sentido muy cercanas a las mías, me han ayudado a seguir caminando. A José Manuel Naredo le debo mucho. Le debo mi enamoramiento profundo con la Economía Ecológica. Le debo la inspiración que me ha ofrecido con su forma libre de pensar, sin sentirse tributario de ninguna disciplina. Por su profunda humanidad, y por una amistad muy generosa. Quiero agradecerle a Manolo González de Molina por escucharme, por animarme a apostar por el análisis de desigualdad, y por la inspiradora lucidez de sus pensamientos. A Jordi Roca, por su confianza, su cariño, su apoyo y su amistad.

En estos años he tenido la suerte de encontrarme con muchas personas a mi alrededor que me han apoyado. Han sido años muy duros, pero a la vez muy nutritivos. Todo el amor, el cuidado, el apoyo que he recibido me ha ayudado a superar los baches del camino. Me gustaría mucho que todxs sintieran esta tesis un poco suya. A la gente de Sur o no Sur, porque sin nuestras escapadas, nuestras canciones y nuestro apoyo tan bonito esto no hubiera sido posible (además Marco y Olly me ayudaron a traducir una palabra al inglés un día ;) ; y Lina casi me ayuda a paginar las secciones). A la Yaiza, Miqui, Lina, Romi, Silvia, Vir, Montse, Kike, Jesús, porque estamos conectadas por las raíces, y juntas somos más fuertes. A la Isa porque forma parte.

Gracias a todas las personas con las que he convivido en estos años. Todas ellas personas maravillosas, con las que he tenido la gran suerte de compartir miles de momentos. Por lxs miembros de La Cuca, porque me hicieron ver que no estaba sola, que había mucha más gente que pensaba y sentía como yo, y eso me hizo más fuerte. Gracias por vuestras enseñanzas, Jordi Oriola, Mariela

Acjia, Alf, Vir y Alfons. Si hubiera parecido que no podía encontrar otro lugar mejor, apareció Can Ajillas. Una agrupación de personajxs con mucha Vida y mucho compromiso. He sido muy feliz entre ellxs. Gracias Adri, Anaïs, Anna, Aina, Carlos, Javi, Maia, Moni. Entre paréntesis, entre Barcelona y Sevilla, gracias a Óscar Flores (y a la Montse y al Pepe). Como guinda, un sueño maravilloso sevillano, algo bastante parecido a Mi Vecindario, un lugar en el que me encontré. Gracias a La Casa de las Niñas; Alma, Artacho, Astrid, Mariluz, Maite, María, Mari Carmen. Una etapa inolvidable.

Y porque 'si no puedo bailar, tu revolución no me interesa' gracias a Las Pies Negros, con las que tuve la gran suerte de tropezar, y que han sido para mi un apoyo fundamental en los últimos años. Gracias por mirarme, por quererme, por guiarme en el camino. Gracias por la alegría y la verdad que compartimos. A Abi, Andrea, Anna, la Agnes, Bibi, Silvia y Tati.

Quiero agradecer también la inspiración y la fuerza que me ha dado, aunque a la distancia, las compañeras y compañeros del Sur. La visita a Santiago del Estero, Argentina, en el verano de 2014 me mostró que todavía hoy son muchas y muchos lxs que luchan por el acceso a la tierra, por el derecho a no ser envenenados. Todavía hoy gritan ¡Ni un muerto más por el derecho a la tierra!. Sin la energía y lucidez que me ha dado sentirme cerca de todas estas personas no hubiera podido encontrar el sentido. Gracias en especial a Delphine Ortega, Martín Drago y lxs cumpas de la Unicam-Suri y de Radio Mundo Real por vuestro trabajo y compromiso. Delphine Ortega no solo está aquí, estaba en La Cuca, estaba en el ODG, y ha estado de manera provindencial e incansable en la corrección del inglés de parte de esta tesis. Gracias por eso y por el apoyo de estas semanas, que ha sido muy importante.

Por último, y para ajustarme a las cuatro páginas permitidas, quería agradecer una de las mejores compañías que he tenido en tantos momentos de soledad. No podría haber aguantado tantas horas interminables sin todxs lxs músicxs y cantantes que me acompañado sin saberlo. La música me ha mantenido conectada, me ha dado concentración, alegría y produndidad.

.

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AWU: Annual Working Units
BR: Biomass Reused
ECB: Equivalent Consumption Basker
EFEROI: External Final Energy Return on Investment
EI: External Inputs
EROI: Energy Return on Investment
DFW: Domestic and Family Work
FBR: Farmland Biomass Reused
FCR: Feed Conversion Ratio
FEROI: Final Energy Return on Investment
FP: Final Produce
FPa: Final Produce agricultural
FP$_{ECB}$: Final Produce in Equivalent Consumption Baskets
FPLab: Final Productivity of Labour
FPLan: Final Productivity of Land
FPs: Final Produce surplus
FPt: FP tools
FPtax: FP taxes
GCV: Gross Calorific Values
HH: Household
IER: Inequality Extraction Ratio
IFEROI: Internal Final Energy Return on Investment
LBR: Livestock Biomass Reused
LEIT: Low External Input Technology
LTBA: Land-Time Budget Analysis
LU500: Livestock Units 500
ME: Metabolizable Energy
MEFA: Material and Energy Flow Analysis
NLS: Necessary Labour Supply
PLS: Potential Labour Supply
SPL: Social Productivity of Labour
TIC: Total Inputs Consumed
TP: Total Produce
TPLab: Total Productivity of Labour
UhB: Unharvested Biomass

PUBLICATIONS DERIVED FROM OR LINKED TO THIS PHD THESIS

Two Chapters of this PhD thesis have been originally published or submitted in the following journals included in the Web of Science:

Chapter 3: Marco, I., Padró, R., Cattaneo, C., Caravaca, J. and Tello, E. (2017) *From vineyards to feedlots: A fund-flow scanning of sociometabolic transitions in the Vallès County (Catalonia) (1860-1956-1999)*. Regional Environmental Change, published on-line first. doi:10.1007/s1011 [JCR IF: 2,919; Q2 in Environmental Sciences].

Chapter 4: Marco, I., Padró, R. And Tello, E. (submitted in 2017 and in review) *Labour, Nature and Exploitation: A first Exploration of the Relations Between Social Metabolism and Inequality in Traditional Organic Farming (Sentmenat, Catalonia, 1850)*. Journal of Agrarian Change. [JCR IF: 2,345; Q1 in Economics and Planning & Development].

During the elaboration of this PhD thesis I have also co-authored the following articles published in journals and international publishing companies included in the Web of Science, which are tightly linked with my research in the International SFS research project:

Tello, E., Galán, E., Sacristán, V., Cunfer, G., Guzmán, G.I., González de Molina, M., Krausmann, F., Gingrich, S., Padró, R., **Marco, I.** and 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. doi:10.1016/j.ecolecon.2015.11.012. [JCR IF: 2,965; Q1 in Economics and in Environmental Studies].

Galán, E., Padró, R., **Marco, I.**, Tello, E., Cunfer, E., Guzmán, G., González de Molina, M., Krausmann, F., Gingrich, S., Sacristán, V. and 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 Modelling, 336: 13–25. doi:10.1016/j.ecolmodel.2016.05.012. [JCR IF: 2,363; Q2 in Ecology].

Gingrich, S., **Marco, I.**, Aguilera, E., Padró, R., Cattaneo, C., Cunfer, G., Guzmán Casado, G., MacFadyen, J., Watson, A. (2017) *Agroecosystem energy transitions in the old and new worlds: trajectories and determinants at the regional scale*. Regional Environmental Change, published on-line first. doi:10.1007/s10113-017-1261-y. [JCR IF: 2,919; Q2 in Environmental Sciences].

Padró. R., **Marco, I.**, Cattaneo, C. Caravaca, J. And Tello, E. (in press) Does your landscape look like what you eat? In: Fraňková, E., Haas, W., Singh, S.J. (eds.) *Socio-Metabolic Perspectives on the Sustainability of Local Food Systems Insights for Science, Policy and Practice*. New York: Springer International Pub., Human-Environment Interactions Series num. 7, pp. 133-164. doi: 10.1007/978-3-319-69236-4_5, ISBN: 978-3-319-69235-7.

Padró, R., **Marco, I.**, Font, C. and Tello, E. (submitted in 2017 and in review) *Beyond Chayanov: A Sustainable Farm Reproductive Analysis of Peasant Domestic Units and Rural Communities (Sentmenat; Catalonia, 1860)*. Ecological Economics. [JCR IF: 2,965; Q1 in Economics and in Environmental Studies].

CHAPTER 1:

A personal and political introduction

Original photograf by Pere Casas Abarca (dated c.1900)
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Col·lecció Museu Nacional d'Art de Catalunya (MNAC)
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CHAPTER 1

A personal and political introduction

'¡Despertemos! ¡Despertemos Humanidad! Ya no hay tiempo. Nuestras conciencias serán sacudidas por el hecho de solo estar contemplando la autodestrucción basada en la depredación capitalista, racista y patriarcal'

[Let us wake up! Let us wake up, humankind! We're out of time. We must shake our conscience free of the rapacious capitalism, racism and patriarchy that will only assure our own self-destruction]

Berta Cáceres Flores
Co-founder of the National Council of Popular
and Indigenous Organisations of Honduras (COPINH)
Goldman Environmental Prize 2015
Murdered in March 2016

…the seeds of this thesis…

This doctoral thesis is the last stage of a larger process, which began at an indefinite time around the year 2002. For a long time, fixed images of people sleeping in doorways of buildings or picking up food in the trash remained in my retina. These images could be seen along those of men and women driving luxury cars, eating at fancy restaurants and wearing expensive clothes. Even today my eyes, my heart and my mind are not used to the systemic inequality we witness every day. In 2004 I had the opportunity to travel to India, where I understood that poverty was territorialised: it was inscribed on a map. Out of naïveté, I decided to study Economics to understand the reasons underlying these situations and to be capable, to the-best of my abilities, of transforming that reality. It was a great disappointment to find myself facing legitimisations of the reality and listening how people talked in terms of *externalities*, *comparative advantages*, or *marginal productivity*... When I was about to abandon the degree, I met Javier Martínez Peinado. I remember well the feeling I had the first time I went to his course: 'this fits with what I observe'. He convinced me that another type of economists was needed. From there I continued the degree with boost, mostly training outside the faculty except for three other extraordinary professors with whom I truly learned: Benjamin Bastida, Cristina Carrasco and Jordi Roca. Today, more aware than ever of the difficult conditions in which heterodox and critical economics can be taught in the Economics' faculties, I want to thank all of them for their great work.

The trajectory that this doctoral thesis somehow closes has been very influenced by the schools of thought that these people represent. I remember a Conference on Critical Economics, in 2012. I had not seen Javier for a long time, and we met there. He wisely advised me: 'you have to move forward to Ecological Economics and Feminist Economics, it is the future'. Later on, when I was in direct contact with both disciplines through Cristina Carrasco and Jordi Roca, I remembered his words. Somehow he had shown me the way; a path that perhaps I followed unconsciously. They all gave me the seeds of this PhD dissertation. I firmly believe that processes cannot be understood if we do not start from the comprehensive understanding of socio-ecological functioning. The dynamics of power establish hierarchies between different perspectives, thus limiting the effectiveness of theoretical discourses and political proposals. But as Audre Lorde says, 'there is no hierarchy of oppressions'. If there exists an auspicious answer to the civilisatory crisis in which we find ourselves, it must be put forward by a set of heterodox approaches.[1]

In the following paragraphs I describe the in-depth questions that guided this dissertation. For the meantime, in this introduction I focus on the most essential and radical aspects that might answer the question about how this dissertation could be relevant for society, leaving for the introduction of each chapter the explanation of the specific objectives, especially those related to historiographical issues. Undoubtedly, both the study of history and the concrete study of agricultural history respond to functional objectives, and are intrinsically linked to the current social and ecological challenges. I first describe some of the most important features of the current socio-ecological system (capitalist patriarchy), to go on to describe which relevant questions could be faced by agricultural history to tackle these challenges.

... about why we need an integrated approach ...

Since the first warnings of the Meadows report (1972), *The limits to growth*, and after decades in which environmentalist perspectives have been accused of being pessimistic, baseless or exaggerated, we could say that a certain generalised awareness of the ecological crisis has endured (or at least the acceptance that it exists). Given the deep problem humanity faces, no less should be expected. Certain data can help us grasp the situation we are in. Here are some examples about the depletion of the essential natural resources for the functioning of the economy: (i) the global extractive capacity of conventional oil has stagnated since 2005 (IEA 2015); (ii) between 2015 and 2024 we will reach the peak of extraction of all liquid fuels (Political Economist 2016; Li 2017); (iii) in a single century we have exhausted 43% of the reserves of non-energy minerals, the estimate until the depletion of the total reserves is 142 years (Valero and Valero 2015:406); (iv) the Global Assessment of Human-induced Soil Degradation (GLASOD) has estimated that 15% of the soil is already degraded, while recent studies show that 24% of Earth's surface has been degraded in the past 25 years (Bai et al. 2008); (v) overexploitation of aquifers and water extraction peak in some countries (Brown 2013a, 2013b; Postel 2013); and (vi) we are experiencing the sixth extinction in Earth's history (Steffen et al. 2004). Regarding the alteration of ecosystem balances, (a) we have altered Carbon cycles

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[1] It should be noted that the issue of race and ethnicity inequality, though highly relevant, is omitted in this study, as the features of this research topic are beyond the scope of this dissertation.

(climate change), (b) Nitrogen and Phosphorus cycles (Vitousek et al. 1997; Galloway et al. 2004; Bouwman et al. 2009; Cordell et al. 2009) and (c) water cycles.[2]

As a reference on the impacts of the current economic model, we can start with the proposal of Rockström et al. (2009a, 2009b), which defines nine planetary limits that should not be crossed if we want to maintain basic activities of humanity within safe limits. Of these nine limits, it is considered that three have already been trespassed: concentration of atmospheric CO_2, the speed of the loss of biodiversity and the disruption of biochemical cycles of Nitrogen. Another two of them, chemical pollution and atmospheric charge of aerosols, cannot be assessed, since they do not have an established threshold yet. Among the rest of the indicators, some have not been trespassed but are dangerously close to the established limits (such as ocean acidification). The intensity of the effect of human activities on Earth is so relevant that humanity is considered a global geological force. For a growing number of scientists, human activity is the most active and powerful geological force that affects Earth's System, posing the beginning of a new geological era, the Anthropocene (Crutzen and Stoermer 2000).

Although there is an open debate on the starting point of the Anthropocene (Smith and Zeder 2013), I agree with those who propose the Industrial Revolution as the beginning of the Anthropocene (Steffen et al. 2011). The identification of the Anthropocene with the Industrial Revolution makes the two faces of the historical process experienced in the last two centuries explicit: the great benefits and advances in material terms have gone hand in hand with strong social and environmental impacts. The Industrial Age, which meant a considerable increase in world's population (from one billion people in 1800 to six billion in 2000), as well as strong increases in the value of world's production (which has multiplied per 50 in the same period; McNeill 2001), cannot be understood without the rupture of the biophysical limits of the former agricultural regimes. This entailed a deeper process of 'colonisation' of nature, that, in the transition to the industrial regime, meant extending the control of terrestrial biomass to controlling the resources provided by Earth's crust (Fischer-Kowalski and Haberl 1997). Krausmann et al. (2008a) estimate that the transition from the agricultural regime to the industrial regime implied an annual increase in domestic energy consumption (DEC) from 30 to 600 $GJ \cdot hectare^{-1}$, and an increase in annual domestic consumption of materials (DEM) from 2 to 50 $tons \cdot hectare^{-1}$ (Krausmann et al. 2008a:643).[3]

In short, we can describe the industrialisation process as one involving a strong development of productive forces, whose key was the shift from bioconverters (human or animal labour force) to fossil fuels (Gales et al. 2007). The era of cheap fossil energy, when the barrel of oil cost $ 1.5, entailed the equivalent of 4,000 hours of human labour for $ 1 (Leach 1981). Availability of cheap energy allowed to increase the size of social metabolism, through the increase in the size of the metabolic flows

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[2] Many of the data and reports quoted here have been collected from the report 'Walk on the abyss of limits: Policies before the ecological, social and economic crisis', published by Ecologistas en Acción (2017).

[3] In relative terms, a DEC variation is estimated from 40-70 to 150-400 $GJ \cdot cap^{\cdot -1} year^{\cdot -1}$ and an increase in domestic consumption of DEM materials from 3-6 to 15-25 $tons \cdot cap^{\cdot -1} year^{\cdot -1}$.

(appropriation, transformation, circulation, consumption and excretion). In this way, some studies have shown the joint trend of total energy use and GDP growth (Stern 2010; Warr et al. 2010; Ayres and Warr 2010). The triangulation and positive feeding between extraction's increase and the use of materials and energy, population increase, and GDP growth is undoubted (Krausmann et al. 2009).

In structural terms, the 'good news' about the development of productive forces, is that it has been accompanied by at least three 'drawbacks'. The first one, which has already been mentioned, is that, given the structural characteristics of the material base of the socio-ecological system, it cannot be maintained over time. Hence, this is an unsustainable socio-ecological regime. The depletion of fundamental resources is the logical consequence of a model based on non-renewable sources, either due to their non-renewable nature (such as minerals), or because of the speed of human consumption, which does not allow reproduction cycles (e.g. fishery resources). The shift from the economy of 'production', based on the generation of plant products (biomass) by photosynthesis, to an 'acquisition economy', based on the extraction and decumulation of non-renewable resources (Carpintero 2005; Naredo 2006), implies that the model can be maintained only for a certain period of time. This aspect is the most analysed one in scientific literature. The processes of ecological degradation and the temporary limits of the industrial regime have been widely described and quantified.

The second 'drawback' is that those generic benefits have been unevenly distributed. In terms of access to energy and materials, Krausmann (2008:648) proposed: (i) a domestic energy consumption (DEC) of 253 GJ·cap^{-1}·year^{-1} for industrialised countries, and 59 GJ·cap$^{\cdot-1}$year^{-1} for developing countries, (ii) a domestic material consumption of 19 tons·cap$^{\cdot-1}$year$^{\cdot-1}$ for industrialised countries and 7 tons·cap$^{\cdot-1}$year$^{\cdot-1}$ for developing countries. This also affects basic consumption. FAO reports indicate that between 2014 and 2016, one in nine people in the world was undernourished, which in absolute terms represents almost 795 million people (FAO 2015). Other indicators show, for instance, variations in electricity consumption (29 GJ·cap$^{\cdot-1}$year$^{\cdot-1}$ for industrialised countries and 3 GJ·cap$^{\cdot-1}$year$^{\cdot-1}$ for developing countries), or consumption of animal products (1.29 GJ/cap/year for industrialised countries and 0.53 GJ·cap$^{\cdot-1}$year$^{\cdot-1}$ for developing countries) (Krausmann 2008). The different intensities of material and energy consumption also derive from the fact that it is currently estimated that two thirds of humanity live~~s~~ in agrarian regimes, transitioning (or not) towards industrial regimes (Haberl et al. 2011). In addition, internal national differences continue to exist, and even increase in some Northern countries, as it is the case for the Spanish State. Campaigns denouncing 'energy poverty' have been activated in recent years, given that economic conditions entailed that some sectors cannot afford basic access to energy (i.e. for cooking, food preservation or house heating).

The maintenance of large pockets of poverty is not random. Although productive capacity has increased due to the inclusion of inorganic energy carriers, these have been added instead of replacing the traditional organic ones, especially the human labour force. This is true for at least two types of work. First of all, the domestic and care work carried out by women has barely decreased in time units, although it has been qualitatively modified in several countries. Secondly, labour market has not diminished, and its conditions continue to be very harsh in many of the countries to which the world industrial and agricultural production has been displaced (although the same occurred with the service sector in many cases). Both processes, 'gratuitous' female labour and 'cheap' workforce from impoverished population, also allowed for cheap and abundant products for mass consumption. As André Gunder Frank proposed based on the dependency theories, *underdevelopment* would be the other side of *development* (Frank 1971). Finally, in many cases, especially in the case of rural population, poverty levels are accentuated by environmental conflicts,[4] and impoverished population are most likely to be affected by environmental degradation.

The third 'drawback' is that the current industrial regime will not only have socio-ecological impacts in the future. As we have just mentioned, it has already had them in the past. This reality still remains in the background. These impacts have taken place for the most part in Southern countries, although not only, and have mainly been studied by Political Ecology. The key impacts have been concentrated in the appropriation of energy and materials processes (mining or land-grabbing), transformation processes (e.g. pollution by discharges or emissions), circulation (e.g. emissions and infrastructures) or excretion (e.g. dumps). In many cases, these impacts have generated resistance processes on the part of the affected people or communities, originating what has been named 'environmental conflicts' or 'ecological-distributive conflicts' (Martínez-Alier 2006). It is worth mentioning that these conflicts entailed a high level of violence. According to Global Witness annual report, at least 200 environmental defenders were killed in 2016, almost four a week. According to the same report: 'Conflicts over the control of land and natural resources were an underlying factor in almost every killing in 2016. Mining and oil are again linked to more murders - 33 cases in 2016 - than any other industry. The number of murders associated with logging increased from 15 to 23, while agribusiness continued to represent a major factor, associated with 23 killings in 2016' (Global Witness 2016:9).

In spite of this, the *maldevelopment* (Shiva 1988) remains as the dominant paradigm, the path to follow. The maintenance of this paradigm has been used to legitimise the status quo, to keep invisible the several peripheral spheres on which economic growth has been built (nature and labour exploitation). Like a funnel, the current global economy has managed to concentrate natural and societal wealth, and working time of men and women, in the hands of a few. This could not work without a legitimation process and, as the Sevillian illustrator Miguel Brieva voices in his brilliant poem 'Deficit of self-esteem'

> 'Inestimable and omnipotent [is] the propaganda campaign that must be breathed every day, every minute that passes, to make us believe that a model of life that keeps half humanity in extreme misery and threatens to destroy the very habitability of the planet in less than a century is, effectively, the least bad of the possible systems. Frankly, you cannot

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[4] For instance, the expulsion of communities from colonised territories where transnational corporations controls the land and the productive processes therein.

think worse about ourselves' (Brieva 2017:88).[5]

A socio-metabolic transition towards sustainability? Challenges for another Great Transformation[6]

> '(…) there is the presumption that a sustainability transition is both inevitable and improbable. It is inevitable, because the present sociometabolic dynamics cannot continue for very long any more, and it is improbable because the changes need to depart from known historical dynamics rather than being a logical step from the past into a more mature future state'
>
> Fischer-Kowalski (2011:153)

Some authors have referred to the beginning of a third stage of the Anthropocene, which distinguishes from the previous ones by the growing awareness of the global environmental impact of human activity, as well as the first attempts to pose global governance systems (Steffen et al. 2007). In spite of that, the structural advances have been very small. While 25 years ago 1500 scientists signed a document warning about the environmental challenges, this year around 15,000 scientists signed a second document stating that not only have we not achieved enough progress, but that most of the environmental challenges are getting worse. This time they warn that 'soon it will be too late to shift course from our failing trajectory, and time is running out' (Ripple et al. 2017:3). The very same message as the one Berta Caceres left us (quoted in the beginning of this Introduction).

In my opinion, it is necessary to make a greater effort to go beyond describing the ecological crisis. We need to deeply understand the social features of the crisis, especially regarding reluctances to urgent behaviour changes. Within Social Metabolism approaches, the works that analyse the material phenomenon predominate, but the ones that consider the non-material mechanisms with which, and within which, the metabolism takes place are still rare (Toledo 2013:51).[7] As I defend in this dissertation, social inequalities have to be taken into account due to its relevant role in socio-metabolic functioning. Furthermore, this will help us to better understand what are the real implications of moving towards ecologically and socially sustainable societies. Although we agree with the foundations of several slogans such as *degrowth* (Kallis 2011), *good living* (Acosta 2013) or *sustainability of life* (Pérez Orozco 2010; Carrasco 2014), we must beware of a certain optimism about the possibilities of achieving a sustainable economic system, both in social and ecological terms. In our opinion, it is not realistic to consider the socio-ecological transition towards sustainability, which for the first time will entail less access to energy and materials (Haberl et al. 2011), as a win-win process. Moreover, to continue raising it in these terms does not facilitate the understanding neither the feasibility of an

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[5] Translated by the author from Spanish.

[6] I allowed myself to use the title of the article by Helmut Haberl, Marina Fischer-Kowalski, Fridolin Krausmann, Joan Martinez-Alier and Verena Winiwarter (2011), published in *Sustainable Development*.

[7] Translated by the author from Spanish.

ecological and social fair transition.

Historical analysis is an essential tool towards a necessary review of socio-ecological functioning. The long-term study of agricultural regimes and socio-ecological transitions allows us to highlight several elements that are usually omitted from a modern perspective. It might allow us to propose more realistic scenarios, bringing to light the challenges and threats of such a transition. The aims of this dissertation could be split into two distinct parts. The first one (Chapter 3) focuses on the analysis of the transition from advanced organic agricultures to industrial agricultures within our case study (Vallès County, Catalonia).[8] In order to represent the three stages of this transition, three time periods are analysed (1860-1956-1999). The specific research questions are the following:

- What were the main features of the chosen stages of this socio-ecological transition from advanced organic to industrial agricultures?
- What were the main drivers of this socio-ecological transition?
- Which kind of agroecosystem imbalances emerged and why?
- What lessons could derive from studying the changing structures of the agroecosystem analysed?

Although some authors have pointed out the links between environmental degradation and the search for a reduction in working time (Rifkin 1987), most of the Socio Metabolic research does not include labour organisation as a key point. Along the second part of this dissertation (Chapters 4 and 5) I highlight the role of labour and social inequalities within a socio-metabolic analysis. Given the lack of a theoretical framework and methodological proposals for the analysis of social inequalities and biophysical limits, a significant part of the effort has been devoted to these theoretical and methodological developments. Thus, in this second part I seek to answer the following questions:

- What were the links between social inequalities and biophysical limits in advanced organic agricultures?
- In which way does the Social Metabolism perspective contribute to the traditional analysis of social inequalities?
- What were the main biophysical exchange flows among social classes?
- What could be the role of social inequalities within the socio-ecological transition studied?

Afterwards, Chapter 2 describes the main features of the case study; then Chapter 6 summarises the conclusions obtained, and Chapter 7 brings back some of the questions posed in this Introduction.

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[8] Advanced organic agricultures are defined by Wrigley (1990) as those which used very little fossil fuel, relied on local resources, and were able to raise land productivity through high labour inputs.

CHAPTER 2:

Basic Soil and Climate Features of the Case study

Photograf by an unknown author (Undated)

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Imatges i records de Sentemenat (Viena Columna)

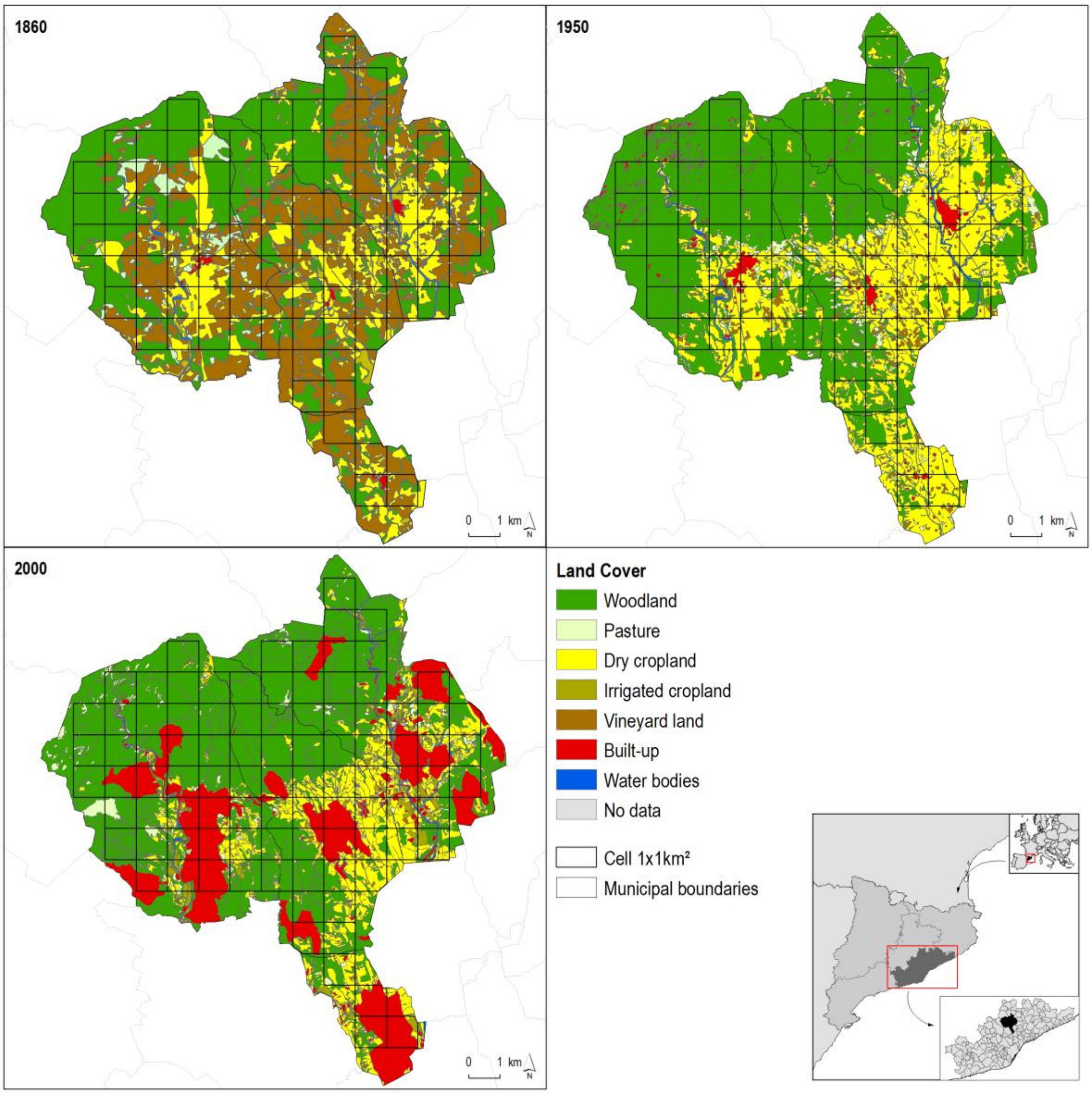
CHAPTER 2:

Basic Soil and Climate Features of the Case study

The Vallès County is situated between the littoral and pre-littoral mountain ranges of Catalonia (northeast Spain). Sentmenat is located 25 km North of the city of Barcelona. Olarieta et al. (2008) describe in detail the edafoclimatic features of Sentmenat and the four municipalities surrounding it. We could define two different edafoclimatic zones within the Vallès County. First, one area with a low relief on its southern half, with altitudes ranging from 130 to 250 m, a mean annual rainfall of 600–650 mm and a mean annual evapotranspiration (Thornthwaite) of 770–800 mm. Second, a more mountainous area on the northern half, with altitudes between 250 and 815 m, a mean annual rainfall of 800 mm and a mean annual evapotranspiration of 700 mm. In the mid-nineteenth century, the characteristics of the area in terms of land suitability were good, as a high share of land was moderately or highly suitable for the most common crops, and 57% of the land could be considered to have high or very high flexibility for agriculture.

In the first part of this dissertation (Chapter 3) we worked with four municipalities of the Vallès County: Caldes de Montbui, Sentmenat, Castellar del Vallès and Polinyà (Map 2.A). We have chosen three time points to illustrate the stages of socioecological transition: mid-nineteenth century, which represents the case of traditional organic agriculture; mid-twentieth century, where there appears an incipient industrialization; and the end of the twentieth century when agriculture has been fully industrialised and globalised. In the second part of the dissertation (Chapters 4 and 5) we will focus in one of them, Sentmenat.

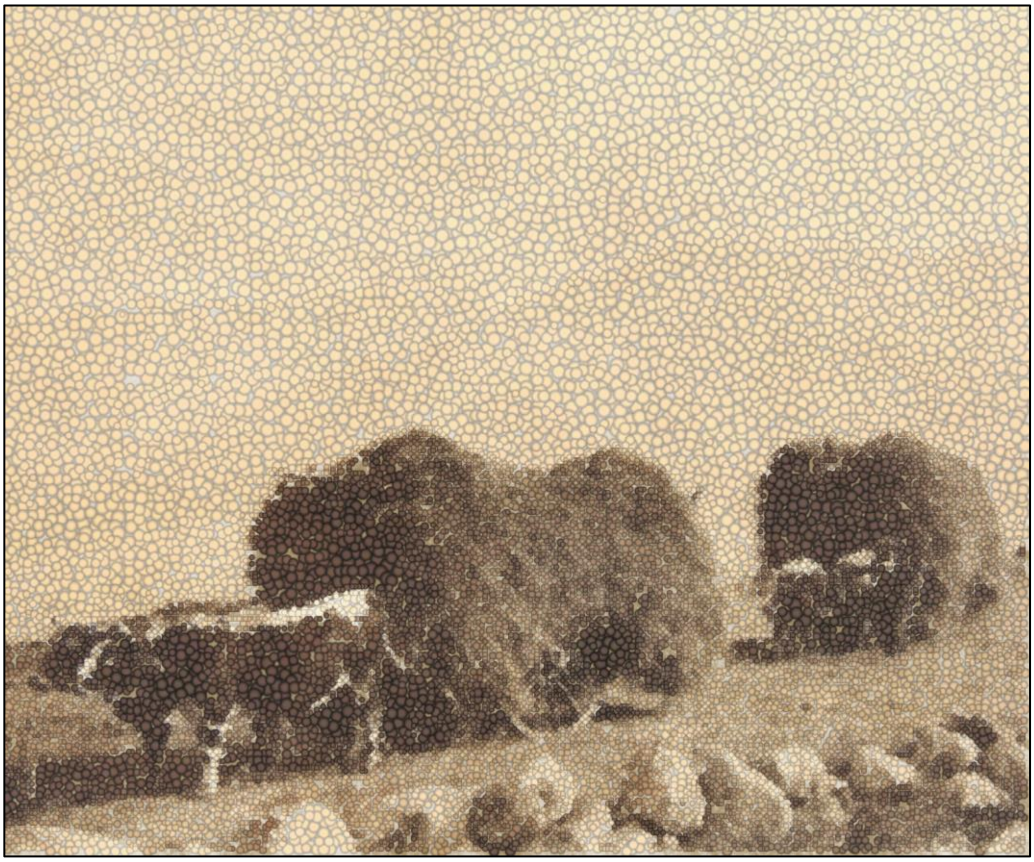
Map 2.A Area of study and land-use maps of the four villages c.1850-60, 1950 and 1999



Source: our own, digitised at the Institute of Regional and Metropolitan Studies of Barcelona (IERMB) from the cadastral land-use maps of mid-19th century kept in the Institut Cartogràfic i Geològic de Catalunya (ICGC); the cadastral maps of mid-20th century provided by the Cadastral Regional Office of Barcelona; and, for the beginning of the 21st century, the third edition of the Land Cover Map of Catalonia generated by photointerpretation made in the Research Center in Terrestrial Ecology CREAF from the colour orthophoto map provided by the ICGC.

CHAPTER 3:

From vineyards to feedlots: A fund-flow scanning of socio-metabolic transition in the Vallès County (Catalonia) (1860-1956-1999)



Original photograf by Claudi Carbonell (dated 1927)

Cosecha [Harvest]

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CHAPTER 3:

From vineyards to feedlots: A fund-flow scanning of socio-metabolic transition in the Vallès County (Catalonia) (1860-1956-1999)[9]

Abstract:

We analyze the changes to agricultural metabolism in four municipalities of Vallès County (Catalonia, Iberia) by accounting for their agroecosystem funds and flows during the socioecological transition from organic to industrial farming between the late nineteenth and twentieth centuries. The choice of three different stages in this transition allows us to observe the transformation of its funds and flows over time, the links established between them, and the effect on their energy profiles. We emphasize the relevance of the integration and consistency of agroecosystem funds for energy efficiency in agriculture and their role as underlying historical drivers of this socioecological transition. While readjustment to market conditions, and availability and affordability of external inputs are considered the main drivers of the transition, we also highlight the role of societal energy and nutritional transitions. An analysis of advanced organic agriculture c.1860 reveals the great effort required to reproduce soil fertility and livestock from the internal recirculation of biomass. Meanwhile, a balance between land produce and livestock densities enabled the integration of funds, with a positive impact on energy performance. The adoption of fossil fuels and synthetic fertilizers c.1956 reduced somewhat the pressure exerted on the land by overcoming the former dependence on local biomass flows to reproduce the agroecosystem. Yet external inputs diminished sustainability. Partial dependence on external markets existed congruently with internal crop diversity and the predominance of organic over industrial farm management. A shift toward animal production and consumption led to a new specialization process c.1999 that resulted in crop homogenization and agroecological landscape disintegration. The energy returns of this linear feed-food livestock bioconversion declined compared to earlier mixed farming. Huge energy flows driven by a globalized economy ran through this agroecosystem, provoking deep impacts at both a local and external scale.

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[9] The list of authors is the following: Inés Marco[a], Roc Padró[a], Claudio Cattaneo [b], Jonathan Caravaca [c], Enric Tello[a].

I have led as corresponding author the publication of this article in the journal *Regional Environmental Change*. My main contributions have been the elaboration of the energy balances for 1860 and 1999, as well as writing the whole paper and the Appendix. Roc Padró made relevant contributions to the elaboration of these energy balances, and made the nutrient balances; Claudio Cattaneo and Jonathan Caravaca made the energy and nutrient balances for 1956. Enric Tello coordinated the whole research team and gave his advice throughout the process.

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3.1 Introduction

Sustainability of agricultural systems is one of the major topics within the research on transitions towards sustainable economic systems. As it has been stated in ecological economics, agriculture is the most important economic sector with the potential to be a net provider of renewable materials and energy carriers to the rest of the economy (Georgescu-Roegen 1971). From a socio-metabolic perspective, agroforestry and mining are two fundamental economic activities where the reproduction of society occurs as a consequence of the human appropriation of natural processes (González de Molina and Toledo 2014). The capitalist economic system challenges sustainability by relying on constantly increasing metabolic flows to support continual economic growth (Kallis 2011). While academics warn about fossil fuel and mineral resource depletion (Sorrell et al. 2010; Valero and Valero 2010), energy balances in agriculture have shown that industrial agriculture is no longer an energy supplier but a sink (Leach 1976; Campos and Naredo 1980). Moreover, agriculture has been transformed into a source of greenhouse gas emissions, water pollution and reduced biodiversity (Tilman 1999; Tilman et al. 2002; Pingali 2012; Aguilera et al. 2013). Its fundamental role within the current socio-economic systems is as a provider of cheap food, biofuels or raw materials for the rest of society. Within the framework of a socio-metabolic transition towards sustainability (Haberl et al. 2011), research on agricultural metabolism is crucial in bringing to light the broader basis on which to build sustainable socioeconomic systems.

In order to understand the social and environmental driving forces that led this process, historical perspective offers a great variety of case studies in terms of edafoclimatic conditions, time periods, and social structures. This type of history is more than an isolated exercise. It can provide relevant knowledge in terms of how past organic agricultures functioned, and how their capacities and limitations related to the interplay between its social and environmental elements. Transitions to industrial agriculture went through different stages in which industrial inputs gradually supplemented or replaced human and animal labour, organic fertilizers and feed. Along the whole transition period, social, economic and environmental factors worked together, and their complex interaction needs to be deeply analysed. From a sustainability perspective, historical analysis can complement contemporary assessment of sustainable agriculture.

Even though sustainability assessment requires a wider multi-criteria analysis (Giampietro et al. 2006), Energy Returns on Investment (EROI) have been highlighted as one of the relevant indicators for this purpose (Hall 2011). Still, differences in system boundaries and methodologies render problematic the comparison among results of energy balances (Pelletier et al. 2011; Murphy et al. 2011). Some attempts have been done to agree on a coherent framework of energy analysis of agricultural systems (Jones 1989), but there is still room to establish common methods to assess the pattern of energy flows in a way that captures the complexity of agroecosystem functioning.

Historical research on EROIs have revealed the relevance of internal loops of biomass flows within farm systems (Tello et al. 2016). Bringing these internal loops to light entails the recognition that agricultural practices are deeply linked with the reproduction of ecological funds, and that it is necessary to not only invest energy in obtaining 'available' biomass for human needs, but also in maintaining the agroecosystem funds. Internal flows of reused biomass ensure the capacity of the agroecosystem to generate biomass in the future and maintain of vital ecosystem services (Guzmán and González de Molina 2015).

This article has both methodological and historiographical purposes. After presenting the basic features of the case study and the time points chosen in the first section, we dedicate two sections to the conceptual approach of the fund-flow energy analysis of agricultural systems and offer guidelines to implement it from a historical perspective. In addition, an Appendix with detailed information about historical sources, estimations and coefficients is provided. In the second part of the article, we present our results from a historically contextualized standpoint. First, we explain the changes to farmland and livestock dynamics over time, linking them to the ongoing historical trends. Second, we offer a detailed accounting of each energy flow to deepen the broader aggregated results previously published on this case study (Tello et al. 2016). Here we include data for a new time point from the mid-twentieth century, which enables us to make a more coherent historical explanation of this socio-ecological transition. Finally, we conclude by considering the social and economic drivers of this transition in the Catalan Vallès County, and focusing on the connections that linked the disarticulation of the agroecosystem's funds with the fall of energy returns, as well as the concomitant environmental impacts that hamper the current capacity to achieve more sustainable farm systems.

3.2 Conceptual approach

We use a socio-metabolic accounting of farm system energy flows, and their interaction with the underlying funds, to highlight how farmers transformed agroecosystem biophysical functioning from past organic to industrial farming and livestock raising (Giampietro and Mayumi 1997; Fischer-Kowalski and Haberl 2007; González de Molina and Toledo 2014). Our fund-flow analysis relies on the distinction set forth by Nicholas Georgescu-Roegen (1971) between funds, stocks and flows, which is particularly relevant when preindustrial and industrial farming are compared from a nature-society interaction viewpoint (Giampietro et al. 1992a and 1992b; Sorman and Giampietro 2011; Giampietro et al. 2013). A biophysical fund provides a flow, is maintained either through natural processes or through management by humans (Faber et al. 1995), and exists within a defined time span to account for a specific process (Mayumi 1991). By contrast, any non-renewable physical stock is depleted at the same rate per unit of time that a flow is extracted from it (e.g. a barrel of oil). A renewable fund cannot be exploited at any desired rate (e.g. an aquifer). Living funds are able to reproduce themselves (Faber et al. 1995), but most (such as a mule, or a farmhand) can only generate flows at a limited rate per unit of time. Furthermore, the renewal of the basic living and non-living funds of an agroecosystem, including the farm community itself, is a key aspect of its long-term sustainability (Daly 2005).

We concentrate on the main four funds of an agroecosystem, which are interlinked by biophysical flows: the members of the agricultural community, the domesticated species, and the non-domesticated species (which includes associated biodiversity and fertile soils). While the former three are living funds, fertile soils can be seen as an interface where a set of complex interactions between living and non-living components take place, behaving as an ecosystem in itself. Through historical sources we are able to estimate the characteristics of three of these funds, while farm-associated biodiversity cannot be account for solely from the energy perspective, despite its importance for maintaining many supporting and regulatory ecosystem services (Tscharntke et al. 2012). We will focus on the ability of the agroecosystem to reproduce soil fertility, livestock, and the farming community. This means that, particularly within the organic and mixed organic-industrial farming, the biomass produce tended to cover three different reproductive energy flows: manure and biomass used as fertilizers, animal feeding, and human food and fuel. Until growing amounts of external material and energy flows became physically available and economically affordable, farmers kept a careful balance between the three funds in terms of land and labour requirements. Farmers maintained these dependences and balances even under industrial farm management and breeding, although the land, labour and fossil energy carriers required for external inputs became territorially delocalized.

Within the energy accounting methodologies, this fund-flow differs from other approaches, particularly the focus on the energy return (EROI) of consumable goods compared with the energy invested by farmers from the rest of the economy. While the latter makes sense on its own right (Pelletier et al 2011; Hall 2011; Hall and Klitgaard 2012), it inevitably conceals the internal agroecological functioning within a black box. Instead of evaluating a single EROI, our approach aims at grasping a broader energy profile of agroecosystems by using several interrelated EROIs in a more complex fund-flow analysis. Although our theoretical frame is thoroughly explained in Tello et al. (2015, 2016) and Galán et al. (2016), here, we summarize its main features. Final EROI (FEROI) (Eq.1) assesses the energy investment made by farmers and the society they belong to, in exchange for a basket of human consumable biomass products accounted in energy terms.

$$Final\ EROI\ (FEROI) = \frac{Final\ Produce}{Total\ Inputs\ Consumed} = \frac{Final\ Produce}{Biomass\ Reused + External\ Inputs} \tag{1}$$

Internal Final EROI (IFEROI) (Eq. 2) assesses the portion of Land Produce reinvested in the agroecosystem as Biomass Reused (BR) in return for a unit of consumable Final Produce (FP). These flows always entail a relevant cost for farmers in terms of labour and land allocations, mainly in organic systems, also measureable in terms of energy (Guzmán and González de Molina 2009).

$$Internal\ Final\ EROI\ (IFEROI) = \frac{Final\ Produce}{Biomass\ Reused} \tag{2}$$

External Final EROI (EFEROI) (Eq. 3) relates External Inputs (EI) to the final output crossing the agroecosystem's boundaries. This ratio assesses to what extent the agro-ecosystem analysed becomes either a net provider or a net consumer of energy in its connection with the broader societal system.

$$External\ Final\ EROI\ (EFEROI) = \frac{Final\ Produce}{External\ Inputs} \tag{3}$$

3.3 Materials and Methods

Agricultural population, which we identify as *Farming Community*, can be deduced from the Population Register (1860) and Agricultural Censuses (1956 and 1999). Land uses are taken from Land Tax Records called *Amillaraments* (1860) and the Cadastral Map (1853); the Cadastral Record and Cartography [1956]; and the Agricultural Census, Cadastral Map and Satellite Digital Images (1999). For livestock numbers we used the Livestock Census (1865; 1950); and the Agricultural Census (1999). Official data were corrected when considered necessary, especially for mid-nineteenth century (see Section 3.A.3). Sources and estimates on crop yields and animal productivity, together with coefficients used for water content and Gross Calorific Values (GCV), can be consulted in the Section 3.A.2.

Data on agroecosystem funds and yields provide an estimate of Total Produce (TP), which is composed of Farmland Produce (Cropland-Woodland and Pasture Produce) and Livestock-Barnyard Produce (Figure 3.A). TP was redirected to Final Produce (FP) or Biomass Reused (BR). This distinction was assessed differently depending on the time point, under the assumption of an unavoidable dependency on local fund sustainability c.1860 that was afterwards lessened or suppressed. Accordingly, ideal conditions were set for farmland and livestock funds in order to highlight the costs of ensuring the reproduction of the agroecosystem. Biomass Reused (BR) represents the reproductive energy flows, which can be further broken down into Farmland BR (FBR) and Livestock BR (LBR). In traditional organic agricultures, BR flows were shaped by the local characteristics of farmland and livestock. On the one hand, site-specific farmland features (crop rotations, intensity, fallow) defined the biomass required to close the nutrient cycles, which in turn were highly dependent on livestock densities and management (manure availability). On the other hand, livestock densities and composition shaped Livestock BR (e.g. ruminants share). Thus, we estimate Farmland BR (FBR) and Livestock BR (LBR) through both funds' requirements. Furthermore, a balance between Final Produce (FP) and Biomass Reused (BR) needed to be reached. Reproduction of Farming Community depended on the capacity of the agroecosystem to supply an adequate amount of BR flows proportional to the quantity and diversity of Final Produce (FP) extracted from the agro-ecosystem to cover human needs, either directly through local consumption or indirectly through market exchange.

The role of External Inputs (EI) partially broke this necessary balance among different reproduction processes of the agroecosystem's funds. Since the mid-twentieth century, growing feed or fertilizing requirements were easily met through EI. Food, fuel and fibre requirements of the Farming Community were increasingly imported from outside the system boundaries, and large inputs in human labour were substituted and/or supplemented by machinery and other industrial inputs. Thus, availability of a growing range of EI allowed the site-specific funds' equilibrium to disintegrate, because their consistency was no longer a fundamental requirement. Methodologically, this implies changes in the hierarchical process of redirecting energy flows. We first accounted for the share of fertilizing and feed requirements provided by EI, and then included what was lacking from local recirculation (detailed process and sources are provided in Section 3.A.3).

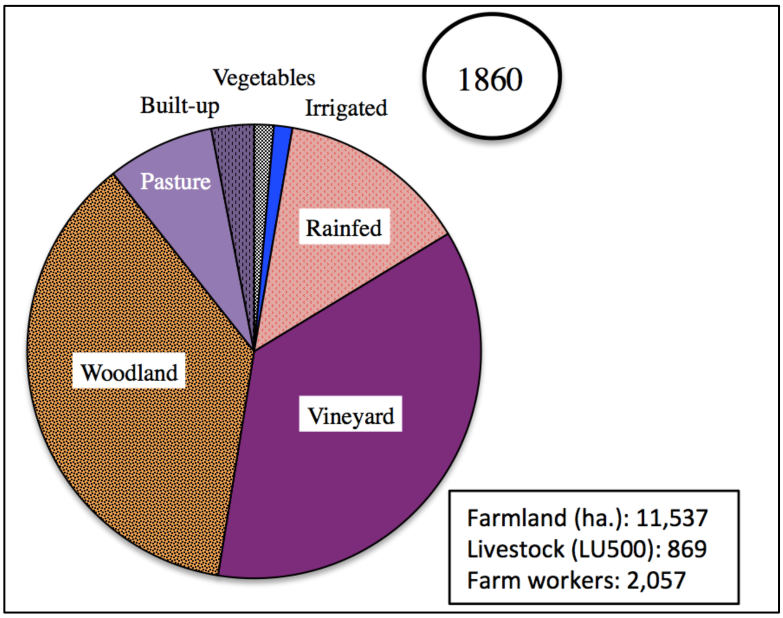
Some limitations of this research should be noted. As mentioned earlier, the choice of the scale of analysis hinders a more detailed assessment of possible funds erosion within preindustrial agricultures, such as soil mining. The agroecosystem scale allows us to discuss the capability of farmers to close nutrients cycles and livestock reproduction. Future research should work at the household level to evaluate if social structures, in particular social inequality, disrupted this fertilizing capacity. In the 1956 and 1999 time points, our approach requires supplementary research to capture the whole transition processes. On the one hand, changes to the global connections of the local agricultural systems (through imports and exports) resulted in an increasing externalization of unsustainability. At this point, we complemented energy assessment with other sustainability indicators. What remains within agroecosystem boundaries was also modified. When assessing energy efficiency in preindustrial and industrial agricultures, we should link them with the system's ability to meet human requirements. While FP in preindustrial agricultures included fuel and building materials, lower efficiency ratios in 1999 were accompanied with a lower ability to meet human needs. We deal with both of these issues in Padró et al. (2017).

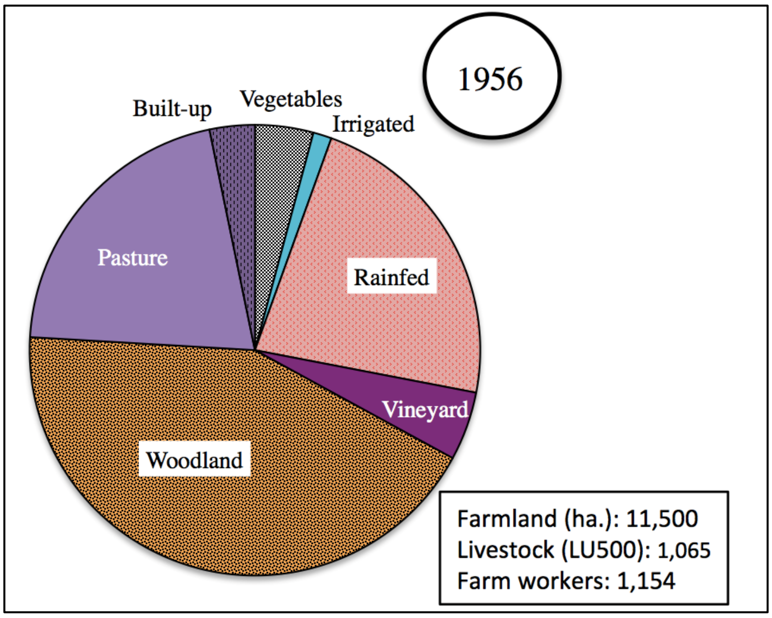
3.4 Results

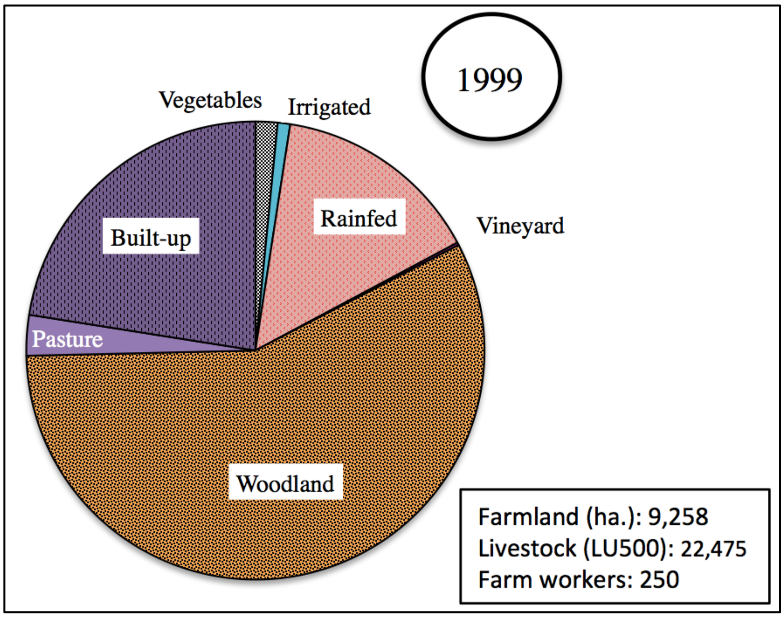
3.4.1 Historical drivers of agroecosystem funds transformation: farmland, livestock and farming community

Cropland area decreased from mid-ninetheenth century to 1956. During the second half of the ninetheenth century, vineyard specialization colonized the territory to an extent that did not continue later on. The growing American and European demand for wine, and from 1867 onwards the arrival of the Phylloxera Plague in France, fostered vineyard expansion until the 1880s. When the Phylloxera insect destroyed all of the vines in the Vallès area, only a fraction was replanted with resistant American strains. After the plague, higher vintages obtained in the newly planted vineyards, increasingly cultivated with industrial inputs combined with the spread of winegrowing in Algerian and Greek areas, resulted in worldwide overproduction in wine markets (Pujol 1984; Planas 2007). Instead of undertaking a risky replantation of vines in poor, sloping lands, many poor winegrowing tenants of the Vallès County searched for industrial jobs in the nearby textile towns (Figure 3.1).

Figure 3.1 Features of agroecosystem's funds (% of land uses [ha])







Source: Own elaboration from sources mentioned in the text.

Decline of vineyard area after the phylloxera plague freed up space to increase pastureland from 1860 to 1956. In this period, part of the land used as vineyards, mainly in the steepest areas, was given over to barren land or brushwood classified as potential pastureland. By 1956, smaller areas of abandoned vines had turned into forests. The decrease in vineyards and olive groves was partially offset in 1956 by an increase in the area allocated to rainfed cereals, legumes and potatoes. After the downturn of wine prices in 1931, and the increase in grain prices from 1936 onwards, wheat and barley crops expanded (Llobet 1968). The severe food shortages during the Civil War, along with the autarkic years of Franco's dictatorship, may well explain the increase in cereal-growing areas observed in 1956 (Infante-Amate et al. 2015). Population growth and dietary transition shaped the agricultural landscape. During the first decades of the twentieth century, the growing meat and milk demand from cities like Barcelona and other nearby industrial towns (Pujol 2002; Pujol et al. 2007; Nicolau and Pujol 2004) offered an opportunity to shift from vineyard to livestock specialization (Planas 2003). This inaugurated a shift towards a greater share of feed-oriented crops, from 13.7% in 1860 to 26.4% in 1956.

The abandonment of extensive livestock rearing, and woodland extractions for fuel consumption, led to the huge increase in woodland area in 1999 (Marull et al. 2015; Cervera et al. 2016). Together with the loss of former landscape mosaics, because of the disappearance of pasture and the integrated land-use management of farms, and the construction of linear infrastructures (roads, power lines), ecological connectivity dropped between 1956 and 1999 (Marull et al. 2010; Marull et al. 2016). Indeed, during the second half of the twentieth century built-up area hugely increased, permanently replacing agricultural land—mainly of the best quality (Tello et al. 2014). Urbanization and infrastructure development destroyed up to 47% of soils of high agronomic value (Olarieta et al. 2008). In 1999, woodland and built-up areas covered 80% of the total area. At this point, 71% of total cropland area was allocated to animal-feeding crops, including barley and fodder. Areas of wheat cultivation decreased by 88%. In spite of their site-specific traits, the main trends of this case study correspond to the paths of Spain (Infante-Amate et al. 2015) and Europe more generally. At the global scale, just over 10% of the grain harvested was fed to animals in 1900. That number rose to 20% by 1950, and attained about 45% in the late 1990s (Smil 2000; Fischer-Kowalski and Haberl 2007). Higher meat consumption has been pushing through an increase of livestock densities, which are reached by the intensification of livestock feeding practices.

Livestock density c.1860 (7.2 Livestock Units 500/km^2 of farmland area) was relatively low compared to contemporary European and American averages (Fischer-Kowalski and Haberl 2007).[10] Average values in intensively cropped Austrian villages in 1829, or in the American Great Plains during the late 1880s, reached 25 Livestock Units 500/km^2 of farmland area (Cunfer and Krausmann 2009, 2016). Yet the very low livestock density was cosistent with the high population density, low availability and natural productivity of Mediterranean pastures. This involved a highly intensive organic farm system where animal feeding competed with human food and where vineyard specialization lessened to some extent the draught power required to toil the land. Draught animals predominated, followed by meat-, wool- and cheese-producing animals, and small domestic animals (Figure 3.A). This composition responded to the multifunctional role of livestock in these preindustrial agricultures (Krausmann 2004), which provided traction, manure, food (meat, eggs and milk), fibres (wool and leather) and heat when stalls were placed near or under farmers' homes. Smaller draught power animals like donkeys and mules, well adapted to plough vineyards,

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[10] Livestock Unit 500 is used to standardize livestock weight, and is calculated adding the total live weight of the livestock and dividing it per 500 kg.

predominated. They were fed mainly with cropland by-products and pastures, a feeding pattern that reduced competition of animal breeding with human food consumption.

During the European agricultural crisis at the end of the nineteenth century, and following the expansion of industrialization, agricultural wages rose (Garrabou et al. 1991, 1999). On the one hand, a decline in manpower demanded an increase in draught power, which explains the increase in the number of horses in 1956. On the other hand, the rise of wages increased the demand for animal produce (Pujol 2002). The beginning of livestock specialization in the Vallès, mainly for milk and meat products sold to Barcelona and other industrial cities and towns (Planas 2003), led to the increase in cattle in 1956. Together with the larger cattle population, a shift in cattle breeding also took place. The change from bovine used for draught power to dairy nutrition and meat production required imports of more productive breeds (Pujol 2002). Both horses and new bovine breeds needed to be fed with better quality products. At the time, oats, barley and fodder were suitable for feeding horses, and these were complemented with wheat crops used for human consumption. Livestock feed began to compete with human food for land, instead of relying to a large extent on by-products as had previously been the case.

In 1999, specialization in livestock production had already reached its peak in the Vallès. At that time, the greatest share of livestock were bred and raised in feedlots for industrial processing. Livestock densities multiplied by 26 and its composition changed tremendously. Working animals disappeared and livestock breeding was totally focused on meat production, particularly pigs. This change can be mainly explained by the increase in meat consumption, which reached its highest point in the late 1990s (Marrodán et al. 2012), but also by the concentration of the meat industry in particular regions. The Vallès is not, however, considered to be a Catalan county well known for specialised meat production, such as Vic, where livestock densities are over 907 Livestock Units 500/km^2 (IDESCAT 2009). The predominance of monogastrics which, on the one hand, have a higher Feed Conversion Ratio (FCR) also entailed, on the other hand, higher grain requirements. Indeed, as part of the shift from working animals to meat production, ruminants experienced a nutritional transition: only 17% of them were fed with grains in mid-nineteenth century, compared to current rates ranging from 67 to 85% of animal diets. These patterns of feeding, richer in cereal and legumes, compete with food crops for land and water (Naylor 2005). Furthermore, the animal feed production in the study area could not meet the huge new requirements, and needed high imports from other countries (Padró et al. 2017).

Population density almost doubled over the first period analysed (1860-1956) and tripled over the second period (1956-1999). This explains the growth in urbanized areas and those devoted to new industrial sites, together with the sociopolitical changes to city planning (Parcerisas et al. 2012). Likewise, the active agricultural population decreased throughout this period. Mechanization, better job conditions, and the crisis in agricultural labour of rural areas of developed countries caused by globalization may explain this decrease. Together with labour decrease, the overall installed power grew along three well-differentiated patterns. The installed power in all sorts of biological and mechanical converters (cows, mules, horses, human agricultural workforce, tractors) grew from 449 to 780 kW between mid-nineteenth century and 1956, while it was nine times higher by 1999 (7,342 kW). In 1860, humans performed 46% of farm work, while the remaining 54% of the work was done by animals. In 1956, manpower (14%) still coexisted with draught power (39%) and machinery (47%). By 1999, however, manpower had totally disappeared.

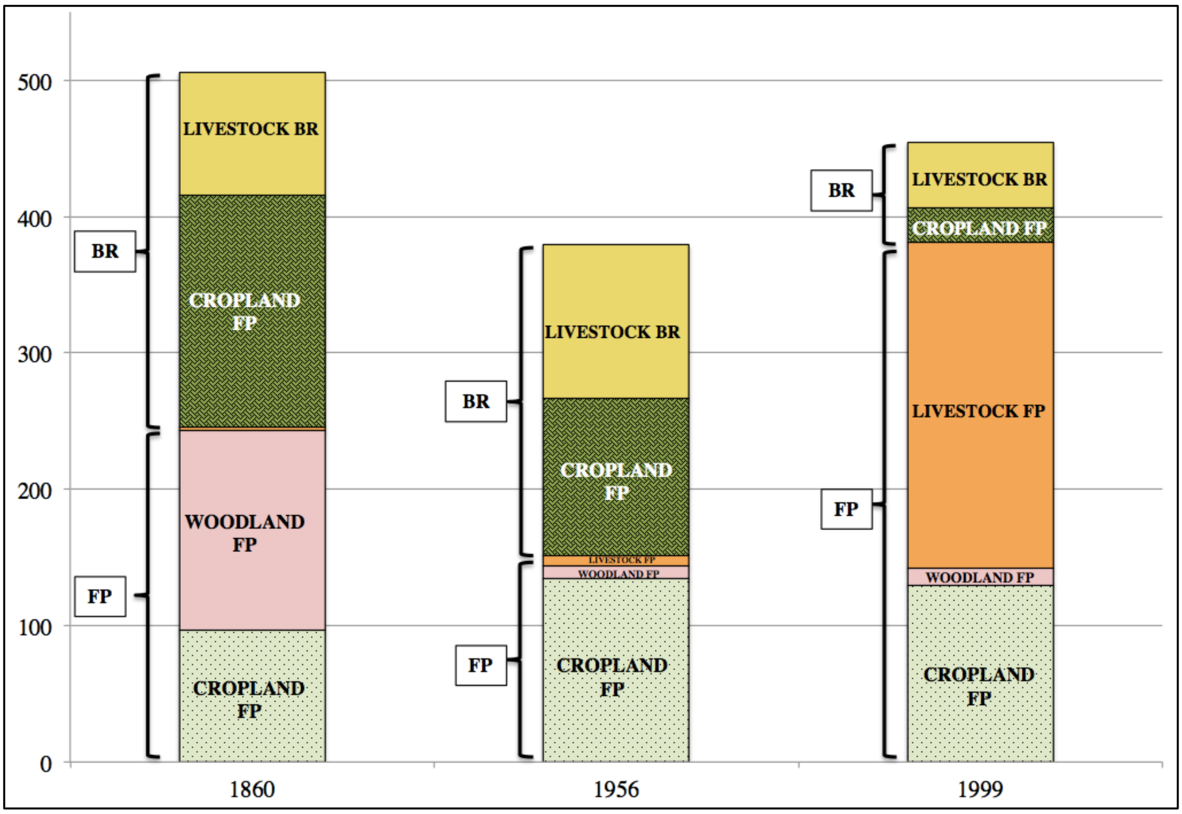
3.4.2 Flows: from organic to industrial farm systems; from cyclic to linear structures

The energy content of Total Produce (TP) decreased 25% from 1860 to 1956, from 42 to 33 GJ·ha^{-1} of farmland. This was the result of several factors: (i) a much lower extraction rate in woodland (from 41 to 21 GJ·ha^{-1}); (ii) the decrease in cropland area; and (iii) the post-Phylloxera loss of vineyards, a very productive crop in energy terms because of its woody by-products. Thus, the agroecosystem in 1956 was somehow subject to less human pressure. Although the human ecological load was partially relaxed within the whole farmland area, cropland area performed differently, and higher cereal productivity resulted in an increase in total harvest from 46 to 54 GJ·ha^{-1} of cropland. Despite this intensification process, the effect of reduced cropland area caused Total Cropland Produce to decrease within the period (Figure 3.2).

In 1999, Total Produce (TP) increased again, coming close to mid-ninetheenth century levels, but with a very different composition. Exponential growth in livestock-barnyard produce substituted for the sharp reduction of woodland produce. Woodland area strongly increased, and livestock grazing practically disappeared. Farmers produced an energy output similar to that in 1956 even though cropland area was halved. As a result, total cropland produce increased to 93 GJ·ha^{-1}. At this point, 90% of Land Produce came from cropland, which only represented 20% of the whole territory. By comparison, this ratio was 70-40% in 1956 and 60-50% c.1860. Farmers concentrated their pressure in the reduced cropland area, and reduced it almost entirely in woodland and pastures. Livestock feedlots also intensified biomass production within the territory. Therefore, we observe a polarization on human disturbance depending on the land use (Marull et al. 2016).

The Vallès County energy transition, which entailed a long-run abandonment of woodland extraction and an intensive adoption of fossil fuels for domestic and industrial uses (Carpintero 2005; Rubio 2005), combined with the human nutritional transition, largely explain the changes in FP composition. Firewood and timber, together with vineyard and olive woody by-products, constituted 84 and 56% of FP in 1860 and 1956 respectively. In 1999, woody biomass only represented 9% of the FP. At the same time, animal produce grew from 1% to 3%, and then to 76 of FP. In terms of human needs, until the second half of the twentieth century, the composition of FP met both food and fuel requirements of the local population. In the late twentieth century, the agroecosystem was unable to cover these needs, now supplied from external territories through imports that embodied a great consumption of fossil fuels. On the other hand, food produce was no longer oriented to meet local or regional demand but was delivered instead to the rest of Spain and Europe (Padró et al. 2017).

Figure 3.2 Composition of Total Produce (TP) between Biomass Reused (BR) and Final Produce (FP) (TJ)



Source: Own elaboration

In preindustrial agricultures the role of BR was mainly to close the nutrient cycles, either directly when applied to cropland as buried fresh biomass or burnt *formiguers* or indirectly through livestock feeding and bedding. This required a complex, multiple use and close integration between land-uses and animal husbandry aimed at maintaining both soil and livestock funds. These looping energy flows entailed a relevant cost in biophysical terms: 48% of TP c.1860 was redirected as BR, 38% in 1956, and 31% in 1999. Although these changes in BR shares appear small (in line with the stability of Biomass Reuse throughout the socio-metabolic transition found in other case studies) (Gingrich et al. *in press*), its role was absolutely transformed. Synthetic fertilizers and the easy access to imported feed in global markets meant that BR played a much larger role in 1999 than it did in the ninetheenth century. While c.1860 60% of BR were put directly back into the land (Farmland BR; FBR), only 9% were in 1999 and the rest went to feed animals (Livestock BR; LBR). Even within

LBR, livestock feeding changed from taking advantage of many by-products and natural pasture grazing to become the main recipient of grains and fodder. BR flows were responsible for the sustainable reproduction of agroecosystem funds c.1860. In 1956, soil fertility was partially reproduced through EI, while livestock was mainly fed with local biomass. In 1999, BR was not capable of reproducing soil fertility or livestock-barnyard needs, which became highly dependent on EI.

In 1860, all EI had an organic origin, more than 50% of which were endosomatic (30% labour, 20% humanure and 50% domestic residues). At that time, EI represented 5% of the Total Inputs Consumed (TIC). Conversely, in 1956 endosomatic and organic inputs accounted for only 7% (5% labour, 2% humanure) and 17%, respectively, while 83% came from outside and were almost exclusively non-renewable in origin, mainly synthetic fertilizers but also machinery. At that point, EI accounted for 37% of TIC. In 1999, EI came almost entirely from outside the agroecosystem's boundaries (humanure and domestic residues were no longer reused, and labour was only 0.3% of EI) and represented 90% of the TIC. The biomass component of these EI constituted nearly 76% of the total, almost all of which was animal feed. The huge amount of feed imports partially hid the increase of EI due to agricultural mechanization, which increased three-fold from 1956 to 1999. Unlike other similar research on agricultural metabolism where synthetic fertilizers and machinery represent the largest energy consumers (Pelletier et al. 2011), livestock specialization in Vallès County reflects the disproportionate relevance of biomass external inputs within industrialised agroecosystems. Biomass flows increased 62-fold in the last fifty years (Mayer et al. 2015).

3.4.3 EROI analysis

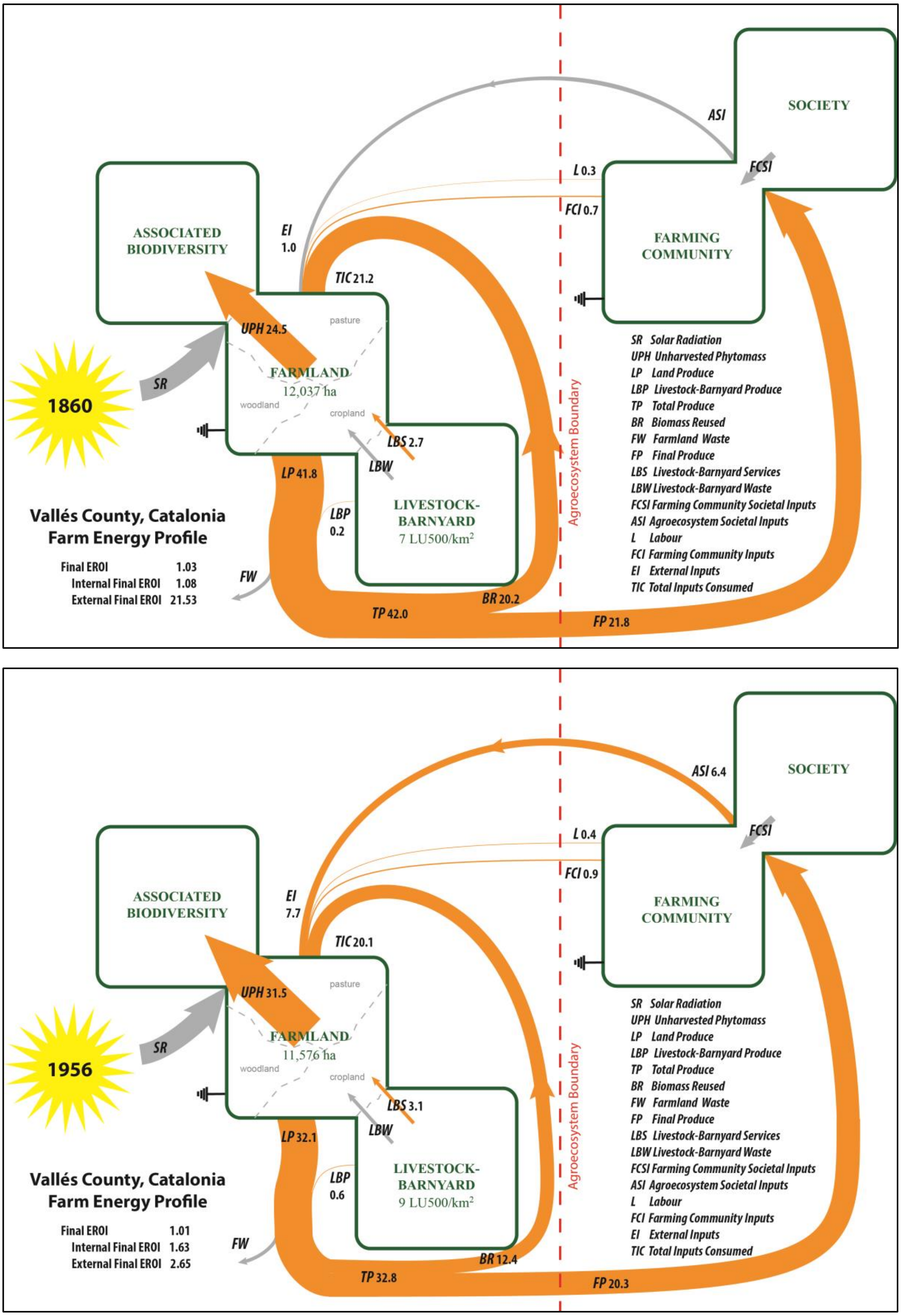
Final EROI (FEROI) decreased steadily throughout the period 1860-1999, and more rapidly from 1956 to 1999 (Figure 3.3). Although both Final Produce (FP) and Total Inputs Consumed (TIC) increased through the whole period, the increase in TIC (+1,140,832 GJ) was much higher than the increase in FP (+49,484 GJ). In spite of the intensive energy requirements of preindustrial fertilizing techniques in the Vallès study area, both FEROI and Internal Final EROI (IFEROI) were higher than 1. The slight decrease of Final EROI (FEROI) between the mid-19th and mid-20th century was led by a higher decrease of FP compared with the decrease in TICs. The reduction of woodland extraction affects the FEROI, but does not imply an explicit decrease in energy efficiency. Farmers substituted local and renewable fuel sources for external and non-renewable ones. Changes in soil fertilization practices explain the shifts in the nature of the inputs required to maintain the nutrient balance. In 1956, the introduction of synthetic fertilization, which increased external inputs (+60,000 GJ) was accompanied by a decrease in Biomass Reused (-115,000 GJ). Therefore, the energy requirements to replenish the nutrients through traditional, intensive biomass fertilizing techniques, especially *formiguers* (which used woody biomass), were higher than those of synthetic fertilizers. This sets a sharp contrast with the strong fall of energy returns found in 1999, when much higher quantities of synthetic fertilizers almost entirely replaced organic ones. Farmland biomass reused came mainly from cropland by-products, while synthetic fertilizers required huge amounts of non-renewable energy. Thus, the implications in terms of internal-external sustainability should be addressed in a more detailed way.

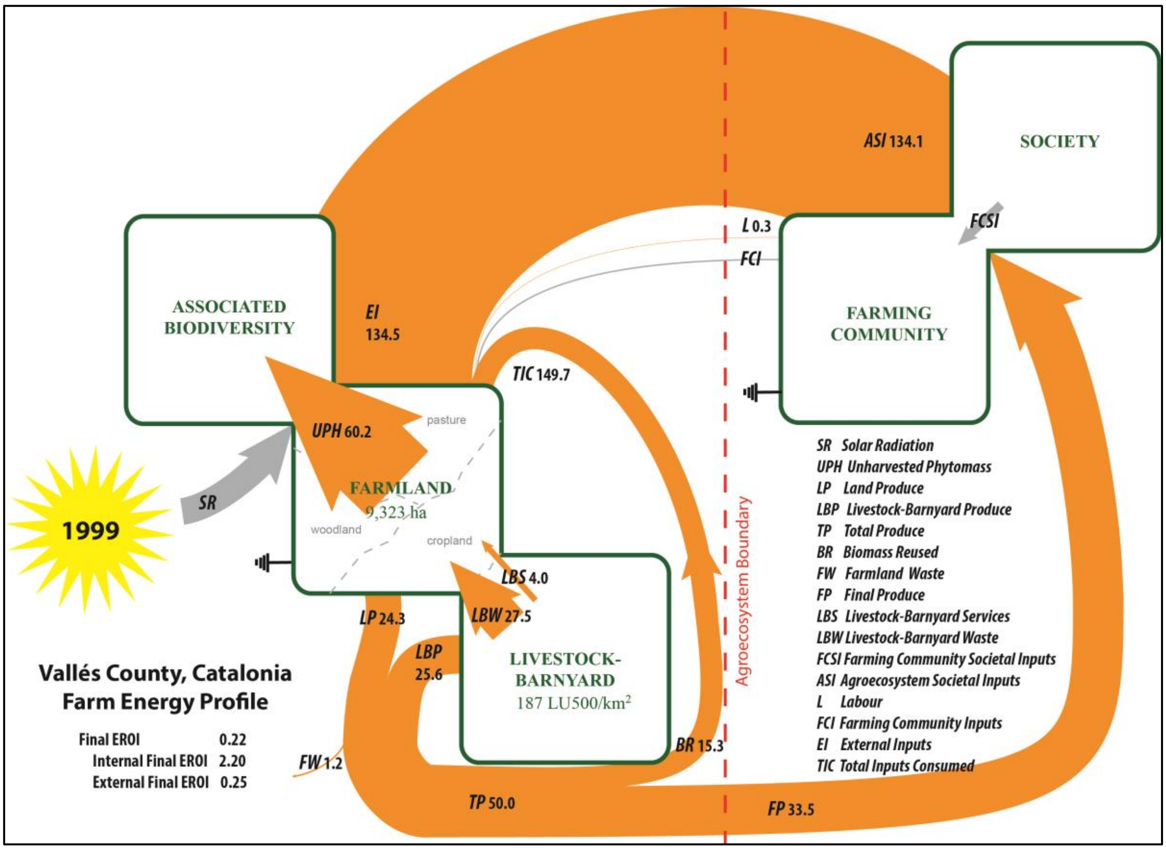
The increase of IFEROI from 1.13 to 1.65 between 1860 and 1956 shows the effect of the abandonment of this effort to recycle biomass. Nevertheless, considering separately Land and Livestock processes, changes to funds' structures had different effects on IFEROI. On the one hand, higher livestock density increased BR to feed meat and dairy cows that provided a smaller amount of FP exerting a downward pressure on IFEROI values. On the other hand, reduction of animal draught power lessened a share of BR that did not provide anything to FP exerting an upward trend on IFEROI values. As a result, the abandonment of traditional fertilizing methods led to a higher internal energy efficiency in Cropland [Internal Cropland EROI: Cropland Final Produce/Farmland BR], which increased from 0.62 to 13.07. At the same time, Internal energy efficiency of Livestock bioconversion [Internal Livestock EROI: L-B Final Produce/L-B BR] increased only to a lesser extent (from 0.03 to 0.05). In the end, the combination of all these countervailing trends—including the reduction of forest extraction in FP which required no BR flows—resulted in an IFEROI increase.

From 1956 to 1999, the increase of TIC was 7.6 times higher than the increase in FP. The share of EI, which rose from 37% to 90% of TIC, drove this increase. FEROI was shaped mainly by EFEROI in 1999. The energy profile in 1999 is closely linked to livestock specialization. The increase in Livestock Final Produce led the increase in FP and the huge increase in EI was driven by the amount of Livestock External Inputs. Thus, the low final energy efficiency is mostly explained by the low energy efficiency of livestock bioconversion. Although the animal Feed Conversion Ratio (FCR) raised during this period, feed requirements entailed a large amount of BR and a huge quantity of feed imports.

In addition, land-use changes may also provide an explanation for the lower returns on investment for industrial compared with organic agricultures (1860-1999). FEROI efficiencies on dry cropland, irrigated and vineyards ranged from 0.4-1 to 0.2-0.3, while the greatest decline was due to the energy transition in forests where FEROI dropped from 47.7 to 1.4. In the same vein, EFEROI experienced an order of magnitude decrease from 2.2-3 to 0.2-0.3 in cropland uses. Despite an increase of 90% in FP, the energy efficiency is lower in irrigated than in rainfed areas because of the diminishing returns on TIC. Here a 1.9-fold productivity increase meant a 2.6-fold growth in BR.

Figure 3.3 Energy profiles of Main Funds, Flows and EROIs of the farm systems studied c.1860, 1956 and 1999





Source: Own elaboration. Note: Flows are expressed in relative terms (GJ·ha^{-1} of farmland)

Figure 3.4 plots the different profiles of FEROI of the three time points analysed within the conic surface that represents all the possible relationships that exist between FEROI, IFEROI and EFEROI according to the following equation:[11]

$$Final\ EROI\ (FEROI) = \frac{EFEROI\ \cdot\ IFEROI}{EFEROI + IFEROI} \qquad (4)$$

The set of relationships among FEROI, IFEROI and EFEROI shifted from 1860 to 1956 towards two contrasting regions of the three-dimensional surface in 3.ure 4 (left). The high EFEROI combined with a comparatively lower IFEROI led to the Final EROI of 1.08 attained in 1860 thanks to a strategy of Low External Input Technology (LEIT) (Gliessman 1998; Tripp 2008). IFEROI was much lower than EFEROI because of the strong recycling effort that was the only feasible strategy to maintain high productivity in the absence of synthetic fertilizers or machinery. In 1999, when an industrial farming strategy fully adopted synthetic fertilizers instead of using *formiguers* and of machinery instead of maintaining work animals, EI replaced BR. As a result, the LEIT organic and

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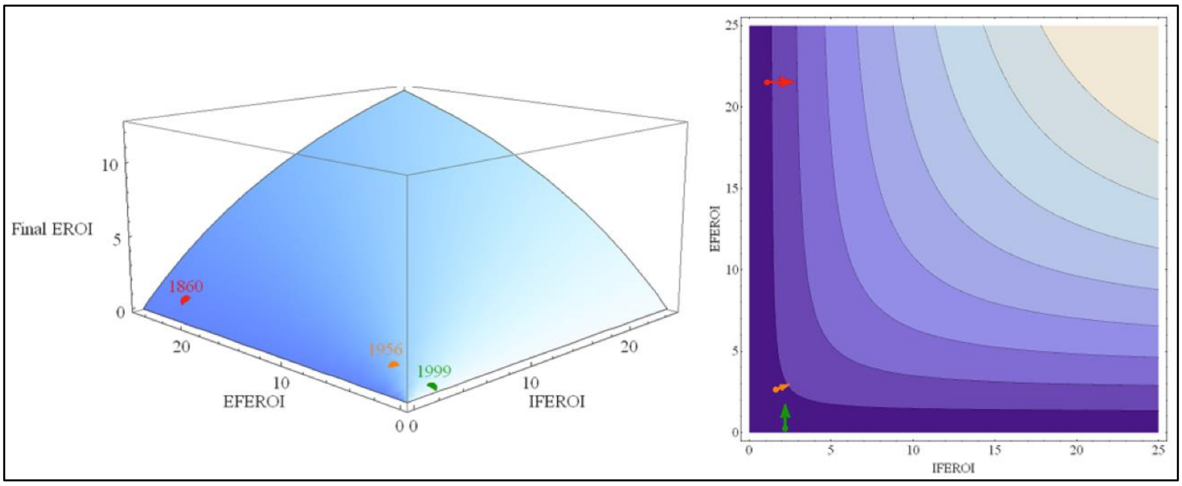
[11] By definiton, $\frac{EFEROI\cdot IFEROI}{EFEROI + IFEROI} = \frac{\frac{FP}{EI}\cdot\frac{FP}{BR}}{\frac{FP}{EI}+\frac{FP}{BR}} = \frac{\frac{FP^2}{EI\cdot BR}}{\frac{FP\,(BR+EI)}{EI\cdot BR}} = \frac{FP}{EI+BR} = FEROI$ (Tello et al. 2016).

the industrial strategies generated two opposite patterns (Tello et al. 2016). The 1956 point remains in between, although nearer to an industrial rather than a LEIT pattern. Interestingly, in this organic-industrial middle ground, the direction of optimal improvement according to equation (1) shown in Figure 3.4. (right) points towards keeping proportional amounts of BR and EI—that is, following the diagonal of 45° where $\frac{BR}{EI} = 1$, leaving only little room to substitute BR with EI. The full industrialization of meat production in feedlots followed a completely different path than the optimal vector seen in 1956. The general change in energy patterns seen in Figure 3.4 was mainly driven by the ratio $\frac{BR}{EI}$, which shifted from $\frac{242{,}864\ GJ}{12{,}210\ GJ} = 19.9$ in 1860 to $\frac{144{,}009\ GJ}{88{,}745\ GJ} = 1.6$ in 1956, and to $\frac{142{,}246\ GJ}{1{,}253{,}660\ GJ} = 0.1$ in 1999.

Figure 3.4 Graphical representation of Final EROI as a function of EFEROI and IFEROI (left), and the directions and comparative lengths of the potential improvement of Final EROI by changing EFEROI-EFEROI combinations at any point (right), in the farm systems of the Catalan study area c.1860, in 1956 and in 1999.



Source: Own elaboration.

3.5 Discussion: Why the fund-flow nexus matters

Through the socio-metabolic scanning of the agroecosystem energy functioning in the Vallès County c.1860, 1956 and 1999 we have identified three very different energy profiles in the composition of basic funds and the pattern of energy flows. Our results highlight that changes in agroecosystem energy efficiency cannot be explained only by a different distribution of flows, but also by the ongoing change in the composition of funds. Therefore, the fund-flow scanning methodology is a useful tool to explain how the energy performance of an agro-ecosystem is strongly related to structural change in their underlying funds. Only when energy efficiency analysis links the pattern of flows with the change in funds composition and integration, can it provide useful insights for a sustainability assessment of agricultural metabolism. First of all, energy flows are strongly influenced by the amount of woody biomass circulating in the agroecosystem. The functions of forests as an integrated element, as well as of woody crops, strongly influence energy efficiency indicators. Conversely, higher livestock densities require greater amount of inputs (biomass flows coming either from the local boundaries or from other agroecosystems) per unit of final product obtained, thus lowering energy returns. Second, although elements outside the structure of funds, such as synthetic fertilization, became increasingly important, the relationship between livestock density and agricultural area allows us to better understand both the higher final efficiency of the integrated preindustrial agroecosystems, and the low efficiency of an industrial model of livestock breeding adjoined to a (mainly abandoned) territory.

By focusing our energy scanning on the role of funds, we also observe how specializations in an advanced organic or an industrial agriculture behave quite differently, mainly due to contrasting scale-dependence. Before the Green Revolution and global trade expansion, even if a significant part of the agro-ecosystem was already market-oriented, there were biophysical limits that could not be broken without opening metabolic rifts in the replenishment of soil nutrients or animal feeding. Preventing these rifts entailed hard labour and land investments, which were overcome through the socio-metabolic transition towards mechanical and oil-dependent inputs. In 1956, we observe an intermediate organic-industrial farm system increasingly oriented towards livestock raising and dairy products, which gave way to slightly lower energy returns, particularly with respect to external inputs.

Yet it was not until the end of the 1960s when the farm system underwent a complete industrialization that totally changed the energy profile. Mechanization of agriculture and the use of synthetic fertilizers and biocides on cropland underwent astonishing growth rates. In Spain, the consumption of fuel doubled between 1954 and 1959; lubricating oil increased by 126%; electricity by 70%; synthetic fertilizers by 64%; and tractor power capacity by 111%, and another 150% between 1959 and 1963. Feed imports, almost non-existent in 1956, grew more than six-fold between 1957 and 1963 at a yearly rate of 36.4% (Ministerio de Agricultura 1954, 1959 and 1963). In 1956, the Green Revolution was only just beginning, which explains why the energy performance was not radically different from that of c.1860. A similar trend is also found in forest abandonment, which was also just beginning. Although forest area increased slightly due to vineyard abandonment, forest extraction decreased overall. This trend was exacerbated later on, when the arrival of gas bottles in urban households of Catalonia marked the end of charcoal making.

It is noticeable how preindustrial organic agricultures, like the one in the Vallès County c.1860, managed to be energy efficient in spite of the high energy investment needed to maintain their funds. On the one hand, the low livestock density and lack of manure led to a costly investment in labour-intensive alternative fertilizing methods (Olarieta et al. 2011; Tello et al. 2012). On the other hand, the unavoidable dependence on livestock to obtain draught power and manure involved large bioconversion losses. These two heavy burdens were offset to some extent by the multiple and integrated uses of land and livestock. Thanks to that, they were able to attain energy efficiency ratios above 1, only slightly higher than the mixed organic-industrial farm system in 1956, but much higher than the agroindustrial system in 1999. What stands out is that past organic farm systems were able to override all these partial inefficiencies, which in a solar, areal-based energy system inevitably involved a high land cost (Guzmán and González de Molina 2009), by taking advantage of many synergic linkages between funds through land-use efficiency (Marull et al. 2016; Padró et al. 2017).

Multifunctional uses of livestock and arboriculture combined with cropland-livestock integrated management were two sides of the same coin. Thanks to the multipurpose character of vineyards and olive groves, the energy flowing from them was able to cover simultaneously diverse human biomass requirements (food and fuel) and animal feeding (e.g. green shoots, leaves). Livestock, in turn, provided draught power and manure besides meat and dairy products. In the same vein, using crop by-products (straw, stubble, husks, brans, and oil and grape pomaces), combined with natural pastures to feed livestock, partially reduced the competition of animal bioconversion with human nutrition. All these looping fund-flow linkages established through land-use integrated management led to complex landscape mosaics, where the production of cash crops such as wine were combined with other biomass flows oriented to sustain the reproduction of three basic funds of the agroecosystem: human nutrition, soil fertility and livestock feeding. This gave way to heterogeneous landscapes where peasants exerted different spatial levels of disturbance, which in turn gave rise to a higher habitat differentiation for a rich farm-associated biodiversity able to perform vital ecosystem services (pollination, control of plagues and diseases, clean water, etc.) — that is, it allowed for the maintenance of another vital fund of the agroecosystem (Marull et al. 2016). This fund-flow internal complexity, and the corresponding mosaic pattern of cultural landscapes, was kept in a context of vineyard specialization that was still compatible with a local sustenance-oriented agricultural and livestock management.

Since the first decades of the 20th century certain driving forces started changing the farm system. First, the introduction of small amounts of synthetic fertilizers allowed farmers to reduce Farmland BR, which entailed a lower energy cost to the agroecosystem's fund maintenance. The introduction of machinery was still scant in 1956, and was accompanied by a replacement of mules with horses. The end of transhumance and the diffusion of industrial animal fattening in feedlots put an end to extensive grazing in pastureland and open woods. Urbanization increased dairy products and meat intake, leading to a deep nutritional transition away from the highly praised Mediterranean diet, and fostered the increase of livestock densities in the Vallès area. The energy transition towards fossil fuels entailed a deep turnaround in the fund-flow complexity kept so far. The widespread use of cheap domestic fossil fuels, like gas cylinders and, later, natural gas, led to forest abandonment and regrowth mainly from the 1956 onwards (Infante-Amate et al. 2014; Marull et al. 2015; Cervera et al. 2016). Inputs coming from outside the local system boundaries, still mainly for cropland uses at that time (industrial fertilizers, tractors), grew rapidly and turned this mixed organic-industrial agriculture more dependent on EI and less based on internal BR. Yet the combination of organic and industrial fertilizers, the coexistence between horses and tractors, as well as the rotation of grains with leguminous crops, also meant that to some extent traditional landscape mosaics were also kept in place in 1956.

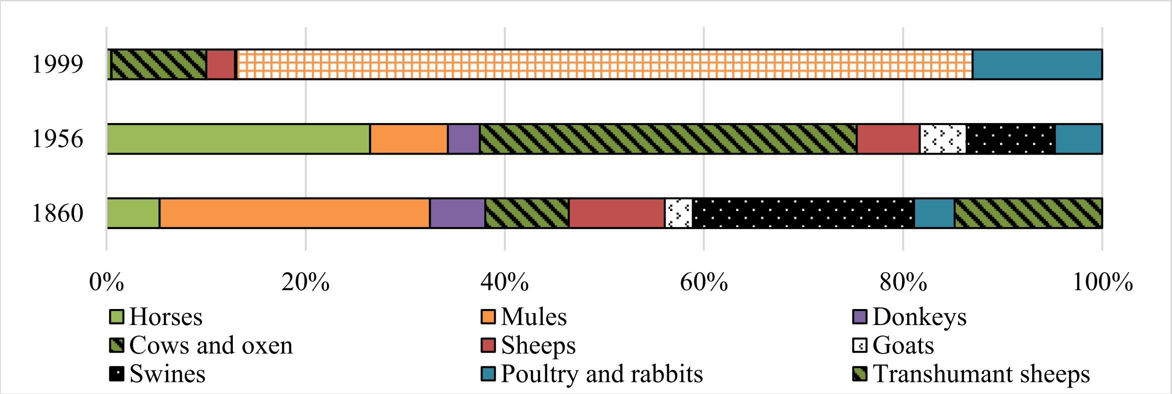
Indeed, the distribution of cropland, pastureland and woodland was more balanced in 1956 than in 1860, when almost no pastureland existed. Conversely, pastured woodland had nearly disappeared in 1956, as had *formiguers* and transhumant sheep. The multifunctional uses of woodland as a source of timber, fuel, fertilizing biomass and pasture were significantly reduced to only one or two uses. These functions were in part substituted with a larger pasture area (so that livestock populations could still be maintained from local resources), and partially by the introduction of synthetic fertilizers. However, if we expand the perspective from how the agroecosystem was capable of efficiently sustain itself (which, in 1956 it was still quite capable of doing) and the needs of the local population, we observe early signs of unsustainability. Local renewable sources satisfied fewer needs, diets changed (Padrò et al. 2017) and people used fossil energy in kitchens, households and for transport-related needs.

Finally, in 1999 the whole farm system was structured around a much larger livestock density, totally oriented towards the meat industry. Human food and fuel requirements were no longer linked to the local land-use system, but to global agrifood chains and fossil fuel industries. Meat production in the Vallès area was part and parcel of this global system that interlinked many regional specializations. The local agroecosystem was then traversed by enormous energy and material flows that simply moved across the territory. Feed is imported from other countries, while meat produce is delivered to the rest of Spain and Europe. The break of complex energy loops of biomass reuse flows has had direct consequences in energy performance, as efficiency fell, and also in material terms. Unbalances between funds (huge livestock densities in this case) combined with market dependence (huge feed imports embodied with external energy and land) entails that while imported feed is required to maintain livestock, more meat is produced locally than what the local population needs (despite population increase and changes in diets). Finally, and above all, all these imbalances end up generating huge amounts of pig slurry concentrated in the small territory of Vallès County. The incapacity to use this ‘potential resource’ within the same territory results in considerable water and air pollution. What was once a very scarce and precious resource, manure, has become a dangerous residue because of its high spatial concration.

APPENDIX CHAPTER 3

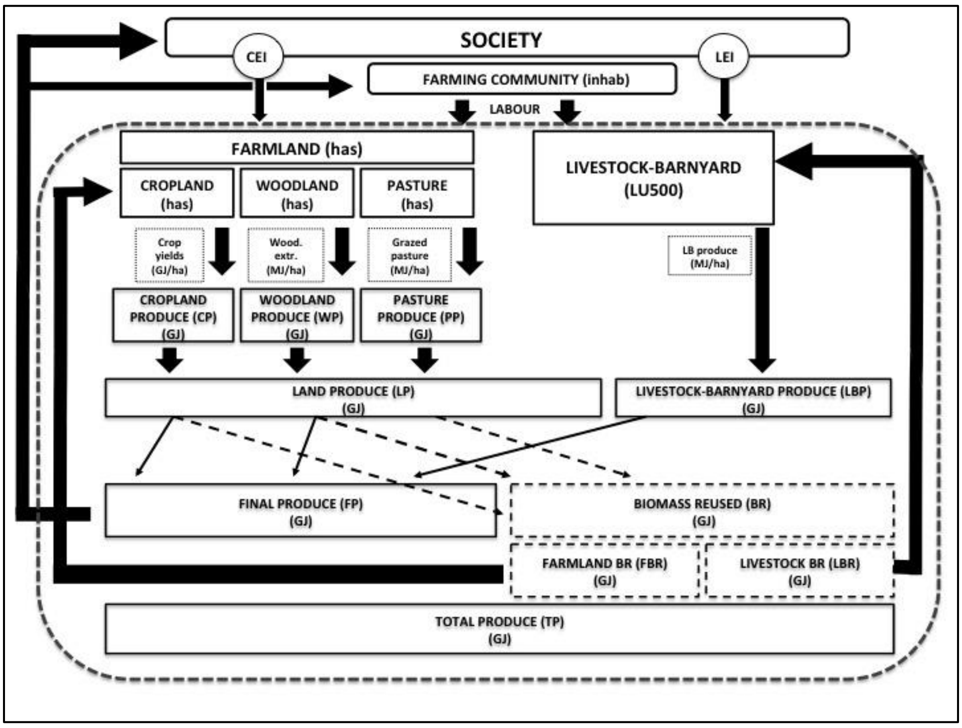
This Appendix provides detailed data on changes of livestock composition (Figure 3.A), and a conceptual map about disaggregation of Total Produce and Biomass Reused, and its links with the agroecosystem's funds (Figure 3.B). It also provides a full description of the process to estimate energy balances within our three time points. It is divided into Total Produce estimates (Land Produce and Livestock Produce) and Total Inputs estimates (Biomass Reused and External Inputs). Finally, Table 3.D provides the raw data for the main energy flows.

Figure 3.A Changes in Livestock Composition (1860, 1956 and 1999)



Source: Own elaboration. Note: Percentages are calculated over the total live weight (kg).

Figure 3.B Theoretical frame to link Total Produce estimate with agroecosystem funds.



Source: Own elaboration. Note: *CEI* and *LEI* correspond respectively to Cropland External Inputs and Livestock External Inputs.

3.A.1 Basic assumptions and criteria to build historical energy profiles of farm systems

When dealing with historical data –in particular the 1860 time point- the construction of energy profiles is made difficult by the lack of information related to physical flows with no monetary value, as records were kept for taxation purposes. We cannot limit our analysis to only the flows with monetary values, because many others are required for an adequate understanding of the functioning of agroecosystems. We present here some important assumptions made in the process of obtaining and interpreting our results.

To reduce the degree of uncertainty, the most important assumption made about how funds were managed is that they were exploited at a sustainable level. Defined as a 'forced local fund sustainability assumption', it is applied for livestock management, soil fertility and timber and firewood extraction. With this assumption, our energy profile accounts for the energy flows and energy efficiency that would remain under the condition of not exceeding sustainability thresholds. We are not assuming, however, that this was always true under actual conditions At the least, we obtain a reference point to know, with the prevailing soil and climate and technological conditions, how much effort would have been necessary to close the nutrient cycles, keep forest exploitation sustainable and provide for livestock feeding. In cases where it was not possible to close some of those gaps, we suppose that the agroecosystem – or some of its elements - were exploited at an unsustainable level. Therefore, we have set the following hierarchy on how cycles are closed: first, maintaining a share of the total food and fuel for the farming community, whose population is known. This is obviously conditioned by the socio-metabolic regime to which the time point belongs. Then livestock feeding is balanced, estimating feed imports when they existed. Finally, soil fertility levels are determined, knowing that this is the most suitable fund to be degraded through the mining of its nutrients.

Finally, our model does not consider the physical distance and the social inequalities that exist in access to land and in agroecosystem flows. This limits the interpretation potential of case studies, which do not use data at a more disaggregated level than the municipal scale. As flows are assessed and balanced at the agroecosystem level, we suppose there are no institutional or cultural restrictions for any flow to move wherever needed (i.e. the manure hypothetically obtained from one farm could be used to fertilize any other, regardless of the distance or the social relations between them). The result is interpreted under the hypothesis of the greatest possible efficiency while nutrient cycles were closed at soil, livestock and human nutrition levels. This obviously conceals other potential inefficiencies due to physical distances or social inequality.

3.A.2 Total Produce estimates

Land Produce

Crop yields are taken from local sources (IACSI 1879, Garrabou and Planas 1998) and provincial averages (MAGRAMA Statistical Yearbook using an average between 1954 and 1958, and 1999 for the latest period). Water content and GCV are taken from Haberl (1995), except for hemp (Sacilik et al. 2003), vetches (Mansourifar et al. 2013) and grape juice (analysis made by Xavier Remesar and Mar Grasa in the Labouratory of the Department of Nutrition and Food Science; at the Faculty of Biology of the University of Barcelona).

Table 3.A Main Products: Yields, Water content and GCV (1860, 1956, 1999)

Main Products		Yields (kg·ha^{-1})			Water content (%)	GCV (MJ·kg^{-1})
		1860	1956	1999		
gardens	Vegetables	10,873	16,422	23,459	92.0	18.7
	Fresh fruits	5,250	3,004	6,892	84.8	20.1
	Nuts	1,250	-	1,250	4.4	25.0
irrigated	Wheat	1,146	2,549	5,907	14.0	18.3
	Barley	-	-	4,960	14.0	18.2
	Corn	1,093	2,431	-	14.0	18.5
	Hemp	1,199	-	-	7.9	17.6
	Potatoes	-	-	23,397	78.0	16.8
	Fodder	-	-	56,848	79.8	18.5
	Beans	951	1,127	-	15.0	18.0
rainfed	Wheat	1,136	1,231	2,795	14.0	18.3
	Associated Wheat*	731	-	-	14.0	18.3
	Corn	512	910	-	14.0	18.5
	Rye & Wheat mixture	736	-	-	14.0	18.1
	Rye& Oat mixture	-	1,188	-	14.0	18.1
	Barley	527	1,382	2,296	14.0	18.2
	Oat	-	-	1,752	14.0	18.8
	Fodder	8,258	-	16,479	66.7	18.5
	Potatoes	1,743	6,472	8,518	78.0	16.8
	Beans	731	406	-	15.0	18.0
	Vetches	2,967	-	-	80.0	20.7
	Lupins	658	-	-	14.0	20.7
	Legumes for feed	-	-	798	80.0	16.8
	Rape and Turnip seeds	-	-	2,700	78.0	26.7
woody crops	Olive oil	186	192	270	0.0	39.7
	Grape juice	1,164	3,779	6,355	83.1	17.2

Source: Our own, from sources detailed in the text. Note: Associated wheat refers to wheat crops combined with others in the same land, in particular permanent crops like olive trees, along trees or vineyards.

By-product yields are taken from local or provincial sources when available (mainly grain straw and vine pruning). When date was unavailable, we used several complementary sources. For vegetable by-product yields, we used Guzmán et al. (2014); for fresh fruits and nuts pruning, Bilandzija et al. (2012); for cereal husk and stubble, Kernan et al. (1984); for hemp, Mutjé et al. (2008); for corn, beans, potatoes, vetches and lupins by-products, Unal and Alibas (2007); for rape and turnip seed by-products, Vázquez de Aldana et al. (2011); for olive tree by-products, Infante and Parcerisas (2013); for vine leaves, Kok et al. (2007); for grapevine pomace, Kavargiris et al. (2009).

We made our own estimates for olive tree and strain replacements. For olive trees, we estimated 400 kg per tree, 100 trees per hectare and a 300-year lifespan. For vineyards, we estimated 22 kg per vine, 3,000 vines per hectare and a 60 year lifespan. Water content and GCV were taken from Haberl (1995), except for water content of corn stalks and cobs (Lu et al. 2006), olive tree pruning water content (Carone et al. 2011) and GCV (Porceddu et al. 2010).

Table 3.B By-products: Yields, Water content and GCV (1860, 1956, 1999)

By-products			**Yields (kg·ha^{-1})**			**Water content (%)**	**GCV (MJ·kg^{-1})**
			1860	**1956**	**1999**		
gardens	Vegetables	Leaves, straws & weeds	11,018	16,641	23,771	88.0	18.0
	Fresh fruits	Fresh tree pruning	1,170	1,170	2,879	6.5	17.1
		Tree replacement	625	625	4,133	30.0	17.1
	Nuts	Fresh tree pruning	1,170	1,170	1,779	6.5	17.1
		Tree replacement	625	625	2,938	30.0	17.1
irrigated	Wheat	Straw	1,798	2,973	6,492	14.0	17.8
		Husk	504	1,121	2,599	14.0	17.8
		Stubble	83	184	427	14.0	17.8
	Barley	Straw	-	-	4,816	14.0	18.2
		Husk	-	-	2,182	14.0	18.2
		Stubble	-	-	359	14.0	18.2
	Corn	Stalks & Cobs	1,672	3,720	-	7.9	17.1
	Hemp strains	Hurds & shives	1,354	-	-	10.0	17.6
	Potatoes	Stems & Leaves	-	-	3,833	92.0	18.0
	Beans	Bean straw	1,379	2,273	-	85.5	17.0
rainfed	Wheat	Straw	1,783	2,705	3,072	14.0	17.8
		Husk	500	541	1,230	14.0	17.8
		Stubble	82	89	202	14.0	17.8
	Associated Wheat	Straw	1,147	-	-	14.0	17.8
		Husk	321	-	-	14.0	17.8
		Stubble	53	-	-	14.0	17.8
	Corn	Stalks & Cobs	783	1,392	-	7.9	17.1
	Rye & wheat mixture	Straw	1,154	-	-	14.0	18.1
		Husk	324	-	-	14.0	18.1
		Stubble	53	-	-	14.0	18.1
	Rye & oat mixture	Straw	-	3,362	-	14.0	18.1
		Husk	-	522	-	14.0	18.1
		Stubble	-	86	-	14.0	18.1
	Barley	Straw	826	3,022	2,230	14.0	18.2
		Husk	232	608	1,010	14.0	18.2
		Stubble	38	99	166	14.0	18.2
	Oat	Straw	-	-	1,596	14.0	18.0
		Husk	-	-	771	14.0	18.0
		Stubble	-	-	127	14.0	18.0
	Potatoes	Stems & Leaves	784	2,912	3,833	92.0	18.0
	Beans	Bean straw	4,503	649	-	80.0	17.0
	Vetches	Vetches straw	593	-	-	80.0	17.0
	Lupins	Lupins straw	4,101	-	-	80.0	17.0
	Legumes for feed	Legume's straw	-	-	1,157	85.5	17.0
	Rape and Turnip seeds	Rape Straw	-	-	13,500	5.9	19.3
woody crops	Olive trees	Olive tree pruning	1,864	372	2,524	29.2	19.6
		Olive tree browsing	543	113	-	28.0	19.6
		Tree replacement	133	133	1,779	29.2	19.6
		Olive oil pomace	822	94	1,192	40.2	22.0
	Vineyards	Vine pruning	1,342	564	4,255	40.9	18.8
		Strain replacement	1,100	1,100	840	40.9	18.8
		Vine leaves	1,250	1,250	-	60.6	19.0
		Grapevine pomace	496	1,024	496	59.4	21.8

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

We estimated forest and pasture produce through different sources, because it has not been possible to find reliable historical sources. In order to reduce uncertainty, we adopted the above mentioned critera of sustainable extractions. First, using MIRABOSC data (Vayreda et al. 2007) we identified the average productivity of a forest depending on its main species composition. For 1860, and considering the qualitative information from historical sources (Garrabou and Planas 1998), we assumed that extraction was equal to productivity, because the pressure on forests was very high due to domestic firewood consumption and charcoal making. Conversely, we know that in 1956 and 1999, because of the energy and forest transition, the use of firewood and wood for construction declined dramatically. For 1956, we used the average between statistical data on provincial extraction (average 1954-1958), and a value found in the Historical Archive of the Vallès County for 1956. For 1999, we used data from provincial extraction (MAGRAMA 2009), assuming a similar pressure on forest resources in the Vallès area. Finally, regarding grazing extraction, as will be highlighted in further sections, what matters is to have a livestock density below the maximum allowed, given the pasture productivity available. So we depart from a potential maximum productivity of 900 kg dm·ha^{-1} (Olea and San Miguel-Ayanz 2006), and we then check that not all of it is consumed.

Livestock Produce estimates

We estimated animal produce per animal c.1860 using Cussó et al. (2006). We re-estimated wool productivity data (1.5 kg per unit·year^{-1}), and goat milk productivity (0.94 liters per day during 3 months) from local sources (IACSI 1879). For 1956, we considered animal produce per head equal to that of c.1860, although milk and eggs produce per head came from the Agricultural Census (1962) where provincial data was available. For 1999, the Agricultural Census includes detailed information about livestock composition. Given that in an industrial breeding system most animals lived less than one year, we included an animal feeding life cycle analysis to estimate feeding demand and livestock productivity over one year. For that purpose, we considered the reproductive cycle of each species (fertility ages and period, number of broods in a year). To estimate how many were sacrificed in each age group, and the slaughter weight per animal, we consulted the Slaughter Survey 2004, with provincial data, and maintained the criteria of livestock reproduction (a number of individuals from younger stages should be kept from slaughter to replace older ones). For dairy cows, we estimated a produce of 7,198 liters·head^{-1}·year^{-1} (García and Larrull 2001). We considered that sheep and goat milk was consumed by suckling lamb and kids, and therefore did not end up as produce milk for human consumption. We took the number of eggs per hen (261) from Catalan sources (García and Larrull 2001), and egg weight (60 gr) from the Annual report of the agri-food industry in Catalonia (Generalitat de Catalunya 2000). Water content and GCV were taken from Haberl (1995).

Table 3.C Animal produce (1860, 1956 and 1999)

Animal Produce		kg of product per head (f.m.)			Water content (%)	GCV ($MJ\cdot kg^{-1}$)
		1860	1956	1999		
Horses	meat	370	370	-	14.0	18.2
	hides, leather, wool,..	2	2	-	14.0	18.2
Bovine	meat	400	400	180	14.0	18.0
	milk	1,500	3,007	7,198	92.0	18.0
	hides, leather, wool,..	4	4	-	80.0	18.0
	slaughter residues	-	-	66	10.0	19.0
Sheeps	meat	35	35	14	80.0	18.0
	milk	34	3	-	80.0	17.0
	hides, leather, wool,..	2	2	-	85.5	17.0
	slaughter residues	-	-	6	10.0	19.0
Goats	meat	40	40	8	5.9	17.0
	milk	85	108	-	29.2	17.0
	hides, leather, wool,..	1.5	1	-	29.2	19.3
	slaughter residues	-	-	4	10.0	19.0
Swines	meat	110	110	31	40.2	19.6
	hides, leather, wool,..	7	7	-	10.0	19.6
	slaughter residues	-	-	7	10.0	19.0
Poultry and Rabbits	meat	3	3	4	40.9	19.6
	eggs	4	10	16	40,9	22,0
	hides, leather, wool,..	0	0	-	60,6	19,0
	slaughter residues	-	-	1	10,0	19,0

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

3.A.3 Agricultural Inputs: Biomass Reused and External Inputs

The share of the total biomass produced in the agroecosystem that was reused within its borders was also calculated assuming the forced local fund sustainability assumption. Accordingly, we first estimated the biomass reused for livestock feeding and then the corresponding one used for closing nitrogen cycle in cultivated soils.

Biomass Reused

Livestock-Barnyard Biomass Reused

Accurately accounting how livestock were or were not properly fed is relevant in order not to overestimate the external flows of animal husbandry. We based our methodology on a simple bottom-up model from animal feed requirements to the dung composition, assuming maximum efficiency on feeding and taking into account the several losses among the processes due to bioconversion and decomposition. From livestock-barnyard data, we calculated feed requirements in accordance with the main activity and age of each type of animal — e.g., the energetic daily consumption for a cow can range from 1.9 MJ for calves to 9.1 MJ for dairy cows. Energy requirements were estimated from Church (1984) or from several reports written by the National Research Council of the USA. The next step was to define feed sources, their contribution in terms of metabolic energy and, when they had to be provided from local sources, their availability. In past organic systems, and still during the mid-twentieth century, diet was adapted to a variety of available sources (i.e. grain, forages, crop by-products), while current consumption is adapted to planned diets based on grains. We used only some physiological limitations considering historical and current data on organic livestock breeding. For instance, for certain feed typologies (i.e. alfalfa hay), no more than the maximum share could be included in their diets. As well, animals did not all consume the same type of feed (i.e. feeding cows with acorns made no cultural sense). On the other hand, current feeding includes other typologies which have to be imported from abroad, which we estimated from Flores and Rodríguez-Ventura (2014). If animal feed was not locally supplied, energy in transport was considered. We calculated the national average apparent consumption of each product, the region or country of origin, the distance from its main commercial harbour and, depending on the type of transport, an assumed energy expenditure in terms of GJ/t·km following Pérez Martínez and Monzón (2008). The embodied energy of feed also includes energy consumption for its processing (Cooperativas Agro-alimentarias 2010). Besides ensuring the endosomatic requirements of metabolic energy, livestock maintenance also required other biomass and energy flows. In organic agriculture this was mainly stall bedding, estimated from Cascón (1918) and Soroa (1953). Nowadays, the main non-feed expenditures are electricity and fuel used to heat and illuminate feedlots.

Soil Nutrient Balances

Data on aggregated nutrients cycling c.1860 is available from Tello et al. (2012). Based on this previous study, we considered only the Nitrogen (N) cycle which is, at the aggregated level, the limiting one. A general framework on how to estimate nutrient balances in historical perspective can be found in González de Molina et al. (2010). We estimated N extracted through harvesting by taking the N composition of all the products and by-products given by Soroa (1953). To estimate potential looses of soil N we used Hofstra and Bouwman (2005); for basal denitrification Hofstra and Bouwman (2005), and IPCC (2006); for denitrification associated to organic amendments, IPCC (2006); and for leaching estimates due to irrigation, Junta Consultiva Agronómica (1916). Furthermore, there are some natural and anthropogenic nitrogen inflows to the soil that are not directly related to fertilizing practices. The natural inflows are related to atmospheric deposition (Holland et al. 1999), non-symbiotic fixation (Loomis and Connor 1992) and symbiotic fixation (Gathumbi et al. 2002, Wichern et al. 2008). The anthropogenic ones are related to seeds and irrigation. Data on irrigation without pumping is taken from the Junta Consultiva Agronómica (1919) and, after the introduction of fuel motors, we estimated through water balances. We carried out this balance using sources on rainfall and evapotranspiration (Gázquez 2005) and crop coefficients of water consumption (Allen et al. 2006).

From this pre-balance we obtained the total extraction in N as an annual average. These are the requirements for fertilization that must be satisfied through historic fertilization practices. In terms of fertilizing practices, first we identified different nutrient sources and their contemporary importance. After the Green Revolution, the main source is synthetic fertilizer, although organic amendments still played a role. In past organic or mixed industrial-organic farming, the most common fertilizer was livestock manure, which we estimated due to the scant historical data available. Based on the modelled animal diet, we performed a mass balance to estimate the total amount of dry excretes. The difference between the Gross Calorific Value (GCV) and the Metabolic Energy (ME) accounts for all the energy excreted either as solid droppings, or methane emissions due to enteric fermentation (IPCC 2006). However, not all the excreta was available for fertilization, so we deducted the losses due to collection factors according to Cascón (1918) data. Then we included methane losses during the composting process based on IPCC data (2006), while weight losses come from Michel et al. (2004). We also included night soils, since we know it was highly valued in Catalonia used until the end of the 19th century (Tello et al. 2012). There were also other organic amendments in 1860 that did not come from animals or humans, like burying vegetal crop by-products and burning *formiguers* (a series of small charcoal kilns incorporated into the soil). The latter was a very labour intensive task, abandoned after the diffusion of synthetic fertilizers (Olarieta et al. 2011).

Once all N sources and requirements are known, we established how N demand was met through a hierarchical process, starting from the most reliable sources and feed quality and ending with the most uncertain ones. Inorganic fertilizers, if they existed, were the first to be accounted, followed by manure and humanure and finally the inclusion of re-ploughed biomass and – if necessary or historically relevant — of *formiguers* burnt and ploughed into the soil following the explanations of Garrabou and Planas (1998). In the second and third time points, burying biomass was still a fertilizing method used, together with manure or dung slurry application. Although the results of nutrient balances are not explicitly shown, this process has been necessary to calculate the required Farmland Biomass Reused (FBR) expressed in energy values. The result of the N balance is significant at the aggregate level of the agroecosystem, but local variations (in excess or deficit) are not visible unless research at the household level is undertaken.

External Inputs

External Inputs include very different typologies of energy flows coming from outside the agroecosystem. They can either come from the farming community or from the rest of society.

Farming Community Inputs: Labour and Domestic residues and humanure

This is the labour that farming community puts into the agroecosystem. Although it represents a small share of the total energy throughput, labour has a great effect on the way the agroecosystem is managed and the landscape appears. Humanure and domestic residues are the other category of farm community input that were relevant in the first two data points.

We deduced the agricultural population from the Population Register (1860) and Agricultural Censuses (1956 and 1999). Pluriactivity of rural family members (including manufacturing) and flexibility of household structures c.1860 and 1956 made it difficult to determine a reliable agriculture population. We corrected the official data through an estimation of the required population to reproduce the agroecosystem. This estimation was based on the required working days per hectare of cropland, distinguishing among different crops, woodland and livestock densities (IACSI 1879, Garrabou and Planas 1998).

In accordance to the SFS international research project, we proposed a mixed methodology for assessing Labour Energy Flows (Tello et al. 2015) that includes endosomatic and exosomatic energy accountancy (Lotka 1956) based on the 'total energy of food metabolized while working' (Fluck 1992). This methodology starts by calculating the Gross Calorific Value (GCV) of the dietary intake of male adults within an average food basket consumption c.1860 taken from local historical research done by Cussó and Garrabou (2001, 2007, 2012), and other authors (Colomé 1996; Nicolau and Pujol 2005). For 1956 and 1999, we took statistical data from the average Catalan food consumption (INE 1969; DARP 1998). Details on diet changes are specified in Padró et al. (2017). Over this period, total endosomatic energy intake per person has been stable at between 12 and 13 $MJ\cdot labourer^{-1}\cdot day^{-1}$. We calculated the total energy content of food intake by taking into account the hours worked (a yearly average of 8 hours a day) and the intensity of the activities related to agricultural tasks and other human activities (coefficients that range from 1 for sleeping to 7 for more intense agricultural tasks). This reduced the yearly energy content of human labour to 7 to 9 $MJ\cdot labourer^{-1}\cdot day^{-1}$ for 240 days of work.

This energy accountancy of labour is consistent with the farmer standpoint adopted, and avoids treating peasants as livestock or slaves who were only fed to work. This approach makes the accountancy sensitive to farmers' time allocation among labour, other non-agricultural tasks, domestic chores and leisure. Shifting the sustainability assessment from this local farm system scale to a wider societal scope would entail adopting a wider reproductive accounting to include all energy requirements by all members of this local community, whether agriculturally active or not (Tello et al. 2015).

We included the embodied energy of these food baskets when some of their ingredients came from outside the local community. We used national averages for international food trade. We obtained the percentage of imports over apparent consumption for each product from the Statistical Yearbook of MAGRAMA, which provides information about domestic production, imports and exports, other uses, and apparent (human) consumption.. Data on the proportion of each type of transport used (maritime, railroad, road and air transport), and energy consumption associated to each type of freight was calculated according to Pérez Neira et al. (2014) and Simón et al. (2014). Then we made an assessment of embodied energy that included the expenditure of internal transports and the energy spent in packaging-processing, retail outlets and preservation and preparation of food at home. For that aim we relied on the estimates of the Spanish agri-food system in the 1950s and the 2000s (Infante-Amate and González de Molina 2013; Infante-Amate et al. 2014). Including the embodied energy of diets, changes to the embodied energy of Labour remained stable during the period (3,610-4,350-3,176 GJ respectively), although the number of labourers declined (2,057-1,154-250 people). Labour energy flow rose from 1.8 GJ per labourer c.1860, to 3.8 and 12.8.

Farmers used organic household residues and human excreta to close nutrient cycles before the Green Revolution. Farmers fed organic household residues to livestock, which we estimated using average organic production of residues in Spain in 1995 (Junta de Residus 1998) and applied this to the entire population of the case study area. For the 1999 time point, this flow was not considered, because livestock were fed in feedlots and domestic animals had disappeared from households.

Humanure is a source of nutrients for the soil. In 1860 and 1956, prior to the introduction of water closets in all households, humanure was composted together with animal dung and was mainly applied to vegetable gardens. It has not been accounted for the 1999 time point. The recovered share of human excreta was estimated from the part of the agrarian population, applying the information available in Gootas (1956).

Agroecosystem Societal Inputs (ASI)

The flows coming from the rest of society were of a very different nature. We have accounted for five different categories of flows: seeds, feed, machinery, synthetic fertilizers/biocides and direct energy consumption. All of these flows are the result of the Green Revolution, and appear for the first time in the 1956 data point.

We estimated the seed imported in or 1956 as the difference between total seed requirements in the case study area and the estimated productivity of local seed-oriented farms (using information derived from the 1962 census for the Barcelona province). In 1956, feed imports were still at a minimum, but they rapidly grew thereinafter. With data only available at the Spanish level, we estimated an average of 34 kg·LU500^{-1}·yr^{-1} in 1956 (which would reach nearly 300 kg·LU500^{-1}·yr^{-1} only seven years later). Although there were still pastures and cropland residues in excess with respect to the livestock available, we did not include them. Had we decided to include them, the energy balance would not have changed, since feed imports constituted only 68GJ, that is 0.09% of the External Inputs). Section 3.1.1 shows how they have been calculated for the 1999 time point.

For 1956, we extrapolated the machinery available and the fertilizer and biocide used from the 1962 provincial census. We have calculated the machinery and fertilizer/biocide use per area of cropland, and adapted it to the case study cropland area. Since the conditions in 1956, at the beginning of the Green Revolution, were quite different from those in 1962, we determined the annual growth rate of these external inputs from the Agriculture Ministry sources (Ministerio de Agricultura 1954, 1959 and 1963).

We obtained data on the existing machinery in the four municipalities studied from the 1999 Agricultural Census, which shows machines owned exclusively by farms. Information from the 1999 Agricultural Census provides information on the number of seeders, trailers, fertilizers distribution tanks and fertilizer centrifuges. In addition, each tractor includes a cultivator, a harrow and a roller. For direct fuel consumption and embodied energy in machinery, fertilizers and biocides we used Aguilera et al. (2015).

To estimate fertilizer applications c.1999 we used the standards proposed by the Ministry of the Environment and Rural and Marine Affairs (García Serrano et al. 2010). Considering that fertilization depends on the yield level, we adapted the ratios proposed to the crop yields of our case study. For vineyards we used the Guide to Good Agricultural Practice for wine exploitations.

Direct energy consumption included pumping for irrigation (1956 and 1999 data points) and infrastructure heating for livestock husbandry (1999 data point only). For 1956, we applied an irrigation energy input of 0.5 $GJ \cdot ha^{-1} \cdot year^{-1}$ based on Aguilera et al. (2015). For 1999, we calculated a water balance using system efficiency on water distribution (ACA 2014), and information on the share of different distribution systems of water (INE 2000), in order to obtain the total water consumption. Using data on energy consumption for water disposal on agriculture (Hardy et al. 2012) and the energy efficiency from primary energy to electricity (Barracó et al. 1999), we estimated the total embodied energy for irrigation.

Finally, energy use increased with livestock in feedlots and the diffusion of new varieties unsuited to some climatic conditions, whether from fuel or electricity. We used energy studies from different species of livestock (as the breeding conditions vary a great deal across animal typologies). For pigs, we used Lavola (2008); for cows and cattle, Bartolomé et al. (2011) and Irimia et al. (2012); for sheep and goats, Gil and del Pino (2011); for hens, broilers and other poultry, Fundacion Entorno (2006). We transformed these energy values into primary energy demand using conversion and efficiency factors from Barracó et al. (1999), and added the embodied energy for transport used (Pérez and Monzón 2008) weighted by the provenance of oil (FECYT 2002).

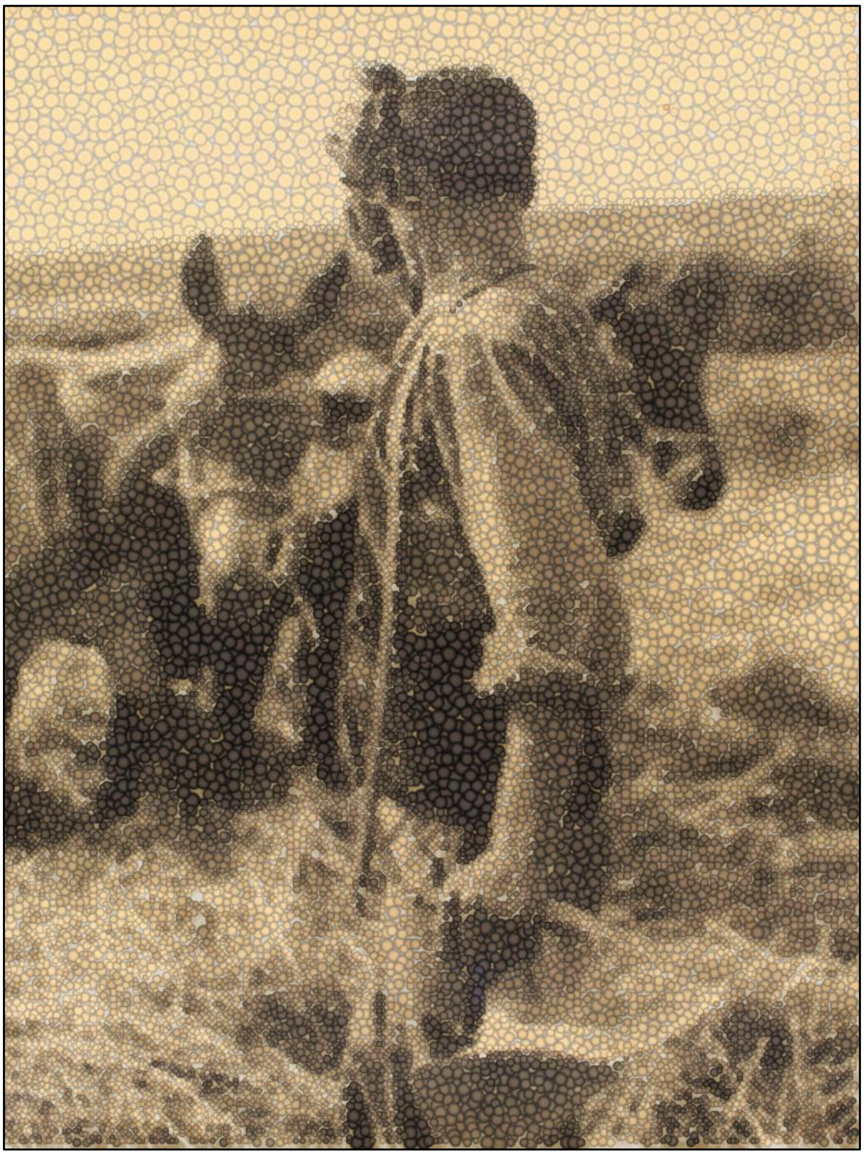
Table 3.D. Composition of the main energy flows

MAIN FLOWS	Units	1860	1956	1999
1. Total Produce	**GJ**	**505,707**	**379,127**	**465,723**
2. Final Produce	**GJ**	**262,843**	**235,112**	**312,327**
2.1. Cropland Final Produce	%	34.4	47.9	15.3
2.1.1 Food, fibre	%	14.1	25.6	4.6
2.1.2. Vineyard and Olive By-Products	%	20.3	7.3	0.4
2.1.3. Animal Feed	%	0.0	15.0	7.7
2.1.4. Industrial Crops	%	0.0	0.0	2.7
2.2. Woodland Final Produce	%	64.5	49.0	8.2
2.3. L-B Final Produce	%	1.1	3.2	76.4
3. Biomass Reused	**GJ**	**242,864**	**144,009**	**142,246**
3.1. Cropland Biomass Reused	%	60.3	6.5	8.7
3.1.1. Seeds	%	1.6	3.4	1.5
3.1.2. Buried Biomass	%	39.4	3.1	7.2
3.1.3. *Formiguers*	%	19.3	0.0	0.0
3.2. L-B Biomass Reused	**%**	**39.7**	**93.5**	**91.3**
3.2.1. Feed (main products)	%	10.9	18.6	47.7
3.2.2. Feed (by-products)	%	19.7	27.3	17.9
3.2.3. Grass	%	5.6	28.6	0.7
3.2.4. Stall bedding	%	3.4	19.0	25.0
4. External Inputs	**GJ**	**12,210**	**88,745**	**1,281,534**
4.1. Labour	%	29.6	4.9	0.3
4.2. Humanure	%	20.5	1.8	0.0
4.3. Domestic Residues	%	49.9	10.4	0.0
4.4. Fertilizers & Biocides	%	0.0	69.5	1.6
4.5. Machinery	%	0.0	13.1	15.2
4.6. Feed	%	0.0	0.0	73.9
4.7. Energy consumption	%	0.0	0.1	8.7
4.8. Seeds	%	0.0	0.3	0.2

Source: Our own, from sources detailed in the text. Note: All the disaggregated percentages are calculated over total Final Produce, Biomass Reused or External Inputs.

CHAPTER 4:

Labour, Nature and Exploitation: a first exploration of the relations between Social Metabolism and Inequality in traditional organic farming (Sentmenat, Catalonia, 1850)



Original photograf by Antoni Arissa (dated between 1922-1928)

Ganarás el pan… [You will earn the daily bread…]

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CHAPTER 4:

Labour, Nature and Exploitation: a first exploration of the relations between Social Metabolism and Inequality in traditional organic farming

(Sentmenat, Catalonia, 1850)[12]

Abstract:

What are the links between social inequality and biophysical constraints? Based on the Ecological, Feminist and Marxist Economics we argue that a biophysical tension exists between appropriation of nature through production, and the social organization of labour. Exploiting the labour of other people has historically been one of the main strategies to tackle this tension, giving rise to the exploitation of the labour of women and to social class hierarchization. Through a methodology that integrates energy, material, time and cash balances we analyse socio-metabolic flows between social classes in traditional organic farming. The results show that land and livestock grabbing originated and legitimised a process of accumulation through dispossession. Our estimates of energy labour surplus reveals that wage remuneration obtained 88% of the Equivalent Consumption Basket that it would have get by applying it to the own land. This dependent labour had incorporated in itself a relevant amount of hidden domestic family labour.

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[12] The list of authors is the following: Inés Marco[a], Roc Padró[a], Enric Tello[a].

I have led as corresponding author this article submitted to the *Journal of Agrarian Change*, which is currently in the reviewing process. I contributed to it with the original idea, the proposal of the theoretical framework, the development of the methodology, and writing the paper. Roc Padró contributed in several methodological issues, specially linked with the nutrient balances, and supported the whole process providing significant advices. Enric Tello did contribute to the theoretical framework and interpretation of results.

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4.1 Introduction

> ‘Differences between individual 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)

Historically, peasant unrest has been explained by the search for greater access to the means of production and the reduction of ‘labour, food, taxes, rents and interest’ extractions (Hilton 1988; Rösener 1994; Scott 1985).[13] In preindustrial agricultures, the rebellion of peasant communities mainly took the form of small but abundant acts of resistance, which Scott (1985) defined as ‘the weapons of the weak’. These actions included ‘foot dragging, dissimulation, false compliance, pilfering, feigned ignorance, slander, arson, sabotaje and so forth’ (Scott 1985:29). Together with their claims, these strategies had a clear reproductive purpose, since through these they were able to obtain the resources (food, fuel, pasture) needed for the reproduction of families and livestock. In this sense, as proposed by Thompson (1978), the conflict over access to the means of production and the strategies of produce distribution could be defined as a ‘class struggle without class’. The exploration of the links between the Social Metabolism approach to farm reproduction, social inequality, and social conflicts in preindustrial agriculture is necessary to open debates of great relevance in the current context. Understanding the role of biophysical boundaries and constraints in the generation of conflicts over access to resources, and over the produce distribution, requires an in-depth research of biophysical links between different social classes, not only to better understand past societies but to analyse the present and think about the future.

First, the dynamic analysis of preindustrial societies on a micro level allows us to ask about the role of social inequality as a driving force of socioecological transitions. In addition to population growth (Boserup 1981) and the ensuing scarcity of land and other resources (Sieferle et al. 2006), the role of social inequality as a driver of socioecological transitions has not yet been analysed in depth. No doubt, some reserachers had considered the topic. Guzmán et al. (2000) argue that social inequality constitutes an ‘ecosystemic disease’. As González de Molina and Toledo (2014) developed later, inequality often entailed an increase of exosomatic consumption by a small social group. If this was not compensated by an equivalent reduction of exosomatic consumption of other social groups,

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[13] Quotation marks refer to Scott (1985:29).

the whole metabolic pressure increased the societal demands over the territory beyond the size of its population. This might have been a powerful driver of the historical evolution of societies. Indeed, referring to transition to industrial agriculture, Gonzalez de Molina and Toledo (2014) pointed out that social imbalances in social produce distribution led to increasing commodification (of products and inputs). The process of commodification, which forced to increasing yields (land and labour), was the underlying thread that allows to understand the metabolic change towards industrialization of agriculture.

Some characteristics of the industrial socio-metabolic regime make us think about other links between social inequality and socioecological transition. Social inequality was a necessary condition for the socio-metabolic transition to the industrial regime, mainly because of the proletarianisation process and capital accumulation, but also because of its links with greater demographic pressure and land scarcity. On the one hand, capital accumulation, was both a condition for industrialization, and a consequence of social inequality. On the other hand, industrialization cannot be explained without proletarianisation.[14] Industrial socio-metabolic regime needed to mobilise workforce from the rural to the urban and from agriculture to industrial. The debate on the causes of the process of proletarianisation in Europe has been over two issues: demographic pressure (Chambers 1953; Clapham 1967) and the effect of enclosures (Marx 1996 [1867], Chapter 24; Dobb 1946; Humphries 1990). While the first hypothesis might be lead by ‘natural forces’, the second highlights a more direct effect of increasing social inequality. Furthermore, probably both causes were interlinked. As Tilly (1984) pointed out, until the beginning of the 20th century the increase of the rural proletariat explained the increase of the European population: ‘on the average, proletarians responded to economic expansion with greater declines in mortality and greater increases in fertility than non-proletarians’ (Tilly 1984:64-65; Medick 1976).

The second aim of analysing the links between social inequality and biophysical constraints in less-complex preindustrial agriculture is to better understand the present. As Wilkinson (1973) argued, the Industrial Revolution did not imply the emancipation of natural limits, nor the disappearance of the conflicts by the control of natural resources. This transition was linked to the ability to export and redistribute these limits in a global society. If we understand technological advances as a process from which we save time or space, we must take into account that local savings are possible by the expense or loss of time and space elsewhere in the global system, in a global process of appropriation of time and space (Hornborg 2003). If we start from the distinction between internal, external and intergenerational inequality proposed by González de Molina and Toledo (2014), the socio-metabolic transition shows the change from a regime with greater pressure on internal inequality, towards a regime that shifts the pressure towards external and intergenerational

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[14] We understand proletarianisation as Humphries does, as a ‘gradual process whereby access to resources other than wages was slowly eliminated’ (Humphries 1990:41) ‘rather than pushing families out from one category (propertied/peasant) into another (proletarian)’ (Humphries 1990:18).

inequalities. Thus, it has been necessary to maintain social inequality, in this case with a Global North-South structure, which together with the legitimacy of trade exchanges allows this process of accumulation by dispossession (Harvey 2003). The environmental load displacement of pressure on extraction of natural resources to the Global South has also meant the displacement of conflict. While land reforms almost dissapeared of the European political and social scene, in the Global South access to land continues to be a source of conflict and one of the main political concerns, although the new visions include other issues such as the reference to *territory* beyond *land*,[15] or the claim for an Integral and Popular Agrarian Reform (Rosset 2013).

Thirdly, all of the above should enable us to better understand the deep articulation between land, labor and energy in the processes of social reproduction. This knowledge could be nourished by the analysis of traditional organic farming, were land-labour-energy processes were more plain and easier to understand. The ultimate aim is to introduce this perspective in any proposal of socio-metabolic transition towards sustainable societies, in what has been named Third Great Transformation (Haberl et al. 2010). The reorientation towards economies that are not based on these unequal exchanges (social, sexual, ecological and territorial) must take into account the implications for the internalization of costs in time and space, and the consequent impact on the potential social conflict. This would mean to complement the Land Cost of Sustainability (LACAS) put forward by Guzmán and González de Molina (2009) with the Time-Labour Cost of Sustainability here proposed. Indeed, if both labor and energy could be considered the productive forces of any production process (Hornborg 2003), we need to understand how they are related one another and socially organised. Exploring in depth the links between biophysical limits, social reproduction processes and social organization of labour allows us to identify which are the potential conflicting elements that have to be tackled. Within this analytical framework, we highlight the need to name the domestic work and care, carried out mainly by women, linked to labour force reproduction. If these works of sustenance of the whole life cycle of each human being are not counted, but simply taken them for granted, not only the sexual division of labor becomes invisible. A primordial root of all other forms of social inequality that have historically been built upon it is also concealed (Salleh 1995, 2010).

We propose that the Social Metabolism approach, and in particular its historical application to traditional organic farming, is a useful tool to explore this issue. To this end, it is necessary to make progress in the development of methodologies that make it possible to visualise two elements that have not been worked out in depth so far from this perspective: the role of human labour in the reproduction of agroecosystems and the existence of a social conflict in the human appropriation of production. Until now, the emphasis of the analysis about sustainability of agrarian systems has been

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[15] ‘For rural communities, especially indigenous peoples, land is not only a means of production, nor can it be regarded in isolation from other elements of nature. Land is embedded in territory, which includes water, air, forests, plants, animals, fish, other living creatures, culture, sacred sites, ceremonies and practices. Territories connote holistic relationships between people and their environment’ (Rosset 2013:740).

centered around 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). The socio-metabolic analyses, in general, have payed less attention to the role of the mentioned third fund, peasant units and their reproduction. The role of those communities as labour suppliers, as well as the consideration of time as a key resource in the handling of agroecosystems has been analysed in less detail (Fischer-Kowalski et al. 2010). In addition, the reproductive analysis of agrarian communities necessarily implies examining the relations between different social groups. This relates to four essential questions in political economy (Bernstein 2010) which we want to pick up from socio-metabolic analysis: Who owns what? Who does what? Who gets what? What do they do with it? As a result, the analysis has to include ownership social relations, social division of labour and produce distribution. Although these questions have been frequently posed in the study of social inequality in agrarian societies (Tello and Badía Miro in press; Colomé et al. 2012; Garrabou et al. 2014; González de Molina et al. 2014; Parcerisas et al. 2014), the pending challenge is to raise a reinterpretation from the knowledge contributed by Social Metabolism and Political and Social Ecology.

The objective of this article is to contribute to the development of a socio-metabolic analysis of the historical forms of exploitation in traditional organic societies as a result of unequal access to two key funds of agroecosystems: land and livestock. In the first section we propose the theoretical framework from which we understand the links between the biophysical constraints and the role of work as a fundamental element that shapes the social metabolism. The second section summarises the methodology proposed for the biophysical analysis of social inequality in traditional organic farming, and the main hypothesis of this work is presented. Then, we describe the main features of the case study (Sentmenat, Catalonia, 1850) and argue the choice of the selected households anaysed. In the third section we present the results, and in the last section we discuss them. A methodological annex details the main criteria and data on which the empirical exercise is based.

4.2 Theoretical framework: nature, labour and exploitative relations

> ‘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 we analyse social inequality and the conflicts it generates from a socio-metabolic perspective? What original contributions could this perspective provide? Starting with the notions of social organization of labour, produce distribution through market exchange, and the underlying exploitative relations, we offer a first proposal that can help think in that direction. As recently pointed out from the perspective of Agroecology and Political Ecology, the main shortcomings in the analyses of the two best known trends in the study of Social Metabolism —the Ecological Economics schools of Vienna and Barcelona—are, precisely, the inclusion of inequality and social conflicts, the role of institutions and politics and a theory of human needs (Gerber and Scheidel 2018). On the other hand, the authors that recently resumed the long lost connection between Marxism and ecology (Martínez Alier and Naredo 1982; Tello 2016), have not yet proposed a quantitative specification of their theoretical proposal regarding an unequal ecological exchange (Hornborg 1998; Foster and Holleman 2014).

The concept of labour is greatly relevant when it comes to understand the biophysical, cognitive and social links that economic activity establishes between society and nature. We are aware of its complex multidimensionality, but we believe that for the purpose of this work it is enough to start with a quite strict 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 1997 [1867]). In biophysical terms, the concrete implementation of this labour-capacity is the fundamental process through which human societies are able to appropriate, transform and distribute a part of the energy and material flows of nature in order to have suitable energy and materials for their consumption. In this process, human labour implies more than the mere application of an energy flow, given that it also produces a structuring process of that energy by means of a purposely-oriented information (Passet 1996). Analogously, the existence of basic human needs is founded in the insertion of the human species in the biosphere, which implies that its fulfilment is as abided to thermodynamics as to energy and materials deployment by human labour. But the formulation of the socially produced satisfiers to fulfill those needs, although rooted in human species nature and its biophysical environment, also become socially determined cultural constructs. Acknowledging the multiple and relational nature of labour (biophysically, cognitivelly and socially determined) has always been part of the basic core in the long conformation of a substantive economy, historically opposed to the main tendency of the liberal Neoclassical economics which only operates with exchange values. The substantive economic vision defines itself as the study of 'the interchange with his natural and social environment, in so far as this results in supplying him with the means of material want satisfaction' (Polanyi 1957:243). According to that vision, the primordial aim of human labour is the production of use value.

The relation of every human being with its own labour-power has also a double role. On one hand, labour is the process through which goods and services necessary for life (food, fuels, fibres, transportation) are obtained. On the other, the own capabilites of a human beings (both physical and mental) are their first means of production. The body is central in both processes: it is the living tool through which human beings act upon nature, and also a fund element that requires materials and energy for its reproduction. As stated by Maria Mies (1987:52), on one hand the human body produces use values and on the other hand it consumes them. As a mean of production that develops a physical labour in a world subdued 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). It is the insertion of the human species in its biophysical context what defines both processes: the inevitability of the appropriation-distribution processes to fulfill the consumption of materials and energy needed for human reproduction, and the inevitability of labour as a means to obtain them. In a world subject to physical laws, labour is the necessary evil, the eternal condiction imposed by the very nature of human existence (Mies 1987).

Given that human beings organise labour as well as consumption in a social manner, individual decision-making ability is extremely 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 1987:46). In that case, any increase of consumption must be met by an increase in labouring time (Chayanov 1986 [1925]; Van der Ploeg 2014). Therefore, perception of abundance/scarcity in differente human communities has been always (culturally) defined by the relation between means and ends, that is, by the link between productive forces and social needs (Sahlins 1972). A given consumption level is not perceived as 'abundant or scarce' in an isolated manner, but in relation to the effort and labour implied. In such conditions, if the people/social groups that benefit from the appropriation-transformation and consumption are the same ones that assume the efforts associated with that labour process, there will be no inherent tendency towards indefinitely increasing the levels of appropriation-distribution and consumption, thus leading to a certain stability of the socio-metabolic structure.

Despite the above, even in societies based in relatively egalitarian small human groups a latent biophysical tension can exist, derived from a potential pursuit of an increase of the consumption flows while keeping stable the labour needed for it or, on the contrary, the labouring-time reduction keeping the same level of resource appropriation. Different strategies have been formulated facing this disjunctive, amongst which we can emphasise the emergence of the incentives for technological innovations so widely covered in academic research. In the light of the perspective of human beings defined as an essentially incomplete being (*Mängelwesen*) (Gehlen 2016 [1940]) who naturally seeks an increase in accessing material goods, technical progress can be understood as an 'organ projection' (*Organprojektion*) that increases his or her power over the processes of nature (Kapp 2015 [1887]). Thus, some authors formulate that a key difference of the human species is its tendency towards the construction of exosomatic organs—in the terminology of Alfred Lotka (1956)—so as to be able to appropriate-transform-distribute larger quantities of energy and materials with a lesser application of labour (Georgescu-Roegen 1977). Another potential strategy that would also differentiate the human species from the rest of living beings, and the one we will center around in this article, is 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).[16] In the large historic record of our species we can observe that 'the disposal over the use of time (own time and the time of other people) is one major main marker of freedom and power' (Fischer-Kowalski et al. 2010:7). In this way, that original biophysical tension could also be working as an incentive to the establishment of exploitative relations, understood as those through which a social group appropriates the productive capacities and/or the products of another social group. This tension would imply a tendency towards social conflict, but not necessarily lead to it. Anthropology has observed social organization strategies that promote stability within social groups, namely, limiting market exchange between members of the same community (Polanyi and Pearson 1977).

This approach leads us to observe exploitative relations from a socio-metabolic perspective. It is very likely that the emergence of the first hierarchical societies was closely linked to this socio-metabolic tension, and with the range of technological and exploitative options opened to tackle it. This gave rise to a differentiation and hierachization of the social and political spheres, where social elites could hold positions of power (Bookchin 1982). From his socio-metabolic vision, Karl Marx already emphasised that the existing links between class societies and biophysical limits were a challenge that led to the development of what Hegel called a 'second nature'. According to Marx, once social classes arose they acquired their *raison d'etre* because the ultimate historical goal of providing a 'good life' to humanity required the domination of the 'first nature'. The domination of first nature, in turn, required the mobilization of labour by a privileged and supervising class of leaders and exploiters. Once the first nature was tamed, dominated and freely open to 'exploitation', the path was open to the existence of classes and states (Bookchin 1982).

Beyond intergenerational or class hierachization, it seems incontrovertible that one of the first forms of exploitation that appeared within human communities originated with 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 and care labour was exclusively assigned to women, partially denying her role in the production outside home, and assuring the (re)productive labour for the preservation of the family and the workforce. Exploitation could be observed as an appropriation of the time of women, as many anthropological studies have described the fundamental role of women as the ones in charge in preparing food and taking care of children, while men had more time for political and religious activities (Sanday 1981). Even though the total amount of labour hours of men and women might be similar within the domestic economy, some research suggests the existence

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[16] Historically, human communities have not worked based on the modern notion of individual (Hernando 2012), and that statement can also be addressed as the appropriation by a 'community' of the product generated by another 'community'.

of unequal food redistribution within the household (Ryan Johannson 1977; Humphries 1991; Nicholas and Oxley 1993; Horrell and Oxley 2013). At the same time, women exploitation would also be connected to more symbolic and institutional matters, such as being excluded of the property of certain resources or the contempt for the tasks they performed. A common feature to those female tasks was that it also included the biological processes of intergenerational reproduction, assuring the (re)production of the labour force (Firestone 1970) to sustain the current 'active' members as well as of the future labourers. The importance of female domestic and care work, which ensures social reproduction, went hand in hand with its devaluation that helped to legitimise the exploitation process of women from the onset.

Once gender inequality between the two sexes of the human species was socio-symbolically legitimised, it led the way to establish, within communities or societies, other forms of social hierarchization. This allowed the unequal distribution of labour and the appropriation of production surplus on the part of dominant classes of non-producers (Bernstein 2010:21). In such contexts, the Marxist currents define exploitative social relations 'those in which non-producers are able to appropriate and consume (or invest) products and services of actual producers' (Mies 1987; Luxemburg 1925). The understanding of power as based on consent (Godelier 1998) also means to search for social legitimation processes. In addition to patriarchal system, the main mechanisms of social legitimation of those exploitative relations in modern societies are basically the ones linked to private property.

Starting with John Locke (1690) the line of thought that led from the Age of Enlightenment to Liberalism has continued to assume that property is the result of the own labour: *'As much land as a man tills, plants, improves, cultivates, and can use the product of, so much is his property.* (…) *The labour of his body, and the work of his hands, we may say, are properly his. Whatsoever then he removes out of the state that nature hath provided, and left it in, he hath mixed his labor with, and joined to it something that is his own, and thereby makes it his property*' (Locke 1690:25-26). But it had to face the fact that this criterion would stop working in the cases where labour was applied to the ownership of someone else. That means, when dissociation occurs between the producer (labourer) and the means of production (proprietary). In this case, Locke argued that the landowner was also legitimated to appropriate the results of the labour performed by the bodies of other people when these bodies belonged to him, whether it was a horse or a servant whose time he hired: '*Thus the grass my horse has bit; the turfs my servant has cut* (…) *become my property, without the assignation or consent of any body. The labor that was mine, removing them out of that common state they were in, hath fixed my property in them*' (Locke 1690:24).

Therefore, all liberal tradition has had to carry with the conceptual problem of assimilating to the possession of a horse the property of the labouring time of another human being. This obstacle was overcome through the consideration that the exchange that takes place between the contracting parties in the labour market is a 'free' one. From there, it could also be admitted that only a fraction of produce had to be compensated to the labourer, thus legitimating that the owner of any means of production (including the time of human labour) could appropriate all resulting produce. Labour retribution tend to be fixed around what in any given moment in history has been considered a ‘subsistence wage’ (that allows the labourer and its family to meet the basic needs), which shows how the logic behind the retribution of hired labour is related to the need of labour-force reproduction, not with a ‘fair’ retribution for the participation in the productive process. Therefore, the product distribution between the different agents that intervene in a complex process mediated by the labour market depends on the previous uneven distribution of the entitlements over natural resources (the power to buy horses and servants mentioned by Locke), which in turn establishes a strong power asymmetry in this labour market.

Historically, the very formation of a ‘free’ labour market is not strange to the ‘origin’ of private property. The pretension to legitimise that private property by means of the alleged accumulation of a surplus derived from the own labour inevitably clashes with the historic evidence that a great part of the distribution of resource ownership on which capitalist development was founded originated in a violent landgrabbing that enabled the establishment and maintenance of the subsequent social order (Wallerstein 1974). Only through that 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, it was possible to found and later legitimise a more stable process of parasitism, dependent on the exploitation of the labour force and resources. Historically, all these domination forms have always been interrelated.

The processes described in this section allow us to observe how biophysical limits, by means of human needs subordination to the attainment and transformation of materials and energy, as well as the links that those processes establish with human labour, raise a series of tensions inherently linked to social organization of labour and the resulting allocation or dispossession of rights in the distribution of production. Exploitative relations that lead to a process of asymmetrical appropriation of production regarding labour distribution must then be understood from a biophysical perspective. This also allows to widen the consideration of ‘inequality’ by referring to ‘exploitation’ between human beings, bringing to light the underlying links between different social groups that are opposed in this process of appropriation, transformation, consumption and excretion of energy and materials. The maintenance of this kind of parasitic relations requires symbolic and institutional mechanisms to legitimise those processes. In this work we will center in two of them: sexual division of labour and private property. Our goal is to move towards a substantive Ecological Economics that, from Social Metabolism accounting, goes into examining inequality, exploitation and the socioecological mechanisms that enforce them (Gerber and Scheidel 2018). For this purpose, we need to go along the ideological veils and institutional mechanisms that justify and preserve them. In this work we are proposing a first accountable methodology applied to the analysis of exploitative relations in a agricultural community of mid-19th century. The results would help us to summarise and better understand both their functioning as well as their further historical development.

4.3 Methodology, hypothesis and features of the case study (Sentmenat, 1850)

4.3.1 Labour, Land and Livestock: a methodological proposal

In the agricultural metabolism of preindustrial organic societies the ability to appropriate the product of the labour of others was closely related to the unequal access to the main fund-elements (farmland and livestock) of the agro-ecosystems. Although we consider three fund-elements (household, farmland and livestock) (Tello et al. 2015, 2016; Galán et al. 2016), in this case the conflict of social appropriation only affects the two funds liable to private appropriation. The product redistribution on the basis of a previous asymmetry of access to land took different forms, one of which were the land tenancy contracts by which the landowner received a part of the harvest. Nevertheless in this work we focus on another form of redistribution in traditional agricultural societies that took place through wage labour. Our initial hypothesis is that through funds' grabbing (farmland and livestock), the big landowners ensured the availability of the low-priced labour they needed to manage their farm holdings. Without the ability to mobilise that labour-force, the management of any farmland estate that exceeded the labour-capacity of a family would not have been possible.

Hence, a necessary requirement for that external labour availability was the existence of social groups 'dispossessed' from land and other means of production required for their reproduction and, therefore, dependent on the sale of labour-force in the market. As a result, interdependence between both social groups was expressed in the establishment of labour and commodity markets where labour and product deficits or surpluses were met. The creation of a labour market would be the result of a previous hoarding of the basic resources needed for reproducing an autonoumous life, which allows a better understanding of what Karl Polanyi called labour and land '*fictitious commodities*' (Polanyi 1944). Thus, labour, which is just another way to define a human activity that is part of life itself, would become a commodity, in spite that it was not 'produced' for its sale and that it cannot be separated from life. Even some mainstream economists admit that, because of the self-esteem that all the workers who sell their time have, the labor market is substantially different from, let us say, the artichoke market (Solow 1990). We are going to test a methodology of socio-metabolic calculation that allows to visualise and characterise the functioning of exploitative relations that took place between different social classes through the labour market.

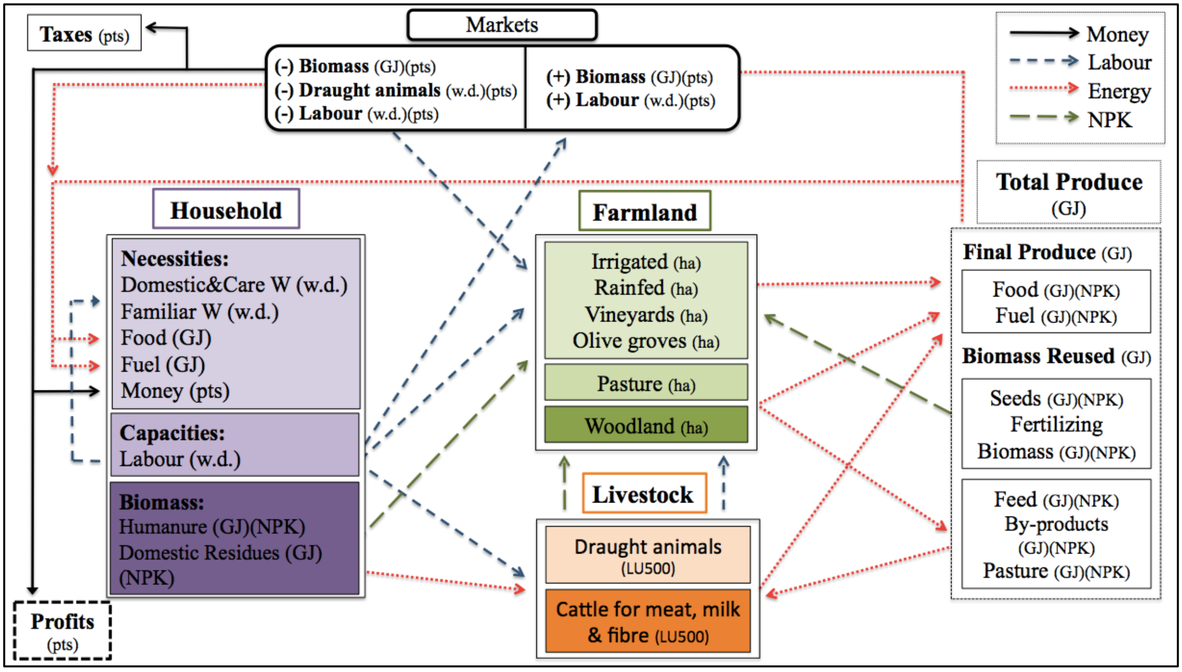
This kind of approach requires the elaboration of balances at household scale, a quite uncommon perspective except in some very recent studies (Nawn 2016; Gizicki-Neundlinger et al. 2017a, 2017b). So far each of these socio-metabolic exploration of social inequality uses its own methodology, which makes comparative analyses difficult. The accounting method we propose to validate our hypotheses is a hybrid that combines methodologies brought forth by other researchers. First we use the Material and Energy Flow Analysis (MEFA) to estimate the different energy and biophysical flows that inteconnected some of the fund elements considered (farmland, livestock and agricultural community) (Tello et al. 2016; Galán et al. 2016; Guzmán and González de Molina 2017; Gingrich et al. 2017). Secondly, we apply the Land-Time Budget Analysis (LTBA), a methodology used in many case-studies for traditional or transitional farming (Pastore et al. 1999; Gomiero and Giampietro 2001; Grunbuhel and Schandl 2005). Lastly, we interlink material-energy flows and labour time with the family cash flows through a circular connection that allows to observe where those biophysical flows came from and where did them finally end. In doing so, for every domestic unit we can specify the flows that connected the distinct funds (household, farmland and livestock) expressed in energy, materials, soil nutrients, labour and money (Figure 4.1).

Every fund has reproductive needs and capacities, and in this work we will mainly center on the 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 (see Sections 4.A.4, 4.A.5 and 4.A.6). In turn, certain capacities were available for every HH that, even though a lot more diverse in human terms, for the sake of this approach we narrow down to labour capacity. All these variables will be defined by the size and composition of every HH (gender and age), except the need of cash flows that also depended on farmland and livestock characteristics.

Total Produce (TP) obtained will, at first, be distributed according to the capacity of every HH to reproduce their funds. We proceed under the assumption that agricultural processes did not just pursue societal reproduction, but also the reproduction of all other funds that made agricultural processes 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 fertilizing biomass availability and the outcome of nutrient balances. A third group of products was meant to reproduce livestock. These last two flows are grouped as Biomass Reused (BR), and the criteria for the drafting of those two processes are detailed in Chapter 3 and Padró et al. (*forthcoming*). The implicit assumption is that in normal conditions these three reproduction processes had to be met, and that the flows that could not be obtained from HHs internal provisions would be acquired in the market (thus increasing cash requirements).

Time balances are drafted 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 the HH size and composition (gender-age). Secondly, we estimated the quantity of farming labour required by each HH according to (i) the size and land uses of the farmland, and (ii) livestock features (see Section 4.A.5). From this comparison we can infer if labour requirements were greater or lower to the HH labour capacity, that is, if a surplus or deficit of HH labour capacity existed. If a deficit of domestic labour existed, the HH had to hire external labour. If there was a surplus, we estimated what part of that surplus will be effectively transformed into wage labour according to the need of cash income. To that end, we estimated the income from agricultural products surplus and deduced the expenses resulting from purchases of products (including food intake, fuels, feed for animals or fertilizing materials). We also included housing rent, clothing and other HH expenses. If the cash balance was negative, a part of the exceeding labour-force would have had to be hired in the market.[17] In doing so, we are interlinking five consecutive balances: (i) human consumption, (ii), livestock feed, (iii) soil nutrients, (iv) labour and (v) money.

Figure 4.1 Socio-metabolic Fund-Flow structure of traditional organic agricultures



Source: Own elaboration. Notes: '*pts*' refers to the monetary unit, 'Pesetas'; 'w.d.' refers to 'working days' and 'LU500' refers to Livestock Units 500 (see footnote 10). 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 (see Section 4.A.5). 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).

Hence we consider that interchange among HHs with different imbalances (surplus of labour or surplus of agricultural produce) were conducted through markets, which operated as key elements in redistributing the necessary production and labour for the socio-metabolic reproduction of funds. In the case of a HH selling part of its available labour-force (Household mismatch$_1$), the exchange of time for products would be shaped by the relative prices of labour [time/money] and products [GJ·money^{-1}] (Figure 4.2). The final result of the exchange process was the purchase capacity (in GJ

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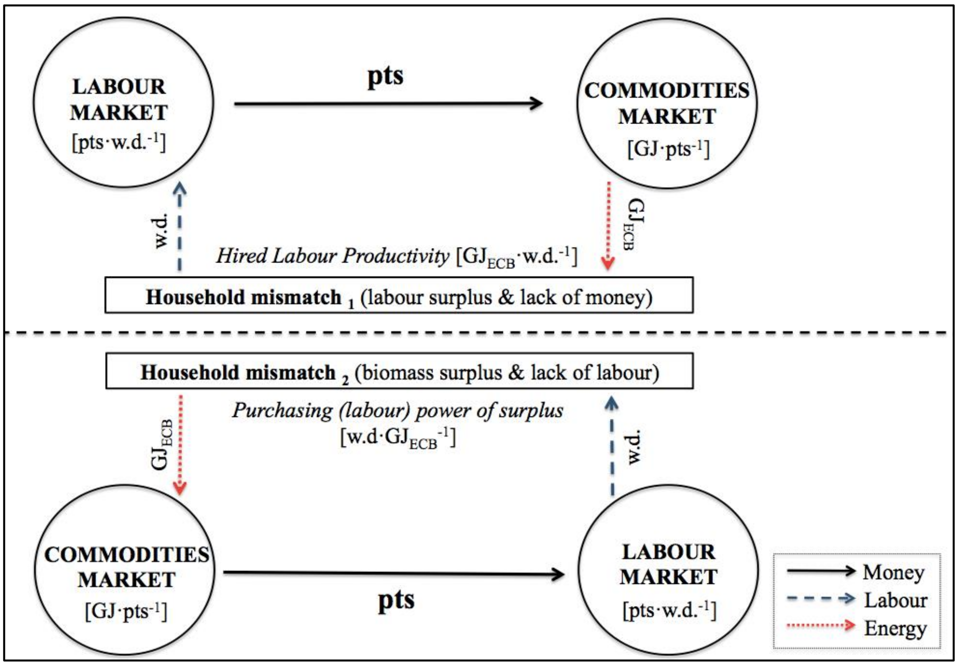
[17] We have considered that only the necessary wages to close cash deficits would be sold, that being the reason why our calculations did not include neither the possibility to sell more to cover other needs, nor the capacity to take the effect of unemployment into consideration.

terms) of a labour unit, in other words, an indicator of the energy productivity of wage labour (GJ·working day^{-1}). These type of data gives us very precise information about the way production was socially distributed, that is, what part of the product was kept in the hands of the labourers and what part ended in those of the landowners. Next, we compare the energy productivity of wage labour with the energy productivity of autonomous labour, obtaining an estimate of the energy surplus value taken by landowners.

Figure 4.2 Commodities and Labour markets as socio-metabolic bioconversors



Source: Own elaboration.

We seek to avoid conflating the different energy qualities between food and fuel energy carriers included in the Final Produce (Giampietro et al. 2013). To this end, we built 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, a food GJ (26 pesetas) was much more expensive than a fuel one (2.3 pesetas). Weighted by their proportions we get the price for the whole basic consumption basket (9 pesetas·GJ^{-1}). This common ratio will be used to convert the Final Produce (FP) into Final Produce in terms of Equivalent Consumption Baskets (ECB) (FP_{ECB}), which is composed by the same proportion of food and fuel energy that we found in the historical consumption basket. 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 that can be calculated in a family farm.[18]

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[18] These process will be explained in more detail in Chapter 5 (see Sections and 5.2.1 and 5.A.2).

4.3.2 Productivity indicators

We use different energy productivity indicators, depending on the output and the inputs analysed. Although all the productivities are measured in energy terms (mainly GJ in ECB terms; GJ_{ECB}), we will not indicate it in every moment in order to avoid repetition. First we analyse the productivities with respect to the Final Produce in Equivalent Consumption Baskets (FP_{ECB}), and we relate it with the major two inputs, land (measured in hectares of farmland) and labour (measured in agricultural working days). Thus, we obtain the *Final Productivity of Land* (FPLan) and the *Final Productivity of Labour* (FPLab). Second, 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 to maintain soil fertility and livestock, but also to reproduce the human workforce. In this case, we maintain FP_{ECB} as the output, and include both agricultural and Domestic and Family Work (DFW) as inputs. This is labelled *Total Productivity of Labour* (TPLab).

4.3.3 Case study and Household selection

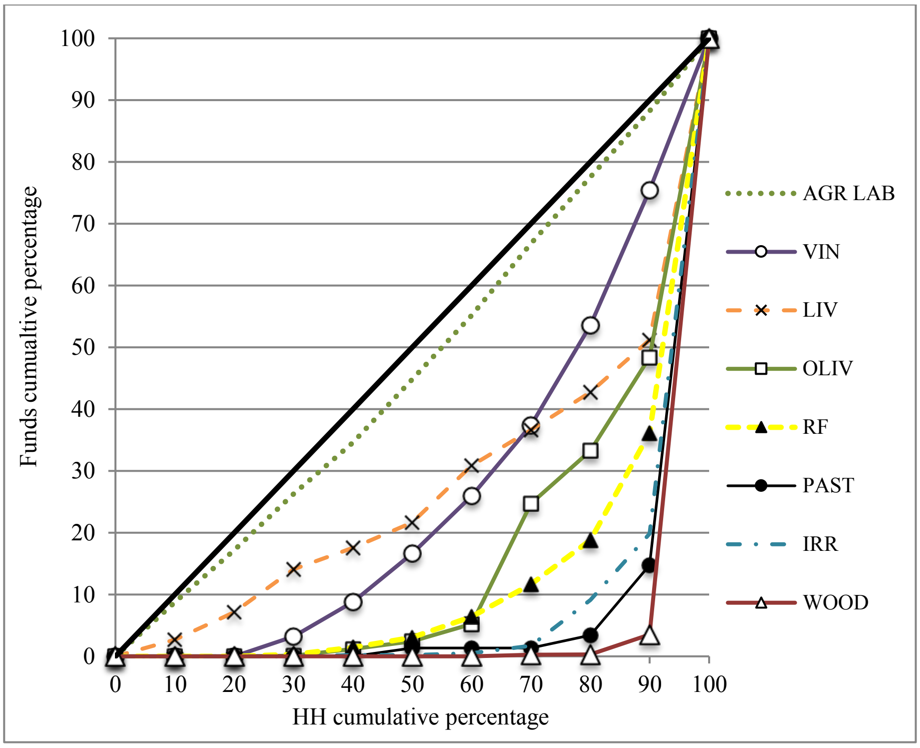
Given the complexity of the methodology presented, in this initial attempt we propose a first application to five representative households of a local case study located in the Barcelona province (Sentmenat municipality, Vallès County, Catalonia, c.1850). Thanks to the availability of historical sources and cadastral maps, and the long lasting historical research made on four municipalities of the Vallès County (Serra 1988; Cussó et al. 2006a and 2006b; Garrabou et al. 2001, 2010, 2012; Olarieta et al. 2008; Tello et al. 2008, 2016; Marull et al. 2016, Galán et al. 2016), our research project has been using them as a test bench to develop and apply a socio-metabolic scanning of farm systems before and after the Green Revolution. Previous research show land use analyses (Olarieta et al. 2008), energy balances (see Chapter 3; Padró et al. 2017; Galán et al. 2016; Tello et al. 2016) and nutrient balances (Tello et al. 2012). In the current work we develop our proposed methodology only for 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 the ones that appear as farm labourers in the Municipal Census of 1857. To those numbers we must add 51 registered agricultural HHs with no access to land or livestock. We must note some aspects about the time point selected in both Chapters 4 and 5. Although we will generally refer to 1850, given that the main historical sources used to account landownership and land uses were closer to this date, other historical records only provide us other type of data for later dates that range from 1850 to 1880. This is especially relevant for cash flows, as most of its sources date from 1870-1880 (see Table 4.J). Despite this, only changes in relative prices would deeply affect our results, specially those between wages and prices of agricultural products. Indeed, the prices and wages used are coherent among them as all of them are refered to the mid-1870. In doing so, we are assuming that landownership distribution and farmland uses had a high inertia, with only small and slow changes from 1850 to 1880. This also means that the results are refered to this whole period. Indeed, they are more aimed at revealing some structural functionings of this epoch, than some short-term historical changes.

Our sample then comprises 244 HHs, which covered 63% of the total area (see Section 4.A.1). To establish the different subgroups in the sample we used the threshold of minimum access to the necessary land for the reproduction defined by Padró et al. (*forthcoming*) for that agroecosystem. By means of a linear programming model this work simulates the dynamics established between the household composition of fund-elements (needs/capabilities) and the biophysical conditionings. In this case study we have established through technical coefficients and consumption standards that the average household c.1850 (5 people; 2 dependent persons) needed 4.36 hectares of total surface (including crops, grasslands and forest) to cover its basic needs and replenish the soil fertility and animal feeding cycles. From this reference farmland area, we have categorised HHs into five groups: (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%). Figure 4.3 describes the cumulative area according to the land uses as the different subgroups are incorporated.

Given that the HH size and composition affected many of the main flows analysed (Domestic and Family Work [DFW], availability of labour, food consumption and clothing expenses), we isolated the effect of the different HH models so as to be able to analyse the effect of inequality in access to farmland. To that end, we defined a representative HH model and selected a HH with those characteristics per each group (see Section 4.A.2). All the chosen HHs (Figure 4.4) were formed by 4 members, two of them active and two dependents, except for HH5 because in this subgroup there was not a HH with those characteristics. In that subgroup, we selected the HH with the most similar size and dependency ratio. The different HHs respectively owned 0, 1.5, 3.2, 7.9 and 34.2 hectares of farmland (Figure 4.4). Vine cultivation prevailed in HH2 and HH3, while the share of rainfed and/or irrigated cereals and woodland increased in larger HH. In a similar way, livestock density increased as the size of the land possessed did: 0.09, 0.09, 0.17, 1.34 and 5.54 Livestock Units of a standard weight of 500 kg (LU500), respectively.

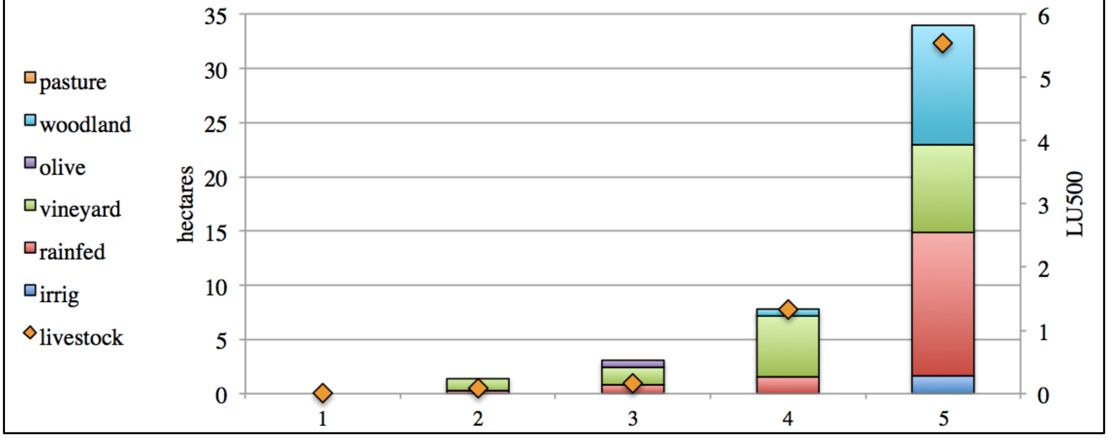
Figure 4.3 Distribution of access to land and livestock[19]



Source: Own elaboration, from the sources mentioned in the text. Legend refers to Irrigated (IRR), Rainfed (RF), Vineyard (VIN), Olive groves (OLIV), Woodland (WOOD), Pasture (PAST).

Figure 4.4 Features of funds of the selected Households

Household Code	HH1	HH2	HH3	HH4	HH5
Household members	4	4	4	4	7
Dependent members	2	2	2	2	3



Source: Own elaboration, from the sources mentioned in the text.

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[19] Figure 4.3 will be analysed in detail in Chapter 5.

4.4 Results

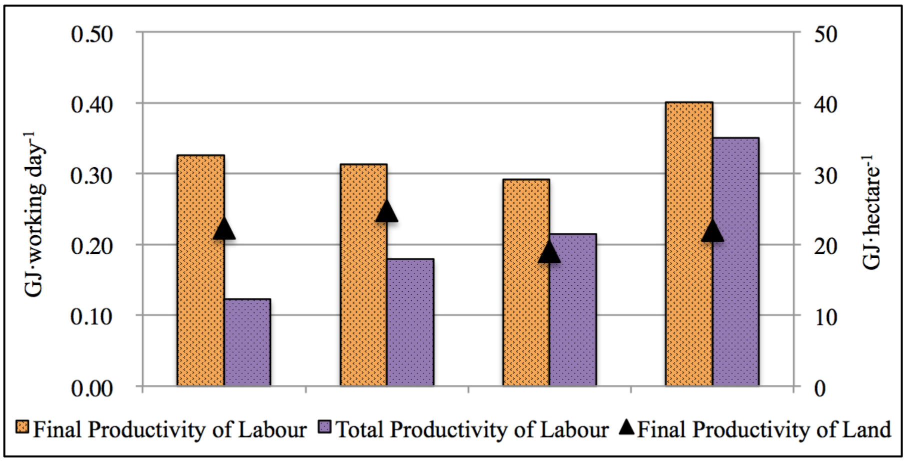
4.4.1 Total Produce and factor productivity (labour and land)

From the results obtained we observe how the Total Produce (TP) of energy increased as the size of the farm did: from 61 GJ for HH2 up to 1,710 GJ for HH5 (Figure 4.6). The percentage representing each of the Total Produce components (Final Produce [FP] and Biomass Reused [BR]) kept quite stable around 60 and 40%, respectively—a result that confirms the relevance of the biomass recirculation to sustain livestock and soil fertility in traditional organic agroecosystems. In relative terms, Final Productivity of Land (FPLan) was one of the indicators with 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 (Figure 4.5). This would be the amount of agricultural produce appropriation per each hectare possessed. To put these data in context, this corresponded to 33 and 45% of an Equivalent Consumption Basket (ECB). Thus, each household with these characteristics would need between 2.3 and 3.03 hectares to meet their fundamental needs (food and fuel) whichever their labour income. Final Productivity of Labour (FPLab) per working day varied between 0.31 and 0.40 GJ_{ECB}, which also showed certain stability among the different farms. Therefore, we find no relevant differences among farms in terms of land or labour productivity. We recall that available sources do not allow to introduce the effect of more extensive agricultural practices (and labour time-saving) in larger farms. So far we only take into consideration the effects of changes in the composition of land uses, as well as the effects of landgrabbing in best quality or irrigated lands into consideration.

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

Domestic and Care Work, including cleaning, kitchen and care tasks, just to name a few, amounted to 118 annual working days per HH. To these works we added Family Work, perfomed also by women, which included fuel and water gathering, and small livestock management, accounting for 66 working days (see methodological details in Section 4.A.5). Altogether, these works represented 66% of an annual working time. Figure 4.5 provides a first exploration of Total Productivity of Labour (TPLab). First, when considering DFW, the average required working days per ECB increased. Now, to get one ECB between 164 and 468 working days were needed (with an average productivity of 0.22 GJECB per working day). Second, we notice a rise in TPLab as the farm size increased. The reason for this growing trend is that the DFW of the smaller farms (HH1 and HH2) was not just useful for the reproduction of the labour force required to cultivate their own land, but also to sustain the part of family labour that would eventually be sold in the labour market to be applied in larger farms. That increase in the TPLab regarding farm size reveals that agricultural labour hired in larger farms had embodied 'invisible working days' assumed by women in the HHs of hired farmhands.

Figure 4.5 Final Labour and Land Productivity in terms of FP_{ECB}



Source: Own elaboration, from the sources mentioned in the text.

An average of 46 annual working days of DFW per person is estimated, meaning that each hired working day had 0.16 DFW embodied working days if we consider the hired worker as an isolated element. We can also calculate the full 'life cycle' of labour force, considering that workers reproduction depended on the existence and reproduction of those women performing DFW, who also took care of the sustenance of dependent people (which assured intergenerational reproduction). Then each hired working day would have had a total of 0.66 DFW working days incorporated. Thus, results show how, when hired labour was contracted, TPLab of landowners (e.g. HH5) would be increased by the appropiation of external DFW. These results illustrate that gender inequality founded on sexual division of labour was not just a remote source of other types of inequalities and exploitation among human beings. Daily functioning and social reproduction of that class structure continued to be based on the invisible and gratuitous labour of women.[20]

4.4.2 Self-sufficiency, and commodities and labour markets

The main interrelations between consumption, time and cash balances of the analysed HHs can be observed in Figure 4.6. The data reveals the importance wine had in the Final Produce (FP) of smaller farms. It was a cash crop without the capacity to directly cover food needs, which explains the simultaneous existence of a deficit as well as a surplus of food in these HHs. As the size of the farm increased, the crops diversified and HHs enjoyed a greater level of food self-sufficiency (18, 20, 57, 66 and 90% respectively). The prominence of vineyards in smaller farms also implied a certain capacity of self-providing fuels in smaller HHs (11 and 49% for HH2 and HH3), although the

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[20] Figure 5.D shows the same trend for TPLab including all the HHs of the sample.

low quality of vineyards by-products for combustion meant that access to forestry resources was essential to reach self-sufficiency regarding fuel.[21] That happened with HH4 and HH5, whose forestry resources allowed them to reach self-sufficiency levels of 77 and 100%, respectively.

As of the capacity to closing soil nutrient cycles, all farms were able to replenish the nutrients extracted. Nutrients extraction per hectare kept stable (around 20-3-11 N-P-K kg per hectare), while total requirements obviously increased with farm size (from 27, 4 and 15 N-P-K kg for HH1 to 490, 79, and 278 for HH5). Humanure was one of the key elements to explain fertilizing capabilities for the smallest farms: 29% (HH2) and 13% (HH3) of N applications came from this source. This also meant that food purchases were an indirect way of importing nutrients in those HH which had low self-sufficiency ratios. With higher total N-P-K extractions than HH2, HH3 needed to use labour intensive fertilizing practices, like burying fresh biomass, which represented 29% of total N application. Higher access to livestock for HH4 and HH5 meant not only access to draught power, but also to manure. Animal manure supposed 95 and 97% of total N applications for HH4 and HH5, respectively. This had also consequences in terms of animal feeding. While HH2 could close nutrient cycles through animal manure (71% of N application), this forced this domestic unit to import animal feeding (60% of the animal intake). HH3 had enough internal feed produce to keep their livestock density. The two largest farms also required feed imports, although higher access to pasture and woodland for HH5 meant a lower presure of feeding imports.

Our proposed methodology allows to estimate how many working days should be offered or hired in the market so as to equilibrate the three balances (i.e. when a surplus of labour capacity was combined with cash needs to close the representative flows in some HHs, and in other HHs with a lack of internal labour force combined with cash capacities enough to hire labour in the 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 the 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 money needs (85 pesetas for housing rent and 85 for footwear and clothing). This was the representation of a ‘proletarian’ HH. HH2 needed to sell only 171 working days, thanks to the income obtained through the selling 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’

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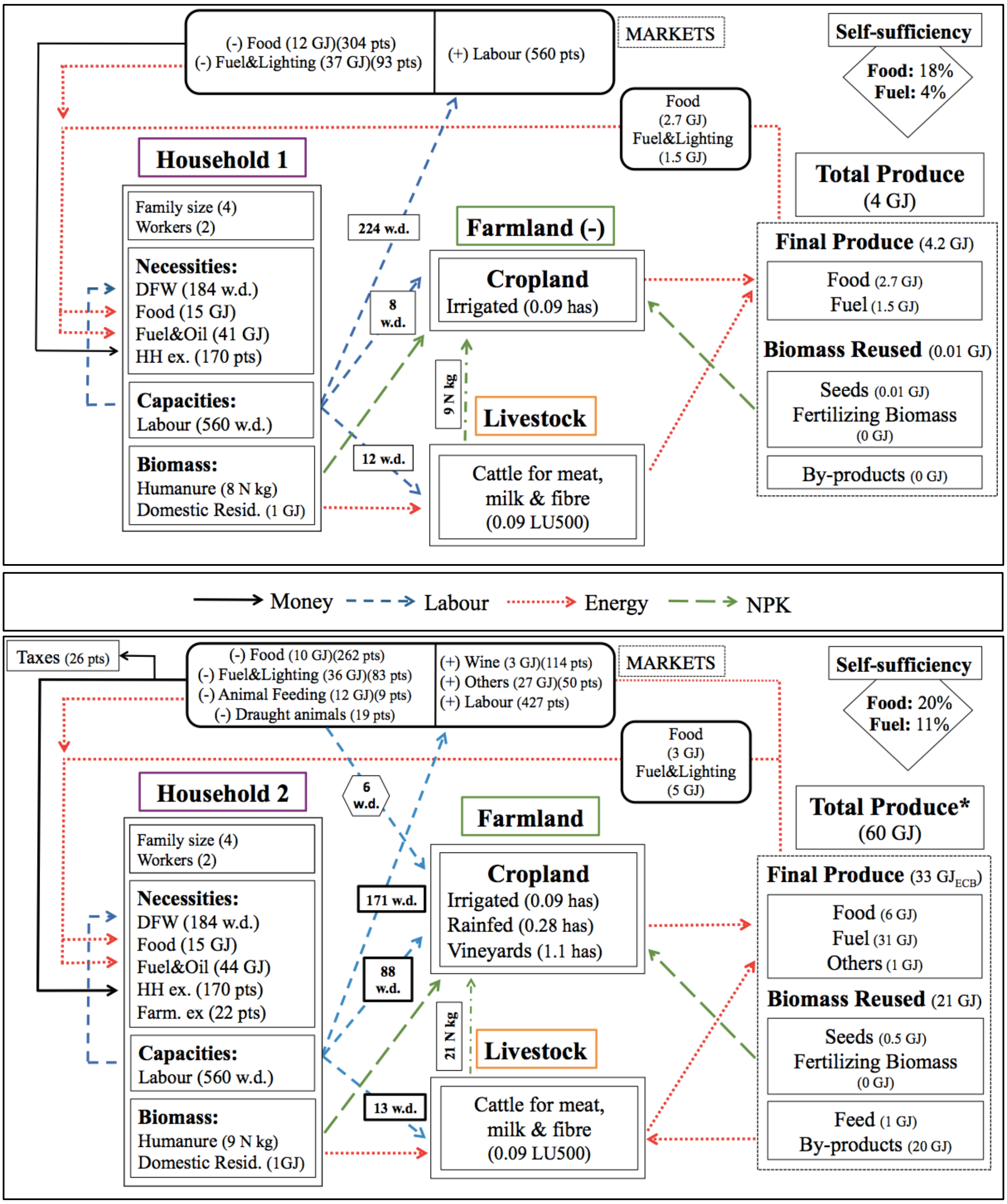
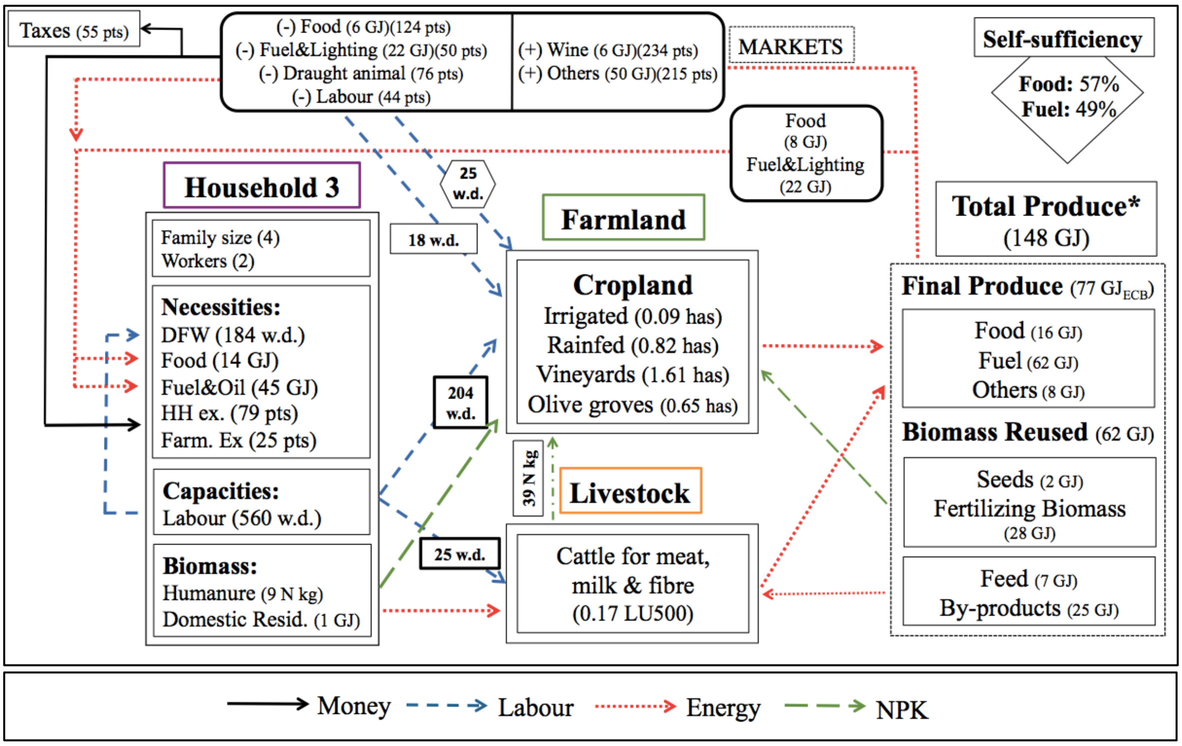
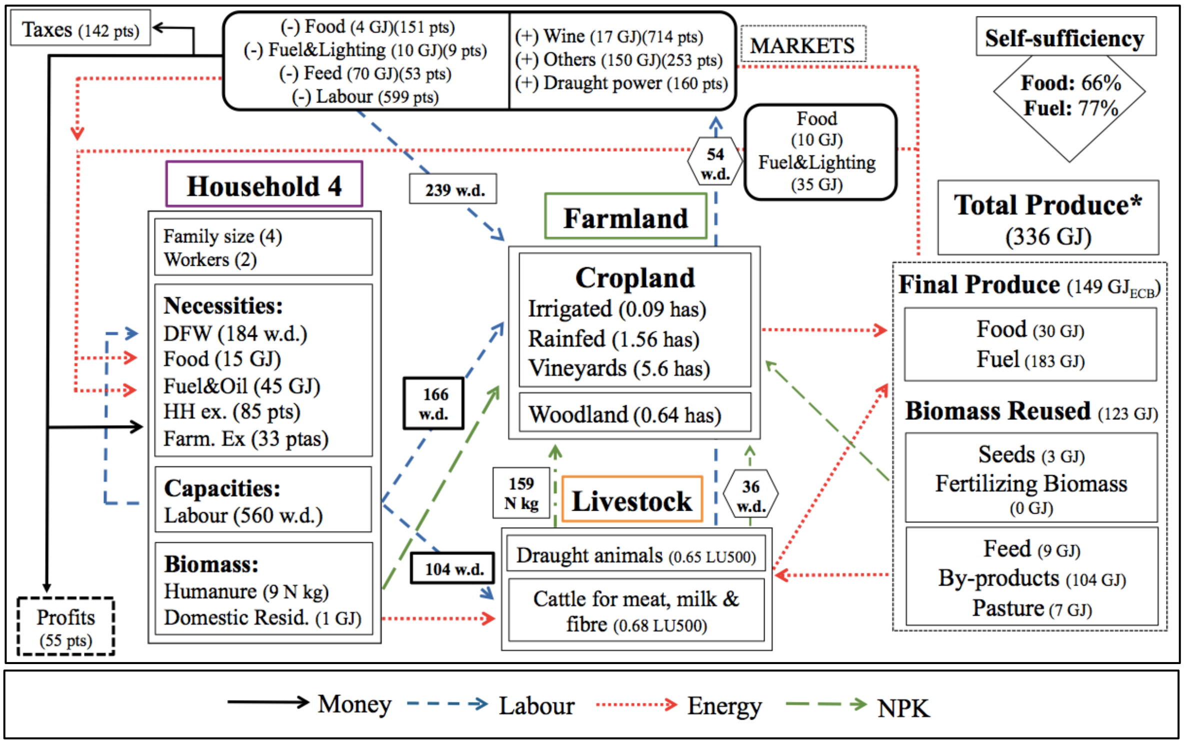
[21] This is a controversial point. Although some authors consider that vineyard and olive pruning were not fully substitutes of other fuel sources like firewood (Colomé *personal communication*) some recent research show the importance of these by-products as fuel suppliers in Southern Italy (Colomba 2017) or Spain (Iriarte and Infante-Amate *in press*). Indeed, Humphries (1990:33) stated for England that although ‘the main fuels were peat and wood, […] those who could do no better burned sticks collected from hedgerows and copses, supplemented with large quantities of cow and horse dung. On islands and along the coast seaweed was burned; inland, depending on the local vegetation, they would cut heather, broom, furze, and gorse. More or less anything that women and children could gather was burned’. For now, we decide to limit vineyard by-products consumption to 10 per cent of total fuel consumption.

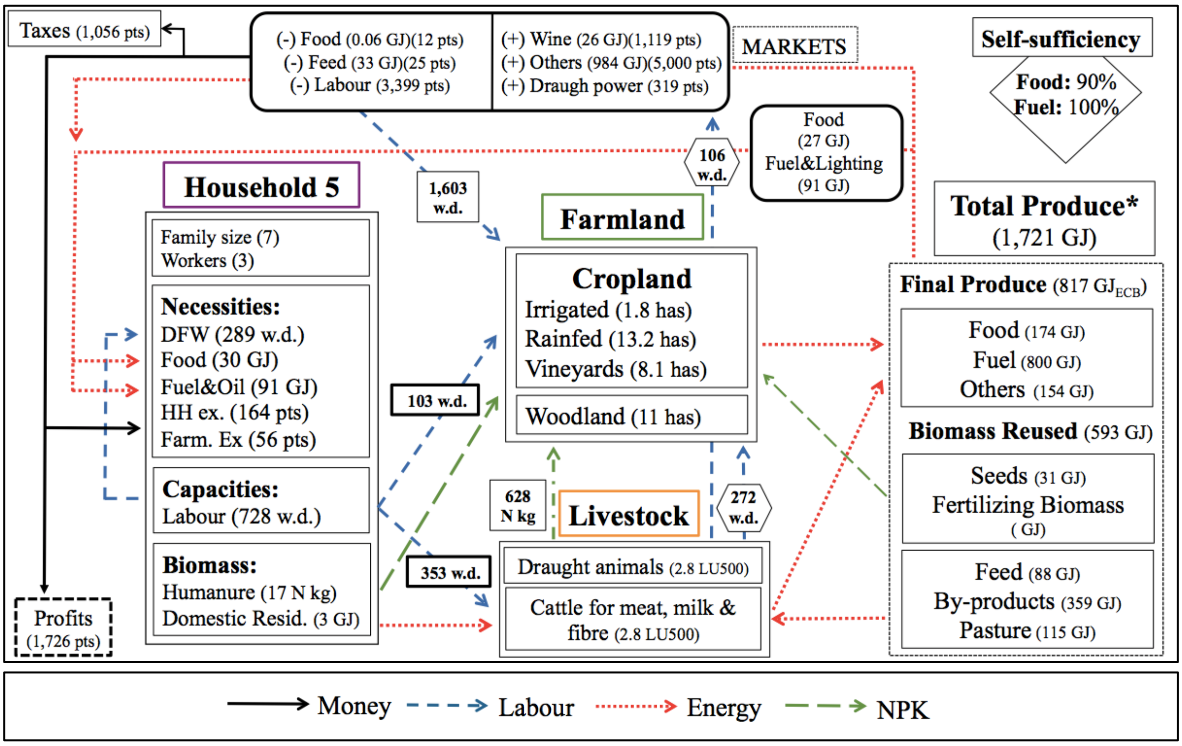
HH. In the case of farms with access to land, expenses increased (taxes, tool expenses and the ones derived from hiring draught power). If we extrapolate the need to sell labour force to the two social groups of the municipality with similar characteristics regarding access to land (which represented 22 and 36%, respectively, of the HHs sampled), we obtain a total annual supply of male labouring capacity 22,368 working days able to be applied to farmland. HH3 represents a HH typology with a certain degree of self-sufficiency. Its needs for external labour were very low (18), altough it needed to go to the markets to exchange wine and fuel surpluses for food products, fuels and draught power.

Figure 4.6 Multidimensional balance of the HHs according to their access to funds




Taxes (55 pts)
(-) Food (6 GJ)(124 pts)
(-) Fuel&Lighting (22 GJ)(50 pts)
(-) Draught animal (76 pts)
(-) Labour (44 pts)
(+) Wine (6 GJ)(234 pts)
(+) Others (50 GJ)(215 pts)
MARKETS
Self-sufficiency
Food: 57%
Fuel: 49%
Food (8 GJ)
Fuel&Lighting (22 GJ)
25 w.d.
Household 3
Farmland
Total Produce* (148 GJ)
18 w.d.
Family size (4)
Workers (2)
Cropland
Irrigated (0.09 has)
Rainfed (0.82 has)
Vineyards (1.61 has)
Olive groves (0.65 has)
Final Produce (77 GJ$_{ECB}$)
Food (16 GJ)
Fuel (62 GJ)
Others (8 GJ)
Necessities:
DFW (184 w.d.)
Food (14 GJ)
Fuel&Oil (45 GJ)
HH ex. (79 pts)
Farm. Ex (25 pts)
204 w.d.
Biomass Reused (62 GJ)
39 N kg
Seeds (2 GJ)
Fertilizing Biomass (28 GJ)
Capacities:
Labour (560 w.d.)
Livestock
25 w.d.
Cattle for meat, milk & fibre (0.17 LU500)
Feed (7 GJ)
By-products (25 GJ)
Biomass:
Humanure (9 N kg)
Domestic Resid. (1 GJ)
Money
Labour
Energy
NPK


Taxes (142 pts)
(-) Food (4 GJ)(151 pts)
(-) Fuel&Lighting (10 GJ)(9 pts)
(-) Feed (70 GJ)(53 pts)
(-) Labour (599 pts)
(+) Wine (17 GJ)(714 pts)
(+) Others (150 GJ)(253 pts)
(+) Draught power (160 pts)
MARKETS
Self-sufficiency
Food: 66%
Fuel: 77%
54 w.d.
Food (10 GJ)
Fuel&Lighting (35 GJ)
Household 4
239 w.d.
Farmland
Total Produce* (336 GJ)
Family size (4)
Workers (2)
Cropland
Irrigated (0.09 has)
Rainfed (1.56 has)
Vineyards (5.6 has)
Woodland (0.64 has)
Final Produce (149 GJ$_{ECB}$)
Food (30 GJ)
Fuel (183 GJ)
Necessities:
DFW (184 w.d.)
Food (15 GJ)
Fuel&Oil (45 GJ)
HH ex. (85 pts)
Farm. Ex (33 ptas)
166 w.d.
Biomass Reused (123 GJ)
Seeds (3 GJ)
Fertilizing Biomass (0 GJ)
Capacities:
Labour (560 w.d.)
159 N kg
Livestock
36 w.d.
104 w.d.
Draught animals (0.65 LU500)
Cattle for meat, milk & fibre (0.68 LU500)
Feed (9 GJ)
By-products (104 GJ)
Pasture (7 GJ)
Biomass:
Humanure (9 N kg)
Domestic Resid. (1 GJ)
Profits (55 pts)
Money
Labour
Energy
NPK



Source: Own elaboration. Note: DFW refers to Domestic & Family Work. HH ex. refers to Household expenses (including footwear, clothing and housing rents expenses). Farm ex. refers to expenses derived from agricultural activity (mainly tools). Land taxes are presented in a separate section. We cannot distinguish, at the same time, between hired labour-family work and farming-livestock labour, so we represent them as if all livestock labour was family work, and all hired labour was cropland labour. Source: Our own, from the sources mentioned in the text. * Final Produce is expressed both in ECB terms (GJ_{ECB}) in the aggregated data, and in GJ within its breakdown. Therefore, Total Produce (GJ) do not coincide with the sum of FP_{ECB} (GJ_{ECB}) and Biomass Reused (GJ). Note that we assumed the access of a small piece of land for gardening and some small livestock for all HH, including HH1. This was estimated to allow for vegetables self-sufficiency (see Section 4.A.1).

HH4 and HH5 had a big labour force deficit, 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. These surpluses entailed the equivalent to 11 and 347% of a basic consumption basket (ECB).

On the basis of these examples, we can establish dependency rates beween the farms that needed to hire labour in the market and those who sold it. For instance, the dependency ratio between HH5 and HH1 was 1:7, and between HH4 and HH1 it was 1:1. Thus, every HH with the same characteristics as HH5 needed 7 HHs similar to the ones of HH1 so as to be able to cover their external labour needs. If we extrapolate these external labour requirements per farm to the total amount of farms belonging to the same social group, we obtain an annual demand of 58,367 working days, a much higher number to the one esteemed offered by groups HH1 and HH2 (22,368 working days). The gap between these numbers can be explained in many ways, and could be solved by means other than recruiting workers from other municipalities. First of all, we are just considering basic needs and excluding social expenses such as weddings or funerals, or other income needs to deal with indebtedness and the corresponding debt payments. Therefore, it is likely that we are underestimating the cash expenses required by small farms and thus their need to sell working days. Secondly, our calculations do not allow for the time being to distinguish between female and male agricultural hired working days. Given the fact that male wage was twice the one of female one, for now we have assumed that male hiring was prioritised. With the current results, not even HH1 should necessarily hire its female labour force, because if male surplus labour was hired in its entirely it would have the capacity to cover the estimated cash deficit. If a part of the working days were female, hired labour should be double to achieve the same income level. These issues should be improved in future research, where the aggregated data of every HH of the municipality will be considered. Lastly, a lot of the larger farms had permanent servants hired on an annual basis living on the employer farmstead, a scenario we would not be considering in this first estimation.**

4.4.3 Markets as converters of energy labour surpluses

> ‘But wage-earning opportunities were sometimes sacrificed, much to the farmer's chagrin: ‘If you give them work, they will tell you that they must go to look up their sheep, cut furzes, get their cow out of the pound, and perhaps say that they must take their horse to be shod that he might carry them to a horse race or a cricket match.’ *Perhaps the laborers preferred to spend time ‘sauntering after their cattle,’ because the return to such activities exceeded the wage*’
>
> Humphries (1990:28-29)
> (emphasis added)

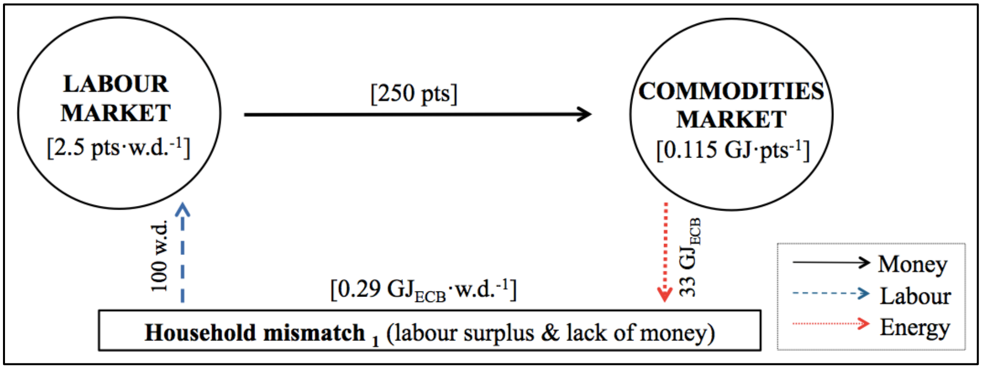
Our results confirm that an important part of production had to be redistributed through labour and commodity markets, where labour for products had to be exchanged (for HH1 and HH2), or in reverse (HH4 and HH5), in order to be able to close their socio-metabolic balances. In the same vein, we want to analyse the indirect outcome of product redistribution through the estimation of wage labour energy productivity, in order to then compare the result with the labour productivity in property regime. To estimate energy productivity of wage labour we have to first define which the products and inputs were, and the way we measure them. The research done by Bayliss-Smith on the South England village of Milton Libourne, in Wiltshire County, at the begining of the 1820s compared the edible produce generated per worker (by dividing the total edible produce at the farm by the number of labourers) with the endosomatic consumption of that worker. The result was a 5:1

** Some of the arguments posed in this paragraph are partially refused within the Chapter 5. Despite this, we decided to maintain it as part of this paper.

ratio (Bayliss-Smith 1982:54). In our case study, the edible part represented between 17 and 22% of the Final Produce, so that productivity in terms of edible produce per agricultural working day would be reduced down to 0.07-0.08 GJ. Compared to the endosomatic requirements of a grown male (0.013 GJ·day^{-1}), we obtain a 6:1 ratio, close to the one of Bayliss-Smith.

When we enlarge the definition of produce and energy requirements, results vary. Our method includes fuel consumption and means accounting for a consumption basket composed of food and fuel. Instead of comparing agricultural labour productive capacity with endosomatic consumption, we compare it to the wage purchase capacity in terms of an equivalent consumption basket (ECB). One of the key elements in this process is the transformation of cash flows into energy flows, and the other way round. As has been explained (see Section 4.3.1), we use the ECB conversion factor, through an interchange coefficient of 0.115 GJ_{ECB}·peseta^{-1}. Thus, as shown in Figure 4.7, the acquisition capacity for every wage earned during a working day was equivalent to 0.29 GJ_{ECB}. If we compare that number with the energy productivity of labour in property regime, whose average value was 0.33 GJ_{ECB} per working day, we conclude that market-hired working days had an energy retribution of 88% of the labour retribution in property regime. The difference between both (0.04 GJ_{ECB} per working day) would be a retribution for land ownership. In the case of female wage labour, surplus value would be much bigger. Given the lesser compensation (half the male wage), productivity would be reduced to 0.17 GJ_{ECB} per working day, meaning 52% of the labour retribution in property regime and a corresponding extraction ratio of 48%.

Figure 4.7 Effect on Hired Labour Productivity [GJ_{ECB}·w.d.$^{-1}$] (Sentmenat, 1850)



Source: Own elaboration, from the sources mentioned in the text.

Our results show that the final energy productivity of agricultural labour in each of the analysed HHs greatly depended on the amount of working days sold at the market, the number of autonomous working days, and the number of hired working days. The more resources farms of their own, the more they approached to autonomous labour energy productivity. Beyond a certain threshold, they had the capacity to increase their own labour productivity thanks to the appropriation of the energy surplus of the hired labour contracted. To illustrate that, HH5 had 439 family working days and 1,603 days of hired labour. Whereas Final Produce was 817 GJ_{ECB}, and average productivity was 0.40 GJ_{ECB} per working day, hired working days were generating 641 GJ_{ECB}, even if the production share assigned to its retribution meant 465 GJ_{ECB} (0.29 GJ_{ECB} per working day). Therefore, the surplus value per working day would have been 0.11 GJ_{ECB}, and the absolute appropriation in this case was 176 GJ_{ECB} (equivalent to 3.1 ECB). Finally, family work productivity raised up to 0.8 GJ_{ECB} per working day. To that number we should add, in terms of time, the DFW working days incorporated in every hired working day. In this case (HH5), the amount of DFW incorporated in hired working days would be between 257 and 1,058, depending on the criteria used.

4.5 Concluding remarks

This article is a first exploration of the socio-metabolic links between biophysical limits and the exploitative relations in traditional organic farming societies. We depart from the existence of a biophysical tension between appropriation and consumption of energy and material flows, and the labour required to do so. This socio-metabolic tension set in motion a contingent tendency towards the establishment of exploitative relations instituted throughout history. That would affect gender relations as well as the ones set among social classes. Although those relations started off from inequality situations on access to natural resources, and reproduced or broadened in space and time, they should be defined as exploitative relations of some human beings by others. Only in this way we can visualise the interdependence generated among classes and social groups, given that the existence of privileged groups could not be possible without the domination of others. The most basic legitimation in the maintenance of this kind of exploitative relations was rooted, from the onset, in the sexual division of labour. To this an unequal distribution of the ownership of the agroecosystem fund elements (land and livestock) was added, structured and legitimised. Land and livestock grabbing by a few, and the dispossession of the rest, led to the creation of labour markets where a redistribution of production between workers and owners operated in a way that endured the appropriation of a surplus value by the latter. These different types of exploitation articulated one another, and established a parasitic sort of relations of some social groups by others which were founded, in turn, in situations of competitive exclusion (González de Molina and Toledo 2014).

We have ascertained how in the village of Sentmenat, in the mid-19th century, the unequal access to the ownership of two basic fund-elements established a clear distinction between autonomous or wage labour, and determined that wage labour was 88% compared to autonomous one. That difference became a rent income for the landowner, swelling his capacity to accumulate surpluses. Thus, while HH1, with no access to farmland, had to deliver 224 (male) working days per year to be able to get the necessary income to cover its needs, HH2 saw those numbers reduced down to 171 working days, thanks to the 1.38 vineyard hectares owned. HH3, with 3.08 hectares of owned land, had almost no need of external hiring to cover its basic needs. Those results should not just be read in quantitative (and static) terms, since the need to be hired in foreign farms endured a higher level of dependency and vulnerability in front of fluctuations and shocks. Wage labour contingency, as well as hiring condition variability, offered greater advantages to the HHs with more access to productive resources. Furthermore, landgrabbing did not just meant a process where a surplus value (here estimated in energy terms) was appropriated. The owners of key fund-elements centralised the capacity to organise and manage the territory, which also implied the capacity to intensify or extensify agricultural processes thus making the dispossessed even more dependent on external labour hired in the market. This had important implications for the capacity of these territoris to admit population.

The inclusion of Domestic and Family Work (DFW) in the analysis allows to visualise its importance not just in social organization of labour, but also for the maintenance of other hidden exploitative relations the were behind the hired agricultural labour. We have estimated that DFW represented about half the entirety of socially necessary human worktime, 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 have not yet enough data to analyse the effects of sexual division of labour on the quality of life of those women, and taking into account that our analysis has still many limitations in estimating the weight of female agricultural labour, the explicit omission of women as subjects excluded from the ownership of the means of production becomes apparent, rescuing them from the oblivion (at least in historical sources) of their participation in (re)productive processes.

This study is a first step towards a necessary debate on the role of the exploitative relations established within traditional organic farming societies, and along the socio-metabolic transition towards agrarian capitalism and industrial agriculture. The tension those exploitative relations implied, not only in social terms but also in economic and socio-ecologic ones (given the weight of wage costs in the big farms accounts), created a conflicting scenario that could lead to the adoption of mechanization of agricultural labour. The Captain Swing uprising which took place in the same region of England where Willam Cobbet first calculated, in biophysical terms, the surplus value extracted by hired labour (Bayliss-Smith 1982:37-55), is a classic example of this (Hobsbawm and Rude 1968; Griffin 2012). Indeed, the extraction of that surplus allowed the existence of social groups with the capacity to accumulate and invest capital able to replace human labour and animal work with machinery. Resorting to industrial fertilisers, another essential element of the Green Revolution, was a focal point of the socio-metabolic tensions endured by small farmers. Due to their limited access to livestock and manure, they had to perform large quantities of labour to keep soil fertility by using other types of vegetal fertilisers (Olarieta et al. 2008; Tello et al. 2012; Tello and Galán 2013). From all this we can draw the following general conclusion, which turns into a hypothesis for future research: although inequality has been considered an element that obstructed ‘modernization’ of agriculture, a deeper socio-metabolic analysis suggests that substituting hired wage labour with mechanised work and agrochemicals could have been a consequence of the strong tensions that inequality in access to land and other resources engendered in rural societies during transitional processes towards agrarian capitalism (González de Molina and Toledo 2014).

APPENDIX CHAPTER 4

In this Appendix we present the most relevant data and the main decisions made for the preparation of the socio-metabolic balances presented in this work. Much of the basic information used for the elaboration of energy and nutrient balances in our case study is detailed in Chapter 3 and Padró et al. (2017). In particular, the calculation of Biomass Reused (BR) flows, both for livestock feeding and soil nutrient replenishment, is detailed in Chapter 3. Here we will focus on the decisions and data that have not been thoroughly presented previously.

In the first place, we describe the main historical sources used, as well as their limitations (Section 4.A.1). Second, we defend the decisions of which type of household (size and dependency ratio) we chose to analyse in the article (Section 4.A.2). Third, we detail crop rotations applied to land uses, which determine the composition of agricultural production (Section 4.A.3). Fourth, we describe the assumptions associated with households' reproduction and food and fuel consumption (Section 4.A.4). Fifth, we show the applied labour ratios for Domestic and Family Work (DFW), and agricultural and livestock labour (Section 4.A.5). We also include the draught power requirements per crop. Finally, we include a summary of wages and the prices of the products used (Section 4.A.5).

4.A.1 Historical sources[22]

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 census, which also indicates the profession of household heads as well as of other members. In our case study, there are available municipal population censuses for 1855 and 1857. We used the latter since it included information on labourers and permanent agricultural servants who were part of the largest farms. In spite of this, the first one has been consulted especially for the identification of the families that appear in some previous sources (i.e. the Cadastre of 1841 or the Mortgage Registry of Sentmenat), since it indicates the name of the father and mother of each member of the family. 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 cadastral sources of the municipality (Cadastre of 1841, Cadastral Map of 1853 [Moreno Ramírez 1856]) and

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[22] For the time being, this work cannot give the Archival references for the historical sources. Since several months ago, and due to political and technical problems, the Archive of Sentmenat has no staff working. Thus, it has been impossible to obtain the necessary references. This question should be solved before the publication of both Chapters 4 and 5.

land tax registers (Amillaramiento [1850], which were municipal registers of all the plots, their land use and ownership). For the farmland area 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 identify 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.[23] The three historical sources (Amillaramiento [1850], Cadastral map [1853] and Cadastre [1841]) register the first and last name of the owner, and some times, the name of the farm. We cross-checked these sources. Beyond the historical sources, we assumed that every HH had access to the necessary land for gardening enough vegetables to meet their basic requirements, and to some small livestock (2 chickens, 2 hens and 1 rabbit for every 5 people). Both criteria were sustained for by local sources (*Sentmenat Medical Memorial).*[24]

Although our sample fits fairly well with the municipal population census (1857), constraints on data availability forces us to omit a significant portion of the total area of the municipality. The Amillaramiento collects 454 land properties, a larger number of households than our sample. Our sample cannot include some foreign landowners (100), who lived in other adjoining municipalities (Caldes de Montbui, Polinyà or Castellar of the Vallès), being this information recorded within the Amillaramiento. These foreigners owned mainly small parcels, a total of 124 hectares of cultivation, of which 100 hectares were vineyards. Given that we do not have information on their family composition, nor can we say that the property consists only of the estates registered in Sentmenat, these households are inevitably left out of the analysis. This also implies a possible bias in our analysis, since probably some of the farms included in our sample owned land in other municipalities. On the other hand, as already mentioned, non-agricultural HHs also appear in land tax registers, although they represented only 1% of the total registered area. The remaining holdings that appear in the Amillaramiento could not be identified.

Rights on the land: owners, tenants and vine-growing sharecroppers (*rabassaires*)

The interpretation of available historical sources present some problems to distinguish between landowners who work their own land, land-tenants and those who had a long-term sharecropping contract for planting the vines they grew (called *rabassaires* in Catalan). Amillaramientos, one of the sources most used by agricultural historiography, has been under debate due to the difficulties of clarifying which was the relation of registered person with the land subject

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[23] The 1850 Amillaramiento recorded 2 mules, 22 head of cattle, 210 swines, 75 sheeps and 20 goats (55.8 LU500). The Cadastre of 1842 counted 138 mules, 36 head of cattle, 286 swines, 557 sheeps and 135 goats (203.3 LU500). It is apparent that these differences cannot respond to a decrease in the livestock density in a 9 years-time period.

[24] For instance, the Sentmenat Medical Memorial stated: 'According to the calendar, Sunday is a market day in the town, but it is reduced to one or two neighbors of Caldas and Riells who sell fresh tomatoes, the planting of the vegetables, and a few others' Pujadas Serratosa (1889:104).

to taxation. The 1850 Amillaramiento of Sentmenat, unlike the one from 1860, explicitly established a distinction between plots whose taxpayer was (i) ‘owner and tiller’, (ii) ‘owner who rents’, (iii) ‘owner with a tenant’, or (iv) ‘another owner’. Actually, this has been the reason for shifting from the analysis of 1860 to 1850, as can be seen comparing Chapter 3 with Chapters 4 and 5. In spite of this, both the number of cases that were not registered as ‘owner and cultivator’ (33 out of 454 cases) and the area they represent (4.4% of the total area and 4.7% of the cultivated area) make us doubt that a rigorous monitoring of the land tenure regime was carried out, especially with regard to the presence of *rabassaires*. For this purpose, we have resorted to the Mortgage Registry of Sentmenat, which registered 225 long-term tenure settlements between 1790 and 1844, together representing about 293 hectares. We have identified 143 of them (185 hectares). From there, we confirmed that in the 1850 Amillaramiento, *rabassas* were registered analogously to the farms in full ownership. Although the selected HHs analysed in this work did not include any plot as *rabassa*, it is necessary to mention that our database does include them.

4.A.2 Household selection

Our analysis is based on a selection of one HH for each of the five 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 land access as a constant, significant variations occur along the family life cycle. In particular, (i) available labour capacity, (ii) required domestic and family work (iii) food expenses (iv) family expenses (clothing and footwear), all affect the need to sell or hire labour in the market. For that reason, we see that among farms with similar land access, both HH size and dependency ratio affect time, material and cash flows.[25] Therefore, in order to analyze the effect of variations on the size and land uses of farms, we need to isolate the effect of HH size and dependency ratio.

To choose the HH model that will be the basis to compare, we firstly analyzed the general characteristics of HHs in the sample. Although the average sample size was 5 people per HH and 2 dependent (2:5), which means a dependency ratio of 40%, the highest frequency was 3 and 4 members, and dependency ratio between 0-10 % and 50-60% (Figure 4.A). In fact, those variations could mean 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). The 3-member HHs had mostly 0 dependent persons (60% of the cases), which corresponds to a couple with an adult child. The rest were composed of a younger couple with a dependent child (i.e. a family that could be still growing or not). Among the 4-member HHs, those with two dependents

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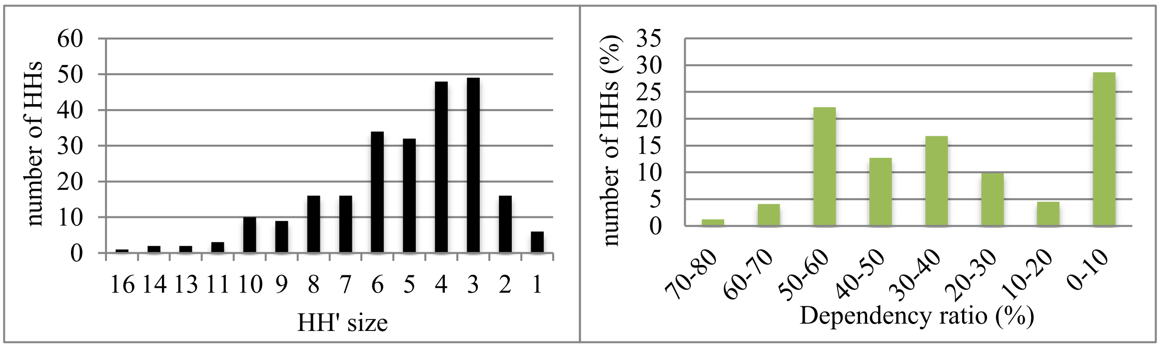
[25] The dependency ratio relates the number of children (0-14 years old) to the working-age population. We present it as percentage. $Dependency\ ratio = \frac{0\text{−}14 \text{ years old population}}{\text{total population}} * 100$ We indicate it as ‘(Dependents:Total)’, i.e. ‘(5:2)’.

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). In the 5-member HHs we found the same representation of families composed of two generations (3 adult children [5:0], or three dependent children [5:3]), or three generations with both living grandparents and a dependent child (5:1) or with a live grandfather and a dependent child (5:2).

Figure 4.A Distribution of the size (left) and dependency ratio (right) of the Households (HHs) (Sentmenat, 1850)



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

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). All selected HHs model respond to the one defined before, except for HH5. In this section [(v); more than 8.72 ha] no HH shows up in with those characteristics. Thus, the most similar one has been selected (7:3).

4.A.3 Crop rotation

Crop rotation data was mainly obtained from the *Estudio Agrícola del Vallés* (EAV) (Garrabou and Planas [1878]1998). The rotation for irrigated cropland (wheat-maize-hemp-bean) is mentioned both in the EAV and in IACSI (1879). These rotations were made in periods of two years, to two crops per year. We found the same rotation in irrigation in the cadastral survey of Castellar del Vallès (1850), so we assume that it remained stable during the second half of the 19th century.

For the rainfed rotations, we basically base upon those that appear in the EAV, which established a sequence of wheat and beans (in 1st and 2nd soil quality), and rye and wheat mixture (*mescladís*) and beans and vetches (3rd class). We considered it necessary to partially modify rainfed rotation to include two relevant crops mentioned in the same historical source. Firstly, fodder, described as a mixture of wheat, lupins, vetches and barley or oats. Secondly, EAV does not include rainfed potatoes, apart from the ones appearing in the crops associated with olive groves (described below). However, this historical source clearly mentioned that rainfed rotation referred only to the most frequent one (cereal-legume). Given the importance of this crop, which was reflected not only in the diet of the population, but also other historical sources (*Reclamación al Catastro de Sentmenat* [1879]), we decided to include it. Therefore, our proposal for rainfed rotation for 1st and 2nd class includes both cereal cultivation and legumes and potatoes.

The rotation would be: wheat-beans-wheat-potatoes (1st class), wheat-fodder-wheat-potatoes (2nd class), and *mescladís*-vetches (3rd class). The information on olive groves where the trees were kept associated with other annual crops cultivated in between (wheat and potatoes [1st land class], maize and *mescladís* [2nd], and barley and lupins [3rd]) has been taken from the EAV (Garrabou and Planas 1878:257).

4.A.4 Household reproduction: food and fuel consumption

Food consumption

Human diets have been reconstructed from the consultation and comparison of several available historical sources at local and national levels (Table 4.B). 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 4.C). 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 4.B References used to estimate the food basket

Source	Localization (year)	Male-adult consumption (gr·cap-1·day-1)								
		Bread	Potatoes	Wine (ml)	Olive oil	Legumes	Vegetables	Fresh fruits	Meat	Fish
Cussó and Garrabou (2012)	Terrasa, Catalonia (1905)	748	460	132		67			95	
Giral (1914)	Spain (1905)		136	283	0.026	47	25	103	70	
Simpson (1989)	Spain (1900)	380	288	224	0.029	26	87	137	35	
Colomé (1996)	Vilafranca del Penedès, Catalonia (1887)				0.01	168			41	7
	Vilanova i la Geltrú, Catalonia (1885)			76					0.027	
	Barcelona (province) (1873)	700								
González de Molina & Guzmán (2007)	Santa Fe, Andalusia (1856)	800	80	6	0.02	80	877	20		
Cerdà (1867)	Barcelona (1867)	800	350			100				
Nicolau and Pujol (2005)	Olot, Catalonia (1885)		56						229	
Cascón (1931)	Spain (1931)	1000								
Bennassar and Goy (1975)	France, Italy, Portugal (19th c.)	700								
Ballesteros (1997)	Cuenca, Extremadura (1849)	964	250		0.02					
Vilar y Ferran (1914)	Viella, Catalonia (begining 20th)	1000								
WHO	contemporary						100-450			

Source: Own elaboration.

Table 4.C Estimation of a daily food basket for an adult-male (18-30) with intense physical activity

Food (per person and day)	Weigth (kg. f.m.)	Metabolizable energy (kcal/kg)	Metabolizable energy (kcal)	Water Content (%)	Weigth (kg. d.m.)	Gross Calorific Values (MJ/kg)	Gross Calorific Values (MJ)	Gross Calorific Values (MJ·cap·year)
Bread	0.700	2,630	1,841	30	0.489	17.05	8.3	3,042
Olive oil	0.018	8,990	165	0	0.018	39.70	0.7	266
Wine	0.132	610	81	83	0.022	17.20	0.4	140
Legumes	0.035	509	18	15	0.029	18.00	0.5	193
Potatoes	0.460	710	327	78	0.101	16.80	1.7	621
Vegetables	0.250	256	64	91	0.023	18.90	0.4	162
Fresh fruits	0.040	447	18	85	0.006	20.10	0.1	45
Nuts	0.020	6,243	125	4	0.019	25.00	0.5	175
Fish	0.007	1,150	8	80	0.001	22.28	0.03	11
Meat, "Cansalada" and "embotits"	0.050	3,032	152	50	0.025	22.00	0,6	201
TOTAL	**1.71**		**2,797**		**0.74**		**13.3**	**4,854**

Source: Own elaboration, from the sources mentioned in the text.

From this reference diet, and from the ratios extracted from the caloric intake proposed by FAO (2001) (Table 4.D), we have adapted the diet for each of the subgroups (sex-age).

Table 4.D Estimation from FAO of the energy requirements depending on the sex-age

	Energy Requirements (kcal·day^{-1}) FAO				**Energy Requirements male-adult comparison**			
Sex	**Women**		**Men**		**Women**		**Men**	
activity / age	**Moderate**	**Intense**	**Moderate**	**Intense**	**Moderate**	**Intense**	**Moderate**	**Intense**
0-5	1,412		1,534		0.41		0.44	
5_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	2,530	2,745	3,174	3,461	0.73	0.79	0.92	1
30-60	2,411	2,601	3,031	3,294	0.70	0.75	0.88	0.95
≥ 60	2,172		2,458		0.63		0.71	

Source: Own elaboration, from the sources mentioned in the text.

Fuel consumption

According to the *Sentmenat Medical Memorial* ‘The 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. Sancho i Puig (1885, quoted in 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.]). Iriarte and Infante Amate (*in press*) estimated an average of 3.1 kg[f.m.]·inhab^{-1}·day^{-1} of firewood consumption for Spain (including industrial consumption), with huge regional differences. For the zone that corresponds to our case study, Mediterranean Coast, the consumption would reduce to 1.4 kg[f.m.]·inhab^{-1}·day^{-1}. In contemporary research, authors found out lower fuel consumption in those countries where charcoal and firewood are still used as the main sources of energy 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) consider a seasonal variation of fuel consumption, so consumption would double approximately during the winter. This coincides with the assumption of Colomé (1996) for wine-growing areas of Catalonia in the 19th century, which proposes to take the values of Sancho i Puig (1885) referring to winter consumption assuming that 50% of consumption is related to cooking needs (1.12 kg [d.m.]) and 50% for heating needs. In fact, Colomé assumes that fuel consumption was lower than the average for at least 7 months a year. Giampietro and Pimentel (1990) propose 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 propose 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 (average daily consumption is 1.56 kg [d.m] or 2.35 kg [f.m.]). It is important to note that, as mentioned in footnote 21, we imposed a restriction on the consumption of vineyard by-products (strain replacement and prunning) as a source of fuel, which can represent a maximum of 10% of total fuel consumption [f.m.].

4.A.5 Labour: availability and requirements

Availability of human labour

To calculate the number of annual working days, we start with an annual potential availability of 280 working days per capita. According to Garrabou et al. (2014), the number of annual working days in La Segarra County, in inner Catalonia (1886-1890) would be around 291. 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 in the case of males, or servants in the case of females. Despite we could not introduce more complexity, we acknowledge that younger members of the HH might participate in the agricultural labour, mainly during the harvesting or grape harvest (Borrás Llop 2002). 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 have introduced coefficients that reduce the working capacity (w.c.) of people referring to the adults between 18 and 60: 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 Le Play (1877-79). Data of Le Play shows a great similarity between the annual working days of men (320) and women (317). 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 homogenise and compare available data (Table 4.E).

Table 4.E Compilation of data on the quantification of domestic and family work in traditional agriculture

Female labour										
Consulted research	**Domestic**		**Familiar**		**External**		**Total**		**DFW**	
	hours·day^{-1}	**hours·year^{-1}**	**hours·day^{-1}**	**hours·year^{-1}**	**hours·day^{-1}**	**hours·year^{-1}**	**hours·day^{-1}**	**hours·year^{-1}**	**hours·day^{-1}**	**hours·year^{-1}**
Le Play (1877); Wall (1994)	2.9	1,060	1.6	590	1.8	672	6.8	2,490	4.5	1,643
Pastore et al. (1999)	2.6	967	n.a.	n.a.	n.a.	n.a.	2.6	967	2.6	949
Gomiero and Giampietro (2001)	6.3	2,286	n.a.	n.a.	n.a.	n.a.	6.3	2,286	6.3	2,300
Grünbühel and Schandl (2005)	2.7	986	2.5	913	3.9	1,424	9.1	3,322	5.2	1,898
Fischer-Kowalski et al. (2010)	7.6	2,774	1.2	420	1.2	420	9.9	3,614	8.8	3,212

Source: Own elaboration.

Wall (1994) presents data for 36 families. The data in Table 4.E is an average between 'landowners', 'sharecroppers', 'temporary-pieceworkers' and 'day labourers'. Domestic work included cooking, washing, cleaning, and childcare. Family work included small livestock management and fuel extraction. Pastore et al. (1999) only shows the data on 'subsistence tasks' as activities, cleaning, childcare, water collection and fuel gathering. Since there is no information on gender sharing, but data is expressed as an 'average adult', we assume that women assume the subsistence tasks of men. Note that, even assuming this, Pastore's data shows the lowest weight of domestic work.

Interpretation of the data showed in Gomiero and Giampietro (2001) was more complex. We assumed that 'chores' refers to Domestic and Care labour, and includes the same concepts than in Pastore et al. (1999).[26] From the available data on the text, we deduced that time dedicated to 'chores' per household was 2,286 hours.[27] Again, as data is not disaggregated by sex, we considered that women performed this work. In Grünbühel and Schandl (2005), Domestic work time includes (i) weaving, sewing, texile care (0.3 hours), (ii) cooking and baking (0.2 hours), (iii) washing, cleaning, and (iv) care for children, adults, and elderly (0.9 hours). Family work time includes fetching water (0.4), collecting firewood (0.9), fishing (0.5), construction (0.5), food harvesting (0.2).

From Fischer-Kowalski et al. (2010), we excluded the Nalang case study (Lao PDR), since it is the one analysed in Grünbühel and Schandl (2005). The average for adults (16-64 years) includes: care for dependents (0-1.59 hours), food preparation (0.09-1.07), house building (0-0.26), repair/maintenance work (0.16-0.34) and domestic chores (1.98-0.64). When it is disaggregated between women and men, we observe how women performed about 85% of the work in the 'household system'. For total work, we took the data from Figure 2 (Fischer-Kowalski et al. 2010, 26), an average of 7 (Trinket) and 10 hours per day (Campo Bello). For the Family and External work, we assume a 50% for what authors call 'Economic System Labor', from an average of 0 hours for Trinket and 4.6 hours in Campo Bello.

From results shown in Table 4.E, and despite that the comparison suggests that Le Play's data might be underestimate, we decided to use data appearing in Le Play (1877-79) and collected by Wall (1994) as a proxy of Domestic and Family Work (DFW). We will also follow this label within Chapters 4 and 5. Therefore, we will take Le Play's data and, 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 uses and livestock have been obtained from EAV (Garrabou and Planas 1878) and IACSI (1879). To accurately capture the surpluses and deficits of work, it is necessary that monthly labour requirements be taken into account, given the strong seasonality. Table 4.F and 4.G show human labour required for each type of crop and livestock, including wages for livestock managenent, since they are lower than the average

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[26] Since part of the authors coincide and other information is not specified.

[27] The percentage of 'chores' over Total Disposable Working Time is 17%, and the Total Worked Time on Total Disposable WorkingTime is 27%. The total time worked per household is 3,630 hours per year, and therefore the total work available is 13,444 hours per year (36 hours of daily work per household).

agricultural wage (2.5 pesetas). Table 4.H presents the data for draught power required by type of crop.

Table 4.F Total and monthly labour requirements per land use and small livestock unit

Crops			**Cropland**												
			working days·hectare^{-1}												
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
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 rotation		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 rotation	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 mix.	0	6	10	4	0	4	10	3	3	5	4	0	**48**
Vineyard			0	0	7	18	6	7	1	0	2	16	1	0	**59**
Olive Groves rotation		Olive Groves	7	0	15	15	12	5	0	0	0	0	0	27	**81**
	1st	Associated 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 mix.	0	6	10	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**
			Small Livestock												
Swines			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: Own elaboration, from the sources mentioned in the text. Note: 1st, 2nd and 3rd refer to qualities of the soil.

Table 4.G Annual labour requirements per livestock types

Livestock	**Care (in no work days)**		**Dunghill management**	
	w.d.	**pts·w.d.$^{-1}$**	**w.d.**	**pts·w.d.$^{-1}$**
Sheeps (90 units)	365	1.3	22	2.3
Ovine (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: Own elaboration, from the sources mentioned in the text.

Table 4.H Draught power requirements per crop

Crops		working days·hectare^{-1}		
		1st	2nd	3rd
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
Vineyard		3	3	2
Olive groves		11	11	11
associated	Associated Wheat	13	-	-
	Potatoes	5	-	-
	Corn	-	15	-
	Rye&Wheat mixture	-	17	-
	Barley	-	-	15
	Lupins	-	-	12

Source: Own elaboration, from the sources mentioned in the text. Note: (-) appears when no draught power is required, but basically when tour rotation estimates do not include the crop for the corresponding qualities of the soil (1st, 2nd and 3rd).

4.A.6 Cash balance

Paid labour and estimates of daily wages

From the comparison between the monthly agricultural work required in the family farm and the availability of agricultural family labour force (after deducting DFW), we estimate a monthly agricultural surplus or deficit. In the event of work deficit, we estimated the number of required annual hired working days. Its cash cost is calculated through a daily wage of 2.5 pesetas (Garrabou and Planas 1878). 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 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) HHs expenses; clothing and footwear

(Colomé 1996),[28] house rent,[29] and (ii) farm expenses.[30] We also estimated tax payment 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 strong assumption, since the choice of selling labour surplus depended not only on the potential income (for which the family would seek to maximise income from the higher wage), but also on the type of work performed, the incentives of those who contracted it (who would seek to minimise 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 research 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 prioritised, as any other criterion would be equally random. This would be better assessed at municipal level including seasonal wage labour demand and supply (see Chapter 5). As mentioned in the text, this assumption implies that the number of total hired working days but also the number of female hired labour are the minimum one.

External Inputs

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

Commodities and fuel prices

Table 4.I shows the prices applied for each of the products and the sources used.

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[28] Colomé (1996) proposes coefficients of expenditure on dress and footwear 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 from this point.

[29] At the Catalan level the average could be set on 85 pesetas (Vicedo et al. 2002).

[30] A study quoted by Colomé (1996) estimated the cost of amortization of the farm tools in Santa Margarida i les Monges, Catalonia, at 2.04 pesetas·hectare^{-1}.

Table 4.I Summary of the prices of the main products

Product	Price (pts·kg f.m.$^{-1}$)	Sources	Comments
Wheat	0.37	Reclamación al Catastro de Sentmenat (1879) [1868]	Historical sources show how wheat prices declined until the end of the century. EAV (1878) shows 0.30 pts·kg^{-1} for 1878 and the same historical source (Reclamacion) for 1878 shows 0.32 pts·kg^{-1}
Corn	0.29	Reclamación al Catastro de Sentmenat (1879) [1868]	Prices declined in the next decade (0.21 pts·kg^{-1} in 1878)
Hemp	0.96	EAV (1878)	-
Barley	0.20	Reclamación al Catastro de Sentmenat (1879) [1878]	No available data for 1868. EAV (1878) shows 0.17 pts·kg^{-1}
Rye&Wheat mixture	0.25	Reclamación al Catastro de Sentmenat (1879) [1868]; EAV (1878)	EAV (1878) shows 0.27 pts·kg^{-1}
Fodder	0.08	EAV (1878)	-
Olive oil	1.24	Reclamación al Catastro de Sentmenat (1879) [1868]; EAV (1878)	EAV (1878) 1.02 pts·litre^{-1}
Wine	0.12	Reclamación al Catastro de Sentmenat (1879) [1868]; EAV (1878)	EAV (1878) 0.13 pts·litre^{-1}
Green Beans	0.42	Reclamación al Catastro de Sentmenat (1879) [1868]	EAV (1878) irrigated green beans [0.372 pts·kg^{-1}], rainfed green beans [0.335 pts·kg^{-1}]
Vetches	0.15	EAV (1878)	-
Lupins	0.15	EAV (1878)	-
Potatoes	0.11	Reclamación al Catastro de Sentmenat (1879) [1868]	Potatoes data show one of the highest variability of prices. Both historical sources (Reclamación and EAV) show a decline to 0.06 pts·kg^{-1} in 1878.
Fish	0.89	NISAL Project	Precios de las subsistencias en Barcelona (1854-1935 (http://www.proyectonisal.org/index.php/en/database/shorten-index)
Meat	0.82	EAV (1878)	Prices were 2.5 pts for capons, 2.25 for hens and 1.5 for chicken. We apply an average weight 3.5 kg for the first, between 2.5 kg for the hens, and 1.5 kg for the chickens
Firewood	0.03	IACSI (1879)	We considered that the prive in EAV (1878) was too high [0.004 pts·kg f.m.$^{-1}$]
Pasture	0.01	EAV (1878)	"For the right to graze cattle from 1 June to the end of the year (...)", 8 pts·hectare^{-1}, and we applied the same yield as one hectare of forest (1,523 kg f.m.)

Source: Own elaboration, from the sources mentioned in the text.

CHAPTER 5:

Socio-Ecological Reproduction of Agricultural Households and the Maximum Feasible Inequality in Traditional Organic Farming (Sentmenat, Catalonia, 1850)

Photograf by an unknown author (Undated)
Sin título [Untitled]
Imatges i records de Sentemenat (Viena Columna)

Chapter 5:

Socio-ecological Reproduction of Agricultural Households and the Maximum Feasible Inequality in Traditional Organic Farming

(Sentmenat, Catalonia, 1850)[31]

Abstract:

The main goal of this chapter is to reconstruct and analyse the socio-ecological reproduction processes in traditional organic agricultures. To do so we combine Ecological Economics, Social Metabolism, Feminist Economics and Sraffian approaches. The key concept of socio-ecological reproduction gives us the opportunity to show the confluence and interlinks among the different reproduction processes. We illustrate the structural framework of these processes through the reconstruction of the main socio-ecological reproduction flows in an organic preindustrial agriculture (Sentmenat, Catalonia) in the mid-nineteenth century. By linking the balances of total time use and domestic work, farm labour, human consumption of food and fuel, animal feeding and soil nutrients' replenishment of each household of the rural village analysed, we can infer through the integrated socio-ecological reproductive analysis the exploitative relationships established among them, the surplus generated and appropriated, the maximum level of feasible inequality, and the actual extraction ratio exerted. From this view, we propose some thoughts concerning socio-ecological transitions.

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This paper is unpublished. I contributed with the original idea, development of the theoretical framework, analysis of the results and drafting the document. Roc Padró made possible part of the technical points, and wisely adviced during the analysis of the results. Enric Tello contributed with theoretical and methodological advices.

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5.1 Introduction

5.1.1 Socio-Ecological reproduction as an integration of perspectives

> 'A society can no more cease to produce than it can cease to consume. When viewed, therefore, as a connected whole, and as flowing on with incessant renewal, every social process of production is, at the same time, a process of reproduction'
>
> Karl Marx (1867, *Capital*, Vol I., Part VII, Chapter 23, on Simple Reproduction).

When we analyse economic processes from the point of view of an integrated system, it is difficult to distinguish those processes that can be considered 'productive' from those that can be considered 'reproductive'. The standard definition of *production* is the transformation of inputs into outputs (goods and services) (O'Hara 1997), while *reproduction* is defined as a dynamic process of change linked to the perpetuation of social systems (Benería 1979). Starting from the statement that the ultimate requirement of the social reproduction process is to meet the material and social needs of human communities (Polanyi [1997]2009:21), we could base the distinction between producing and reproducing on the question of '*what structures have to be reproduced in order that social reproduction as a whole can take place*' (Edholm et al. 1977:105). We seek to answer this question for the case of advanced organic agricultures.

Ecological economics has highlighted the link between basic human consumption and the permanent access to available energy and materials, thus revealing the very process of society-nature interaction. This means that '*the real material bottom line of any social metabolism is its ecological integrity—a recursive web of self-regulating matter/energy flows signified by metabolic value*' (Salleh 2010:212). From the Social Metabolism approach, and its fund-flow perspective (Georgescu-Roegen 1971) it is argued that the reproduction of the capacities of the *ecological funds* is the essential condition on which the processes of social reproduction can occur.[32] We consider funds as the *agents of production* (O'Hara 1997:145), the structures with capacity to transform the inputs flows into output flows (Giampietro et al. 2012:184), which from a classical economics point of view would be identified with human labour power, Ricardian land, and manufactured capital.[33] All these elements could be defined as self-reproducible funds, except manufactured capital. From this, and in order to analyse agricultural systems from a Social Metabolism approach, ecological funds were broaden including associated biodiversity, soil fertility, and the livestock-barnyard complex (Tello et al. 2015, 2016; Galán et al.

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[32] Although we agree with the statement that we need to recognise ourselves as a particular form of nature, thus of ecology, we think it is useful to distinguish between ecological and social funds in order to better understand their links, conflicts and functioning.

[33] We will later discuss our approach to include manufactured capital within the analysis.

2016). But, what did reproducing the capacities of the ecological funds imply for advanced organic agricultures?

Preindustrial agriculture societies were mainly based on renewable material and energy sources, within an agrarian socio-metabolic regime which relied on the energy conversion provided by plant biomass (Sieferle 1997; Fischer Kowalski and Haberl 2007; Krausmann et al. 2008b; González de Molina and Toledo 2014). It was a land use-based energy system that has also been termed *controlled solar energy system* by Rolf P. Sieferle (2001). This meant that a great part of the materials used was mainly biomass, up to 95% of the primary energy supply in many cases according to Krausmann et al. (2008b), and the energy sources were mainly human labour, animal work and firewood (Gales et al. 2007; Kander et al. 2013). As it has been pointed out, the main sustainability challenge was linked to soil fertility replacement (González de Molina 2010; Corbacho 2017). Unlike manufactured capital or other stocks, output flows emerging from funds (i) cannot be extracted at any rate, and (ii) are conditioned by certain flows being reincorporated to maintain their capacities. For advanced organic agricultures, this meant that (i) the maximum amount of output flow per unit of land was limited by ecological constraints, and (ii) its intensification and maintenance were directly linked to the maintenance of soil fertility, which required certain amounts of energy and materials provided by often labour-intensive techniques. Between this apparent trade-off the relevance of ecological funds reproduction prevailed, as, ‘in general, land use systems are optimised more for the long-term stabilization of overall system output than for maximizing yields per unit of area’ (Sieferle and Müller-Herold 1998).[34]

Nevertheless, social reproduction was not only dependent on the energy and material flows that came from the agroecosystems. It also depended on the physical, emotional and spiritual support necessary to reproduce the society. This is what has been grouped under the name of ‘domestic and care work’, which includes ‘*the care of the maintenance of the spaces and domestic goods, as well as the care of the bodies, the education, the formation, the maintenance of social relations and the psychological support to the members of the family*’ (Picchio 2001:2). Historically, women have principally performed this work, as ‘*in all societies women were responsible for food preparation, and in most for childcare*’ (Mellor 1992:131, Sanday 1981). As we consider labour as a fund, ‘these [domestic and care] services are particularly important to maintaining flows and services provided directly by labour inputs or indirectly by those labour services maintaining capital funds and land’ (O’Hara 1997:147). Domestic and care work allows the reproduction of labour force in at least two different ways, between which we will differentiate intergenerational reproduction (through childbearing and childcare) and daily maintenance of current active workers (Carrasco 2000; Picchio 2003). In accordance with the abbreviations and definitions used in the previous Chapter (4), we will

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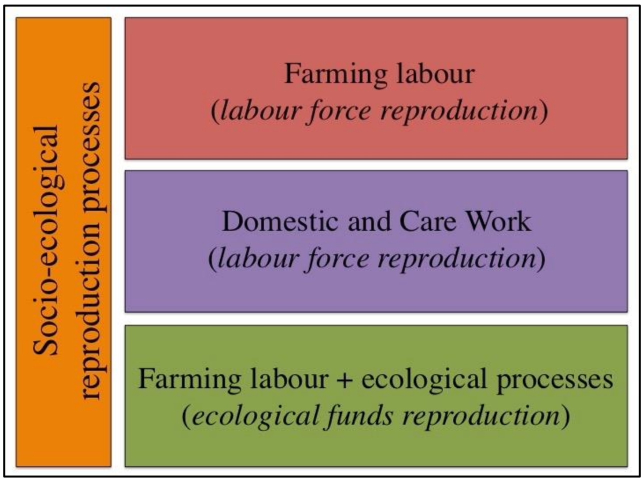
[34] As we will see later, this trade off could also be seen as an equilibrium among the different funds reproductive processes (labour force, soil fertility and livestock), or as a trade off between ‘social’ and ‘ecological’ funds reproduction.

define these works as Domestic and Family Work (DFW).

Finally, ecological sustainability and DFW are not enough for social reproduction to happen. As mentioned, human beings reproduction directly depends on the available materials and energy, through the transformation process of inputs into outputs, that is to say through the 'production process'. This process, together with DFW, will reproduce the whole 'human energy', understood as '*the totality of the energetic power produced by the metabolic effect of the nutritional substances on the human organism*' (Meillasoux 1975:83), part of which could be considered as *labour force*. Due to the indivisibility of human beings reproduction and labour force reproduction, each social reproduction process is at the same time a labour force reproduction process. This last link will be closing the (re)productive economic system, a system that can be better understood 'as an endless spiral (…)' within a circular conception of the economy, where reproduction can be understood as '*the more or less similar repetition of a series of productive and distributive processes that allow the cycle to be restarted again and again*' (Barceló 1981:37). Observing the three processes of (re)production –of ecological funds, domestic care, and the nutritional and basic human needs of the labour force—allows us to describe the process in an integrated way, including both the reproduction of the funds usually defined as 'ecological' as well as the 'social' funds, in what we will call a process of socio-ecological reproduction (Hollingsworth 2000).

Figure 5.1 Basic scheme of socio-ecological reproduction components



Source: Own elaboration.

Figure 5.1 provides us with a clear scheme of the listed basic components of socio-ecological reproduction processes in advanced organic agricultures. This figure also helps us to illustrate our main conclusions about the production-reproduction distinction. What has been historically identified as 'productive' (the farming labour sphere), could be considered as 'reproductive' in two ways. First, as mentioned, because of its role as a necessary step for labour force reproduction. But second, although we can say in a global sense that agricultural labour is 'productive', given that the end result is the generation of biomass for human and animal consumption, it is also true that among the several tasks that compose agricultural labour, some of them have a clearer 'reproductive' sense (i.e. fertilising practices and livestock feeding). Therefore, there is a thin line in the definition of both. Moreover, the distinction between production and reproduction does no give us a very useful information, given that any 'productive' process is only a way to consider a fraction of a wider 'reproductive' cycle. As a matter of fact, Marx's quote in the beginning of this section expresses this idea in a very clear manner.

5.1.2 Surplus and inequality: A Socio-metabolic and Sraffian approach to an analysis of the socio-ecological reproduction of preindustrial agricultures

The approach described above shares several common roots with the Sraffian perspective, which highlights how the productive forces of a given year must guarantee the productive process of the following year. From a fund-flow analysis of preindustrial agricultures, this means that the output flows (Total Produce; TP) provided by the main agroecosystem's funds should be able to reproduce these funds. Within advanced organic agricultures, each fund reproduction process could be associated with two reproductive flows, one of them being of material-energy character and the other one being a labour-time flow. With regard to material-energy flows, soil fertility maintenance (F) was associated with fertiliser biomass (Farmland Biomass Reused; FBR) and Livestock reproduction required feeding and stall bedding (Livestock Biomass Reused; LBR).[35] Both flows were driven by Agricultural Labour (L_A). The reproduction of the Farming Community was associated with the generation of enough biomass for reproduction (Final Produce for agricultural population; FPa), and required both Agricultural Labour and Domestic and Care Work (DFW). For these advanced organic agricultures, manufactured capital played a less significant role. In this case, we associate the reproduction of manufactured capital with the Final Produce (FP) allocated to feed and fuel non-agricultural population working on clothes, footwear, tools and infrastructure reproduction (FPt) (see Figure 5.2).

The difference between the total productive capacity (Total Produce; TP) and the total reproductive flows (FBR + LBR + FPa + FPt)[36] is the surplus (S), which we understand as '*[t]he set of products that remain after the deduction from the total output of the means of production necessary to continue the cycle at the same level and the consumable goods essential to restore the workers so that they can supply the same amount of workforce'* (Barceló 1981:78-79).[37] Surplus can be expressed as a part of the Final Produce (FPs). The emergence of surplus entails some social rules to define which social groups would appropriate it, and how, thereby potentially leading to the emergence of social

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[35] As has been explained in detail in previous works (Tello et al. 2015, 2016; Galán et al. 2016), we cannot specifically define the reproduction processes of Associated Biodiversity. Despite this, we know that above-ground biodiversity would be related with Unharvested Biomass (UhB) and habitat heterogeneity, while below-ground biodiversity would be related with fertility practices and soil quality management. For the purposes of this work, we decide to exclude this fund reproduction from the analysis.

[36] As Labour could be considered the same as FPa, all labour would be excluded from the equation.

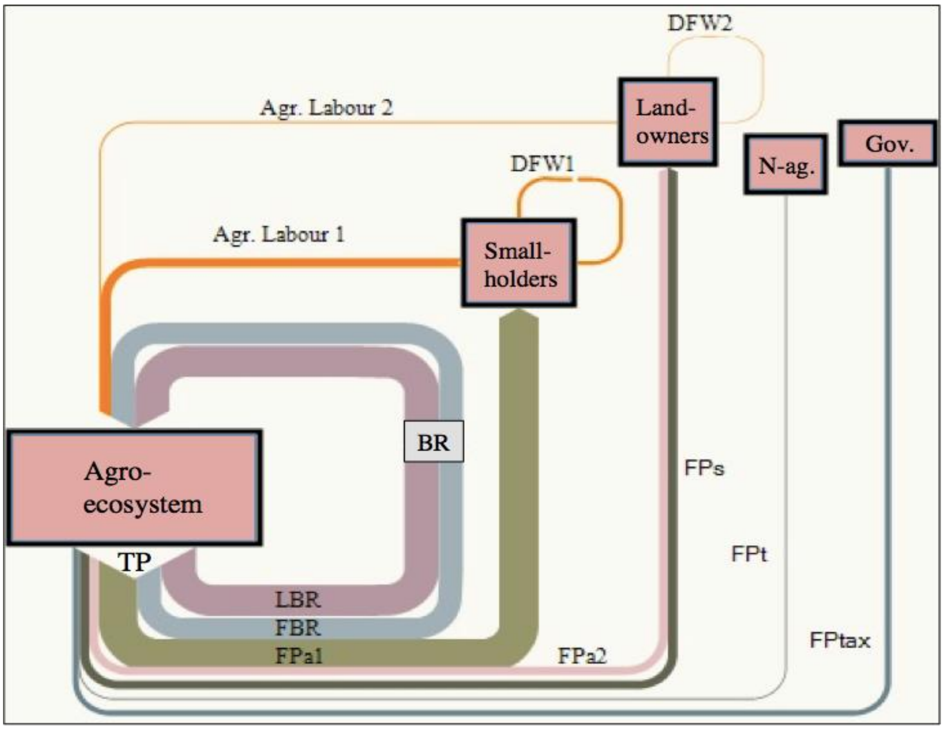
[37] Translated by the authors from Spanish.

hierarchies. Although part of this surplus would be used for sustaining the non-agricultural population of the society which was not related to the agricultural system, there could also be other social groups with the capacity to appropriate and accumulate this surplus. Therefore, for analytic purposes we make a simple division of Farming Community in two sections: those that had no systemic capability of appropriating surplus (smallholders; 1) and those with capacity to appropriate surplus (landowners; 2). In particular, this means splitting labour flows (L_1 and L_2), the associated consumptions (FPa1 and FPa2) and the corresponding domestic and family work (DFW_1 and DFW_2). Our last remark is linked to that part of the Final Produce that went to pay taxes (FPtax), which had a double function. Although it could be defined as a reproductive flow, because it was necessary to reproduce some physical and non-material infrastructures, it could also become part of a non-agricultural process of surplus accumulation by an elite. For this work, we decided to maintain it out of our analysis boundaries although we displayed its size in Figure 5.2. In sum, we can describe the breakdown as follows:

$$\mathrm{TP} = \mathrm{FBR} + \mathrm{LBR} + \mathrm{FPa1} + \mathrm{FPa2} + \mathrm{FPs} + \mathrm{FPt} + \mathrm{FPtax}$$

Figure 5.2 displays the socio-ecological reproduction scheme described in this section for our case study (Sentmenat, 1850). The scheme shows a clear loopy structure, where different reproductive processes are interwoven.

Figure 5.2 Analytical socio-ecological reproduction scheme for Sentmenat (1850)



Source: Own elaboration with the sources mentioned in the text. Note: All labour flows (in orange) are expressed in working days. All other flows are energy flows, and are expressed in GJ_{ECB}, except of LBR and FBR that are expressed in GJ (see section 5.2.1). The values correspond to the village of Sentmenat in mid-nineteenth century.

Sraffa (1960) argued that there exists a maximum feasible profits rate (R), determined by ecological, technical and social aspects of the socio-ecologic system, especially by (i) the 'development of the productive forces' (e.g. Total Produce) and (ii) the different reproduction flows required to maintain the 'productive agents' working. As has been shown earlier, in preindustrial agricultures there were two main reproductive flows that limited the possibility of appropriating the 'natural' produce or Total Produce: (i) the metabolic rate that must be respected to maintain and reproduce the 'ecological' funds (BR), and (ii) the physiological subsistence level of the (whole) labouring force (FP). From here onwards, the actual profit rate will depend on the result of the conflict between land, capital and labour, or the conflict over the distribution of produce. Therefore, an increase of productive capacity of the economy, mainly through technical change, could reduce the social-class conflict (Barceló 1994). In order to assess the surplus distribution and its effects on social inequalities, we followed Milanovic's analytic tools, which are based on the basic Sraffian approach:[38] (i) the *maximum feasible inequality*, which corresponds to the situation where only one individual appropriates the entire attainable surplus and the rest live at the physiological subsistence level, and (ii) the *Inequality Extraction Ratio (IER)*, which measures how close is the actual inequality to the maximum feasible inequality (Milanovic 2006; Milanovic et al. 2011).

From this basic framework, we propose a new approach that, for the first time, combines a Fund-Flow Socio-Metabolic accounting of farm systems with a reproductive Sraffian standpoint. This, in turn, is linked to the household analysis developed in Feminist Economics and the Inequality Extraction Ration put forward by Milanovic et al. (2011). Our methodology, already detailed in Chapter 4, seeks to quantify the socio-ecological reproduction processes in order to understand its structure and dynamics. We will apply this novel socio-ecological reproductive approach to a small farming community in Sentmenat (Catalonia) in the mid-nineteenth century as a first test bench, which socio-ecological reproduction scheme is displayed in Figure 5.2. Here we will describe the main results for the whole municipality including 244 households (HH). We start by describing some methodological issues and the characteristics of the municipal funds (see Section 5.2 and 5.3). We continue with the main features of the Social Organisation of Labour (autonomous vs dependent labour and sexual division of labour) (see Section 5.4.1). Then we show the values of the main productivity indicators (see Section 5.4.2), and analyse the surplus amount and its distribution (see Section 5.4.3), including the Inequality Extraction Ratio assessment (see Section 5.4.4). Finally, we present the estimation for the subsistence wages (see Section 5.4.5). Discussion and Conclusions seek to enter into a dialogue with diverse literature debates and to extract the main relevant aspects of the results obtained.

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[38] Although Milanovic did not explicitly refer to Sraffa.

5.2 Methods

Sources and methods are fully described in previous works (see Chapters 2 and 3, Padró et al. *forthcoming*), including historical records used and the methodology to build-up the different balances. Here we only briefly review three important issues for this paper: (i) the transformation from Final Produce (FP) to Final Produce in Equivalent Consumption Basket (FP_{ECB}), (ii) the description of the different productivity indicators used, (iii) the description of estimations of the female labour force participation, and (iv) the basic aspects of the elaboration of the Inequality Extraction Ratio (IER) assessment.

5.2.1 From Final Produce to Final Produce in Equivalent Consumption Basket (FP_{ECB})

To meet their basic needs, all families needed a consumption basket with a certain amount of food and fuel. Although we could account for the total energy content of this consumption basket in GJ, we should also bear in mind that firewood and coal could not be eaten, while burning food for cooking or heating at home would be foolish. As we have done in in Chapter 4, in order to analyse land and labour productivity indicators we convert the energy content of Final Produce (GJ) (which includes the products that are self-consumed in the same HH or destined for sale on the market) through a transformation procedure that allows us to obtain the Final Produce in an Equivalent Consumption Basket (FP_{ECB}). Through this process we seek to avoid conflating the different energy qualities between food and fuel energy carriers (Giampietro et al. 2013). For this purpose, (i) we estimate the value in cash of the Final Produce through the prices established for each product; and (ii) we calculate the amount of the Equivalent Consumption Baskets (ECB)[39]. which could be obtained with that income. Therefore, this value could be expressed either in ECB or in GJ_{ECB} (one ECB corresponding to 57.5 GJ; see Section 5.A). This means that after the transformation the composition of the FP_{ECB} is equivalent to the composition of an ECB in terms of food and fuel weights.

One of the important issues within the transformation from FP to FP_{ECB} is the possible bias introduced by the transformation through the prices, mainly because of the different ratios between prices and Gross Calorific Values (GCV). At the time of our study, there existed a huge difference between the ratio for food products (26.4 pesetas$\cdot$GJ^{-1}) and the ratio for fuel products (2.3 pesetas$\cdot$GJ^{-1}) (see Table 5.A), so that one GJ of food was much more expensive than one GJ of fuel. For our case study, there was a second differentiating element, linked to the importance of vineyard specialisation and the low caloric content of wine. These two elements ([i] composition between fuel or food products

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[39] The ECB is estimated for the household size (4 people) and composition (2 dependents) (see Section 4.A.2).

and [ii] weight of the wine [produced] within FP) are the ones that will determine most of the changes that occur from FP to FP_{ECB}.

Despite this, we acknowledge that this transformation through prices introduces a steady bias. As Table 5.B shows, we found that prices (exchange value) were defined by the embodied labour, and not so much by the caloric content of the product itself. Indeed, we found that labour costs were a large part of the total production cost (see Section 5.4.3), which perfectly fits with this hypothesis.

5.2.2 Productivity indicators

To the labour productivity indicators explained in Chapter 4 (see Section 4.3.2), we added here the *Social Productivity of Labour* (SPLab). The output measured here is the **social appropriation of the produce**, which accounts for the final distribution of produce after the exchanges between labour force and agricultural produce. Social appropriation of produce includes the minimum consumption of the HH (food, fuel and housing) for all of them [FPa1 for smallholders and FPa2 for landowners], and surplus for landowners [FPs]. The input is the quantity of working days of the family members of the HH. Note that, from this perspective, FPLab (see Section 4.3.2) shows the primary distribution of produce independently of the funds' ownership, while SPLab accounts for the social distribution once the retribution of each of the funds or *agents or produce* get their part. Figure 5.2 describes these flows in absolute terms, distinguishing between smallholders and landowners.

5.2.3 Estimates of female labour force participation

Women's work, and especially domestic and care work, has been systematically excluded from a large part of socio-metabolic analyses with a historical perspective. The limited specific information on women in the main historical sources, as well as the systematic exclusion of women from land ownership, makes it difficult to register these works. Delphy (1984) pointed out the difficulty of distinguishing between the mix of paid work, subsistence jobs and domestic work as one of the causes of their exclusion from statistics, which at the same time facilitated the disparagement of their value. In addition, one of the difficulties of measuring these works, as has been observed in time budget studies, is that they can, and usually are, performed simultaneously (especially care work) (Carrasco et al. 2011). This is why sometimes it is difficult to attribute a single purpose to a complex activity that includes activities that can be considered leisure and work at the same time (Fischer-Kowalski et al. 2010; Singh et al. 2010).

For estimates of female labour participation we made strong assumptions. The assessment used in this work for Domestic and Family Work (DFW) has been previously detailed (see section 4.A.5). We only want to remark here that we assumed the maximum participation of female in DFW, that is, that female performed all DFW within the HH. For agricultural labour, the main assumption was that male labour would have been prioritised before female labour, both for internal labour within the farmsteads and wage labour. Despite this, we assumed that within the HHs, farmer's wives and daughters were prioritised before male labour for some specific tasks (gardening, small livestock, weeding and legumes sowing) (see Section 3.1.2).[40]

In the case of female wage labour, we have two ways to estimate it: from the supply side or from the demand side. The first one refers to when male wage income was not enough to meet the HHs income needs (annually). The second one refers to when potential male wage labourers were not able to cover wage labour demand (monthly) (see Section 3.1.1). This assumption is coherent with what has been noted by researchers; as 'during the periods when the demand for viticultural work increased, so did the participation of the different members of the Peasant Family Units, especially women active in agriculture' (in addition to migrant workers) (Colomé 2000:295). Due to the characteristics of our methodology, the extent to which every women assumed more or less agricultural work depended on (i) the load of DFW they had to assume, (ii) the features of the own farmstead (if it existed), and (iii) the capacity of male labour availability to cover the HH cash requirements.

Accordingly, we account for the minimun female agricultural labour participation, but the maximum participation for DFW. Both assumptions will affect our results. It is possible that agricultural female labour might be underestimated, while DFW might be overestimated. As a whole, the smaller bias of the latter might imply that our results would account for the lowest female labour participation. Although for the moment this has been the best possible methodological way to get a valid proxy of the female agricultural participation, we accept that it cannot exhaustively reveal its importance. As qualitative historical sources suggest, female agricultural labour was probably more frequent:

> *'Thus, it is customary to see, even in the last period of gestation of the primiparous, that [pregant women] keep taking care of the heavy labors of the field, or beating the loom, according to their ordinary occupations; and nevertheless, the fruit of their loves arrives perfectly'*
>
> Pujadas and Serratosa (1888:144).

5.2.4 The maximum feasible inequality

For the analysis of the *maximum feasible inequality* and the *Inequality Extraction Ratio (IER)* we first calculate the Gini coefficient for inequality in the *social appropriation of the produce* ([FPa1] in the case of smallholders and [FPa2+FPs] in the case of landowners; see section 5.2.2). These correspond to the flows defined in Figure 5.2. Second, we calculate the Gini coefficient for the maximum feasible inequality, where all the population lived at the subsistence level, except one household (Milanovic 2006; Milanovic et al. 2007, 2011). For our case study this means maintaining the basic distribution of produce (food, fuel and rental housing), while only one HH appropriated the whole

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[40] Please note here that we refer to the work of who would had been prioritised. This means that in the case that internal agricultural required labour exceeded male potential labour, women's labour would be used.

surplus. Comparing both coefficients (actual inequality/maximum feasible inequality) we obtain the IER (Milanovic 2006; Milanovic et al. 2007, 2011):

$$Inequality\ Extraction\ Ratio\ (IER) = \frac{Acual\ inequality\ (Gini\ coefficient)}{Maximum\ feasible\ inequality\ (Gini\ coefficient)} * 100$$

Still, differences with Milanovic's methodological proposal are based on two issues; (i) the way of estimating the minimum subsistence level, and (ii) the scale of the analysis. Milanovic's estimate of the minimum subsistence level is set at $PPP 300 in 1990 Geary-Khamis dollars. This threshold is inspired and consistent with several sources (Bairoch 1993:106 [$PPP 355]; Chen and Ravallion 2007:6 [$PPP 365]), and it is slightly lower than the estimate proposed by Maddison (1998:12), which 'covers more than physiological needs' [$PPP 400] (Milanovic et al. 2011:262).[41] However, Milanovic's approach means adopting a general baseline supposedly valid for any time and place. Instead, our approach uses a bottom-up analysis to assess this subsistence baseline in biophysical and site-specific terms, where the household structure (size, age and gender), diet patterns and fuel consumption are considered (see Appendix to Chapter 4). Concerning the scale, the case studies compared by Milanovic et al. (2011) refer to national level, including all economic sectors. Our analysis is scaled at municipal level, with many limits detailed in Sections 2.1.5 and 2.3.3, and is restricted to the agricultural sector.

5.2.5 Data and methodology shortcomings

As has been frequently pointed out by agrarian historians, the municipal scale entails some biases. Due to the huge atomisation of the plots, which despite forming part of a same farm but could be sometimes located in different municipalities, the distribution of the farmland sampled may be biased (Garrabou et al. 2014). For the case of foreigners living in surrounding municipalities (see foreigners in Figure 5.3), the 'fragmentation of small farmsteads in various municipalities results in a certain overestimation of the number of small owners and the weight of small property' (Garrabou et al. 2014:63).[42] Garrabou estimated that this would reduce the number of HHs with less than 2 hectares in 1.5% and those with less than 5 hectares in 1.3%.

In addition to the limits of the historical sources, pointed out here and in previous chapters (see section 4.A.1), we acknowledge that the development of this novel methodology is in an initial stage. Particularly, we could not include the likely differences in the management of farmland and livestock funds between smallholders and landowners, beyond the effects of the actual land use patterns and distribution of diverse land qualities. Labour requirements and yields do not change depending on the farm size, and only differences between soil qualities or irrigation would be differentating elements.

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[41] PPP refers to 'purchasing power parity'.

[42] Translated by the authors from Spanish.

Second, labour organisation has been inevitably simplified. We did not include the familiar and community networks that could partially supply labour interchanges out of the markets, or through other mechanisms like debt. For instance, Colomé (2000:294) notes that '[landowners] could also put pressure on the *rabassers* and/or wage labourers through monetary or in-kind loans (…) in exchange for the wages that a certain working time may require'.[43] Finally, we could not include other ways of access to biomass through informal sources, like gathering, hunter or thefts. In spite of these limitations, we consider that the results obtained are robust and very revealing.

5.3 Case study: Labour, Farmland and Livestock

Here we will focus on the basic characteristics of the municipality funds (labour, farmland and livestock), including its distribution among the different households.

5.3.1 Labour Force

The population registered in Sentmenat (1850) was of 1,718 inhabitants, grouped in 328 households (HHs). Population density was 65 inhabitants per km^2 (according to the Cadastral map area, 87 according to the Amillaramiento's one). The population structure showed a certain balance between female (51%) and male population (49%), and the working-age population was around 63% (see population pyramid showed in Figure 5.A). The potential labouring time for the whole society was 252,830 working days per year (903 Annual Working Units; AWU), an average of 770 working days per HH (2.8 AWU). 76% of the total population was considered to be agricultural (e.g. being part of a HH defined as agricultural). The total labour available for agricultural households was 208,593 working days per year (745 AWU).

5.3.2 Land uses: Total farmland and sampled farmland

The land tax register called *Amillaramiento* (1850) registered 1,917 hectares, of which 77% were cultivated. The vineyard represented 65% of this farmland. Our sample includes a smaller part of the farmland area and of the agricultural population (Sample 1). We were able to identify 194 complete biophysical, labour-time and cash balances for which we have information about the characteristics of the HH and the characteristics of the farms. To these, we added 52 HHs with no access to land. Thus, our sample accounts for 65% of the total area registered, 64% of the cultivated land, and 89% of the agricultural population registered in the population census. Although Sample 1 is smaller than the total farmland in the municipality, the land use pattern of Sample 1 was similar compared with the whole *Amillaramiento* land use pattern.

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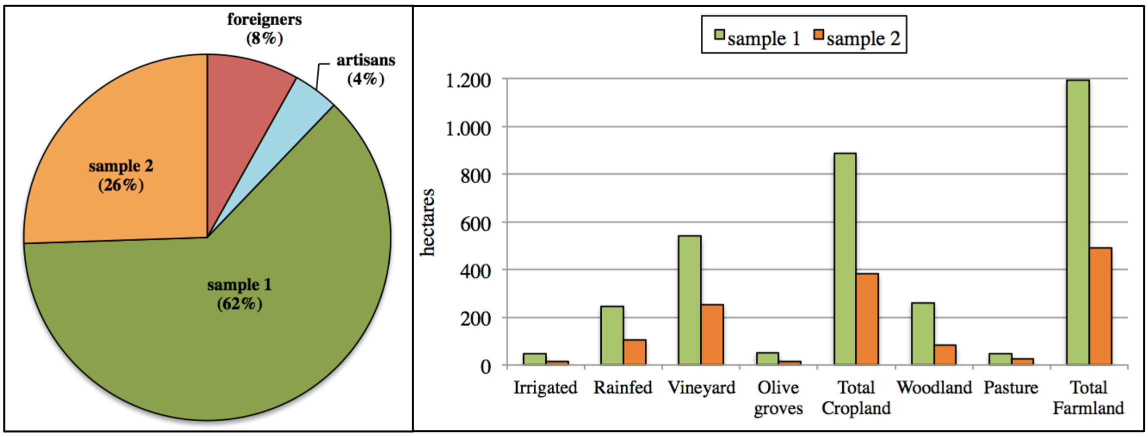
[43] Translated by the authors from Spanish.

Within those who were excluded from Sample 1, we can differentiate between various groups, mainly between the non-agricultural population who owned some plots (4% of the total area), and the foreign landowners whose HHs were not included in the local population census. Among the latter, we can distinguish two types of foreign owners; (i) small vineyard tenants from nearby villages (100 plots) which represent 8% of the total area (labelled as foreigners in Figure 5.3), and (ii) a those of which there is no record of their origin and whose ownership was much more diverse. This second group, foreign landowners that were not identified as living in the nearby municipalities, conformed Sample 2.

We are interested in Sample 2 because, as will be explained in detail in Section 5.3.1, results suggest an imbalance between labour supply and labour demand of Sample 1. This would imply that a share of the proletarian and semi-proletarian population could not get the necessary income to meet their basic needs. Thus, we assumed that part of the foreign landowners included in Sample 2 needed to hire local labour force, which enlarges labour demand. Results are shown in Section 5.3.1. However, it should be specified that this area will only be used for Section 5.3.1, while the results and conclusions will focus on Sample 1.

Figure 5.3 Sample subdivisions and and use patterns (Sentmenat, Sample 1 and Sample 2)



Source: Own elaboration based on the *Amillaramiento* and population censuses.

5.3.3 Livestock-Barnyard

Based on the cross data of the *Amillaramiento* and Cadastre (1848), and including estimates of small livestock per HH (see section 4.A.1), the livestock was 195 LU500 and livestock density accounted for 16 LU500/km^2 of farmland. The livestock composition was balanced among draught animals and cattle for milk, meat and fibre (see Figure 5.B in Appendix). It should also be noted that availability of draught power was around 20,170 working days per year (16 working days per hectare) and the availability of manure was of 360 tonnes (dry matter) (382 kg per hectare of cropland).

5.3.4 The different nature of the Funds: abundance versus scarcity

> *'Human time is a limited resource but – in the short run - evenly distributed among the members of a social system: everybody has 24 hours at his/her disposal'*
>
> Singh et al. (2010:5)

From the above information we can establish the characteristics of an average farm; 7.8 hectares of farmland, and 0.8 LU500, which entails 83 draught power working days and 1,483 kg of manure per year. In Sample 1, 84% of the HHs were below the farmland access, 70% were below the average threshold of livestock ownership (LU500), and 62% had no access to draught power of their own.

Figure 5.4 shows the main features of the distribution of funds, through a Lorenz curve and Gini coefficients. We indirectly infer access to water, from access to the irrigated land, which was the most unequally distributed along with the woodland. On the other side, the vineyard was the most equally distributed. Indeed, the figure shows the unequal pattern of distribution between funds, especially between labour and farmland. While the amount of available agricultural labour (after deduction of domestic and family labour) by HH varied steadily regardless of the farm size (Gini coefficient 0.07), the ability to absorb this labour force depended on the access to the farmland area (Gini coefficient 0.65).

5.4 Results

5.4.1 Social organisation of labour

Autonomous work versus paid work

Of the 83,226 days of agricultural work required to maintain the agroecosystem (297 Annual Working Units; AWU), 62% could be covered by autonomous workforce (184 AWU).[44] The rest of the necessary workforce (38%) had to be hired (113 AWU). Of these hiring needs, 35 AWU were covered by permanent contracted workers (with cohabitation within the same HH). The rest, 79 AWU, can be considered a proxy for temporary labour demand of day labourers. Regarding the characteristics of the HHs with labour deficit, all farms with more than 5.5 hectares (21% of the HHs) would be hiring for more than 30 annual working days, and would be responsible for 82% of the total hiring (see Figure 5.5). For further sections, we will take this reference (5.5 hectares of farmland) as a representative of the HH's size that could start to accumulate surplus through labour hiring.

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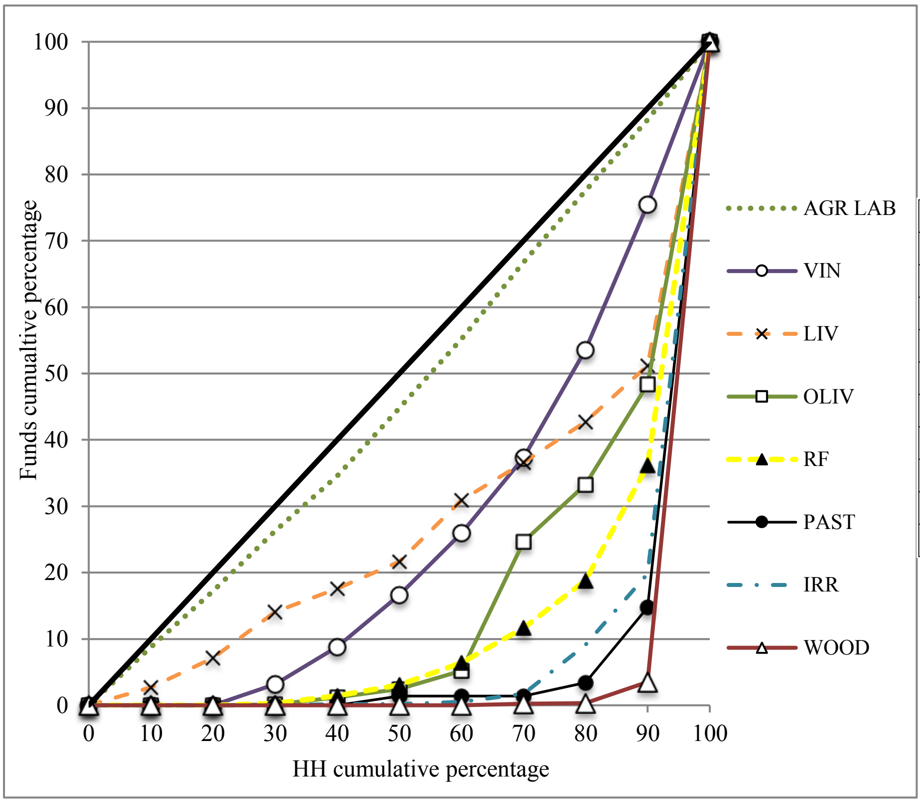
[44] Out of that total, 75% destined to cropland labour, 21% to livestock labour and 3% to woodland labour.

Figure 5.4 Lorenz curve and Gini coefficients for farmland and livestock ownership and labour availability

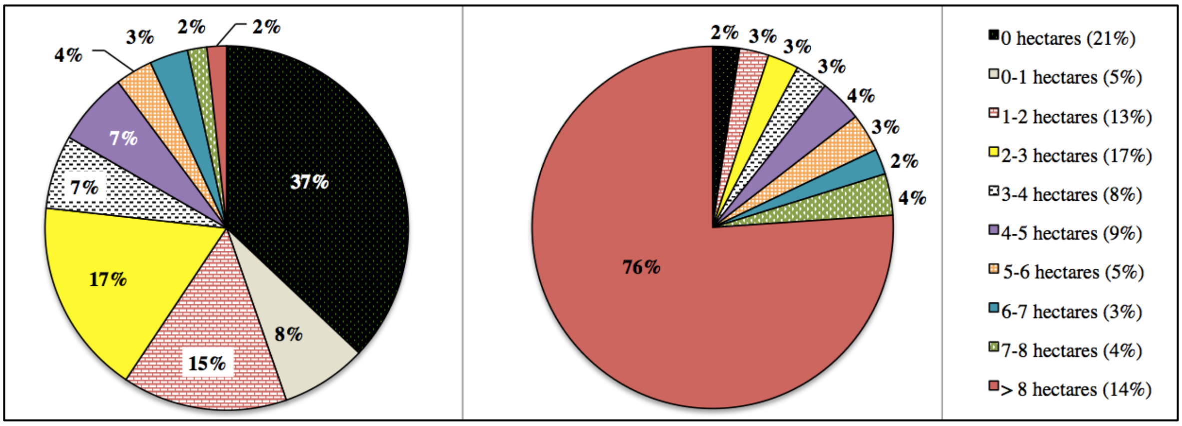


FUNDS	GINI
AGR LAB	0.07
LIV	0.46
VIN	0.47
OLIV	0.69
RF	0.76
PAST	0.86
IRR	0.86
WOOD	0.93
CROPLAND	0.58
FARMLAND	0.65

Source: Own elaboration based on the *Amillaramiento* and population censuses. Note: 'AGR LAB' refers to available agricultural labour, 'VIN' to vineyard, 'LIV' to livestock (LU500), 'OLIV' to olive groves, 'RF' to rainfed, 'PAST' to pastures, 'IRR' to irrigated land and 'WOOD' to woodland.

The need of the HHs to be hired in the labour markets (Necessary Labour Supply; NLS) was 32,820 working days (117 AWU), and 77% of the HHs had to sell more than 30 working days per year. The proletarian HHs (without access to land; representing 21% of the total HHs) contributed to 39% of the working days, and together with the semi-proletarian HHs of up to 3 hectares (representing 57% of the HHs) accumulated 80% of the temporary labour supply (see Figure 5.5). On average, the proletarianisation rate of the municipality was of 44% (assessed as paid work over total family agricultural work). Given the described shortcomings, in particular regarding land tenure records (see Section 4.A.1), the estimate of the proletarianisation ratio, together with the temporary labour demand, should be interpreted only as an order of magnitude. This issue will be further assessed (see Section 5.5.2).

Figure 5.5 Labour supply (left) and labour demand (right) (in annual working days; %)



Source: Own elaboration. Note: We put in brackets the percentage that each section (i.e. 0-1 hectares) represents within Sample 1, in number of HHs over the total.

The number of working days that the proletarians and semi-proletarians needed to sell on the market (NLS) did not have a specific seasonal pattern, but they were hired at the specific times when the demand required them. What was subject to monthly availability was Potential Labour Supply (PLS), that is, the amount of working days that each HH could offer each month. Given the strong seasonality of agricultural tasks, we observe the limits of the potential of the monthly male labour supply (see Figure 5.6), resulting in an estimate of the minimum participation of women and teenagers in paid agricultural activities.

The potential supply of male labour could cover the demand for work in all months, except in April and October (see Figure 5.6; Sample 1). In these two months, wages of women and teenagers were needed, which meant respectively 22% and 1% of the total temporary hired work. Nonetheless, the total PLS did not have the capacity to cover the needs for work hired in October, the month of greatest labour intensity in the vineyards due to the grape harvest (deficit of 2,000 working days). For this reason, the maximum annual hired work for the local population amounted to a maximum of 21,257 working days (80 AWU), which supposed 65% of the Necessary Labour Supply (NLS).

This mismatch between temporary labour demand and NLS may be due to the smaller sample with which we have worked. Although the sample covers a large percentage of the agricultural population (89%), it is not as representative in terms of farmland (65% of the total farmland area). If we include the potential labour demand of the excluded area (Sample 2; see section 5.2.3), the total temporary demand for wage labour increases to 36,999 working days (132 AWU), which would cover 113% of the NLS (see Figure 5.6). In this case, the proportion of female work would decrease to 18% and that of teenagers labour would increase to 2%.[45] Although we cannot assure that all the work of these farms was covered by wage work, we will use Sample 2 as a proxy for the gap of labour demand

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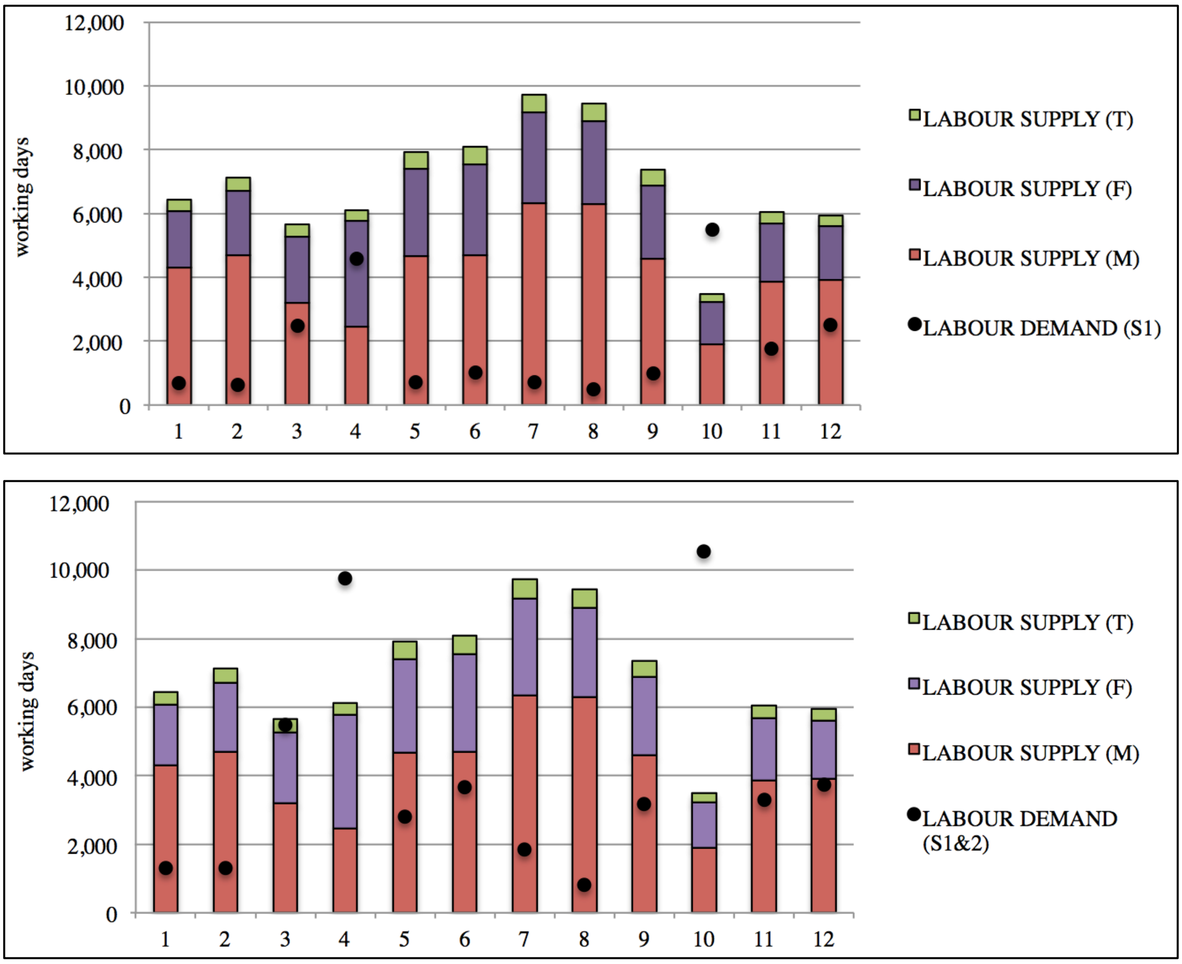
[45] It should be noted that when we include all the working days that must be sold, the total agricultural work of the population analysed increases to 94,028 wages (336 AWU).

and supply. As can be observed in Figure 5.6 (Sample 1&2), the total labour demand exceeded PLS during seasonal peaks, accounting for 38 AWU, which was probably covered by seasonal migrant labour

Figure 5.6 Temporary labour demand and supply (Sample 1 [above] and Sample 1&2 [below])



Source: Own elaboration. Note: Teenager (T), female (F) and male (M) work are indicated in parentheses.

Table 5.1 Temporary Labour Market Supply and Demand (in Agricultural Working Units)

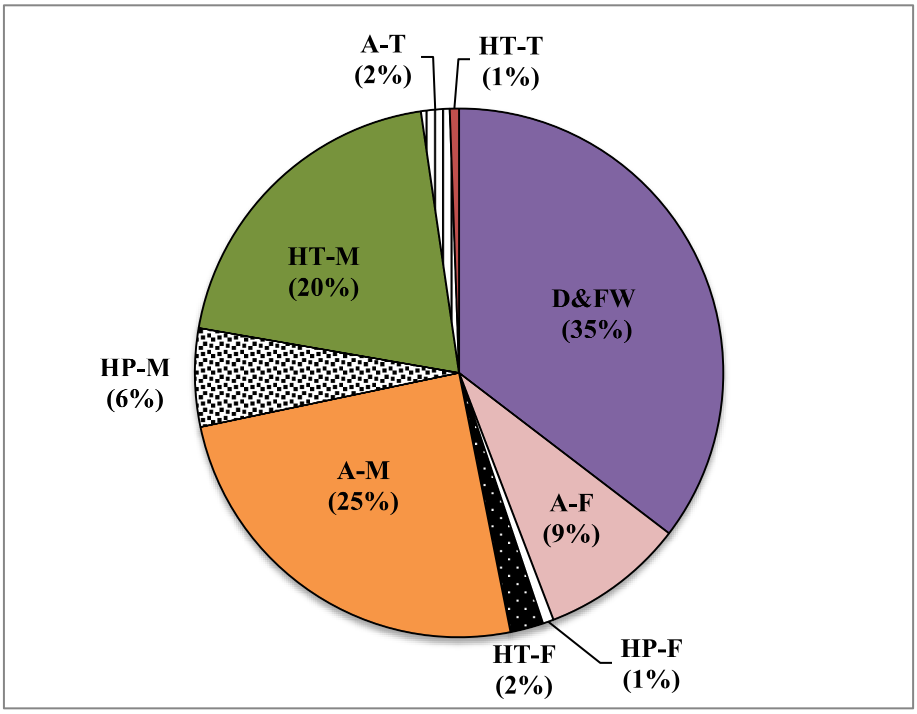
Total Labour Demand	**Sample**		**Potential**	**Feasible**
167	**Sample 1**	Permanent	35	35
		Temporal	79	76
	Sample 2	Temporal	92	56
	Total temporal (S1&2)		171	132
Necessary Labour Supply	117			

Source: Own elaboration.

Sexual Division of Labour

At the municipal level, DFW represented 35% of the total work of the agricultural HHs (184 AWU). The average weight of domestic work on the total work performed was 38%, and it remained quite stable among the HHs despite a slight decrease observed for the largest farms, mainly due to the increase in total work (see Figure 5.C). On average, 62% of the available female work was devoted to DFW (CV = 35%). As we have seen in the previous section, the minimum share of hired female labour, estimated through seasonal shortages of male PLS, ranged between 18 and 22% of the total hired work (female hired wages were 23% of the male wages). The same analysis through supply produces the result of 9%, suggesting higher pressure over female labour from the demand side (see Section 5.2.3). Finally, results show that women performed at least 25% of the total of autonomous work, and teenagers 5%. Overall, women's work represented at least 18% of all agricultural work (including dependent and autonomous agricultural labour), and 47% of the total societal necessary work (see Figure 5.7). Finally, we remind that due to our methodological assumptions the results might be underestimating the weight of agricultural female labour participation, as well as the overall female labour participation.

Figure 5.7 Sexual division of labour (Sentmenat, 1850)

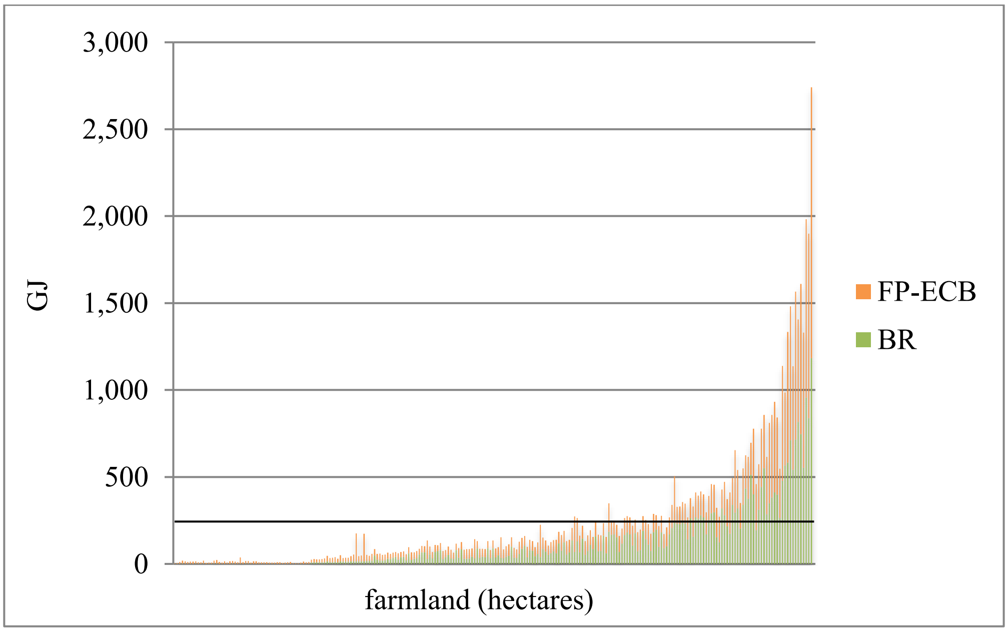


Source: Own elaboration. Note: DFW is Domestic and Family Work, A is Agricultural Autonomous (Male, Female and Teenager), HP is Agricultural Hired Permanent (Male, Female) and HT is Agricultural Hired Temporary (Male, Female and Teenager).

5.4.2 Agro-ecological effort: Biomass Reused and Final Productivity

At the municipal level, Biomass Reused (BR) accounted for 52% of Total Produce (TP), while the biomass that could be used for final consumption (Final Produce; FP) accounted for the remaining 48%; BR was shared between biomass reused for fertilising (21%) (Farmland Biomass Reused; FBR) or for animal feed (31%) (Livestock Biomass Reused; LBR). At HH level, though, distribution between shares of BR and FP vary considerably (CV = 49% for the share of BR and 44% for FP). This was mainly due to the different fertilisation strategies. Those HHs that had to bury biomass to close the nutrient cycles had a higher percentage of BR in TP, due to higher intensity of biomass recirculation of this fertilising techniques. These HHs were mainly characterised by having lower livestock density and/or smaller HH size, which caused a certain shortage of humanure and manure (see Figure 5.E in Appendix). The higher the percentage of BR in the TP, the lower the percentage of FP_{ECB}, which affected the final productivity of the funds (Final Produce [GJ_{ECB}] per unit of land and labor). Final Produce of biomass (FP_{ECB}) was 28,232 GJ_{ECB} (491 ECB), thus average energy productivity per HH was 116 GJ_{ECB} (2 ECB), although 75% of the HHs were below this threshold (see Figure 5.8). The average values were of 23.8 GJ_{ECB} per hectare of farmland (CV = 57%) and 0.34 GJ_{ECB} per working day (CV = 19%) (see Figure 5.9).[46]

Figure 5.8 Distribution of Total Produce per HH (disaggregated by FP+BR)



Source: Own elaboration. Note: The figures only include the HHs with access to farmland, although we assumed some subsistence farmland for landless HHs (see section 4.A.1).

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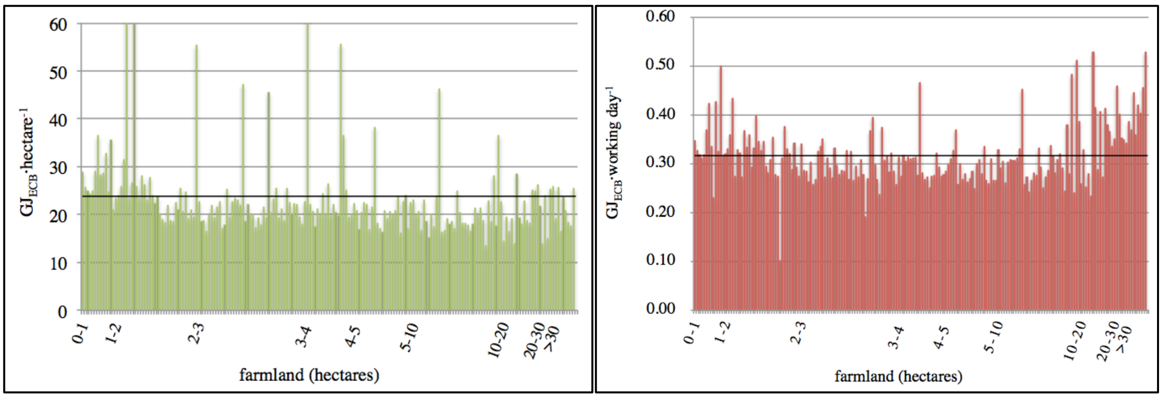
[46] Note that both coincide with the average FPLan and FPLab shown in Chapter 4/Section 4.4.1.

Figure 5.9 Final Productivity Land (FPLan) (left) and Labour (FPLab) (right)



Source: Own elaboration. Note: The figures only include the HHs with access to farmland, although we assumed some subsistence farmland for landless HHs (see section 4.A.1).

5.4.3 Social distribution of produce: Consumption and Surplus Accumulation

The above indicators inform us about the productive capacity of both funds (land and labour), as well as on the effects of access to fertiliser biomass on the percentage of production that can be used for direct consumption or for sale (FP). But these relative indicators (FPLand and FPLab) do not inform us about the different final situations of the HHs, since those were defined by the total access to farmland, in other words, to absolute produce. A first consumption-production balance (before labour markets) shows that 70% of HHs had a shortfall in produce to cover their basic consumption requirements, with a municipal cumulative deficit of 125 Equivalent Consumption Basket (ECB). On the other hand, 30% of the HHs were in a surplus situation, and accumulated 196 ECB.

Two income sources compensated the deficit (or increased the surplus): the sale of draught power (which incorporates a total income of 32 ECB, although mainly for large HHs, thus not reducing the deficit), and the sale of agricultural labour (total income of 155 ECB). These revenues allowed most of the HHs to cover expenses.[47] On the other side of the coin, the introduction of labour expenses in the balances reduces the cumulative surplus to 80 ECB.[48] The Social Productivity of Labor (SPLab) displayed in Figure 5.10 shows an average of 0.17 GJ_{ECB} per working day. As is clearly shown in Figure 5.10 there appears an absolute change in the trend, with a sharp increase of SPL concentrated in largest farms. In order to highlight this, we divide the series into two sections, depending on whether the access was lower or higher than 5.5 hectares (see Section 5.4.1), and we obtain that the average for the first sections (less than 5.5 hectares) was 0.15 GJ_{ECB} per working day (CV = 19%), and the average for the second section (more than 5.5 hectares) was 0.26 GJ_{ECB} per working day (CV = 66%).

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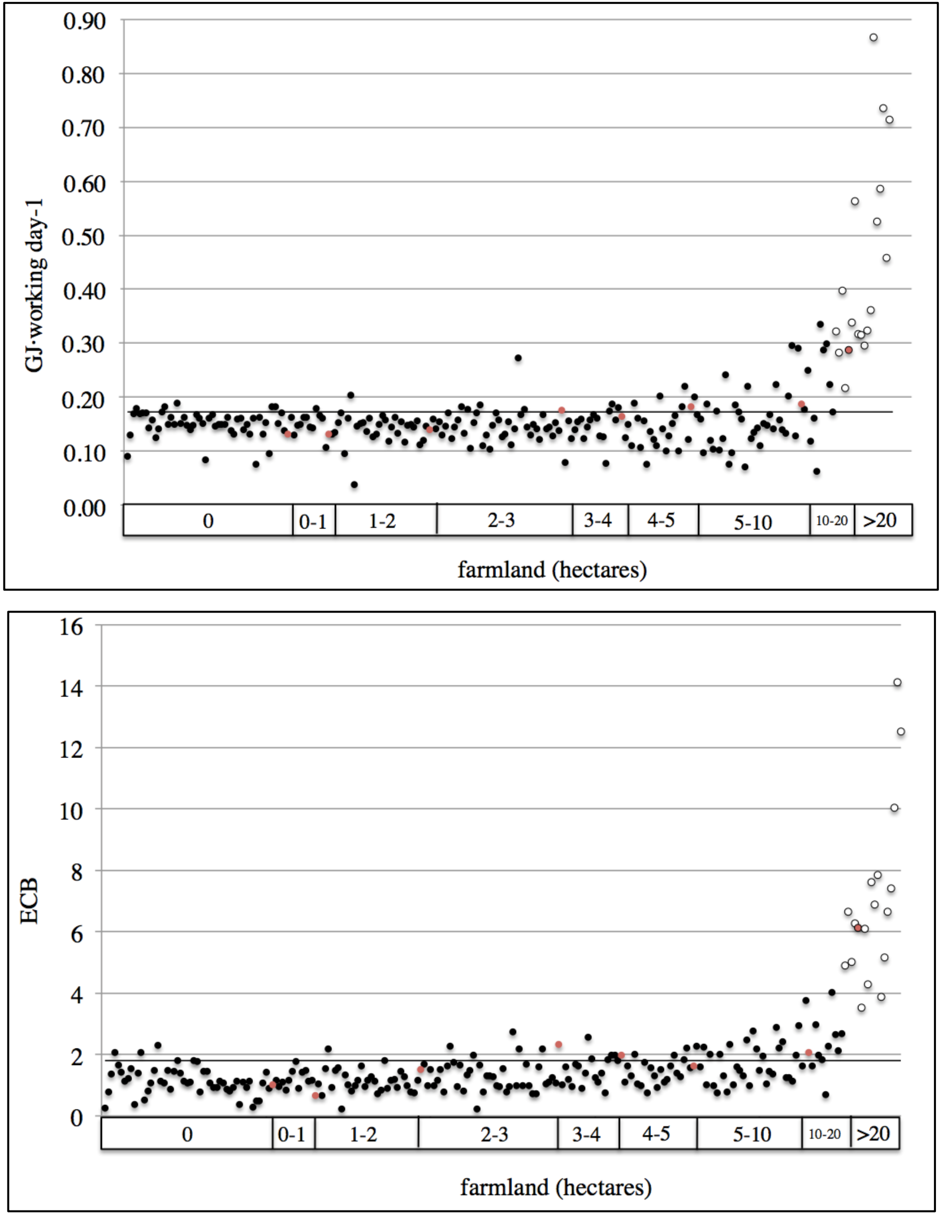
[47] Although we will not present the details here, we point out that still 18 HH had a cash deficit hired than 0.25 ECB and 8 of with deficits higher than 0.5 ECB. In inicial explanaition points towards HHs with a high dependency ratios, or highly dependent on female wages (which was half of the male wage).

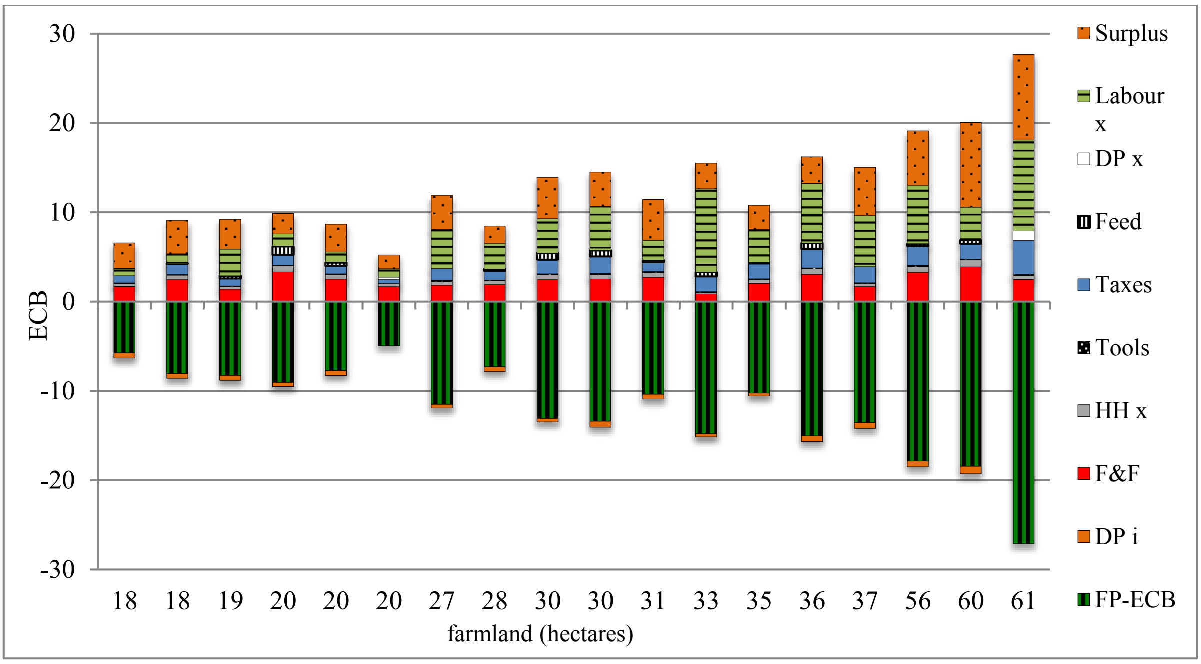
Differences between FPLab (Figure 5.9) and the Social Productivity of Labour (Figure 5.10) are very meaningful. While the rough appropriation per unit of labour (FPLab) is stable, inequality emerged during the social distribution of produce, thus after labour markets. The HHs with a higher SPL coincide with those that accumulate the profits; 80% of the profits (75 ECB) were concentrated in the last 18 HHs, all of them larger than 18 hectares of farmland (white dots in the figures), which coincides with the threshold of the surplus accumulation. Figure 5.11 represents the composition of all the expenses and incomes of these 18 HHs. On average, food and clothing expenses amounted to 32% (CV = 26%). A more detailed analysis of the features of each landowner will be necessary in future research.

Figure 5.10 Social Productivity of Labour (SPL) (above) and Social Appropriation of Produce (below)



Source: Own elaboration. Note: The figures display all the HHs included in the sample. The almost identical shape of both figures are due to the very similar amount of familiar labour within each HH. Red dots indicate the thresholds between different HHs section (i.e. 1-2 hectares).

Figure 5.11 Composition of income-outcome of the largest landowners



Source: Own elaboration. Note: 'Labour x' refers to Labour expenses, 'DP x' to Draught Power expenses, 'HH x' to Household expenses, 'F&F' to Food and Fuel consumption and 'DP i' to Draught Power income.

5.4.4 The Maximum Feasible Inequality

The analysis above allows us to analyse the features of the maximum feasible inequality proposed by Milanovic (2006). In our case study (Sentmenat, 1850) Total Production was 59.184 GJ. From this TP, 50% was devoted to reproducing ecological funds (soil fertility and livestock-barnyard). The biomass left for human consumption could be measured as 491 ECB (FP_{ECB}).[49] This socialised output had to reproduce the agricultural labour, on the one hand, and the domestic and care labourers and dependent population on the other hand. In order to keep the agroecosystem producing, the intergenerational reproduction of the labour force was imperative. If we account for the basic needs requirement (FPa1 and FPa2), 283 ECB were needed to cover the food and fuel consumption, and 74 for the clothing and housing rent. Only this basic needs flow would make a total of 358 ECB, or 73% of the FP_{ECB}, the surplus being 133 ECB. From this surplus, taxes absorbed 52 ECB, reducing the total surplus to 81 ECB (see Figure 5.2). Even if this surplus represented a smaller part of the FP_{ECB}, it still meant that 81 HHs (with the same size and composition of those of the model; see Section 5.2.1.1) could be feed and fuelled (representing 23% of the agricultural population held in the municipality).

The figure below (see Figure 5.12) shows the different inequality measurements of produce and surplus distribution. The first inequality line compares the distribution of the final human-appropriated produce (Social Distribution of Produce; FPa+FPs). The Gini coefficient for this distribution was 0.28

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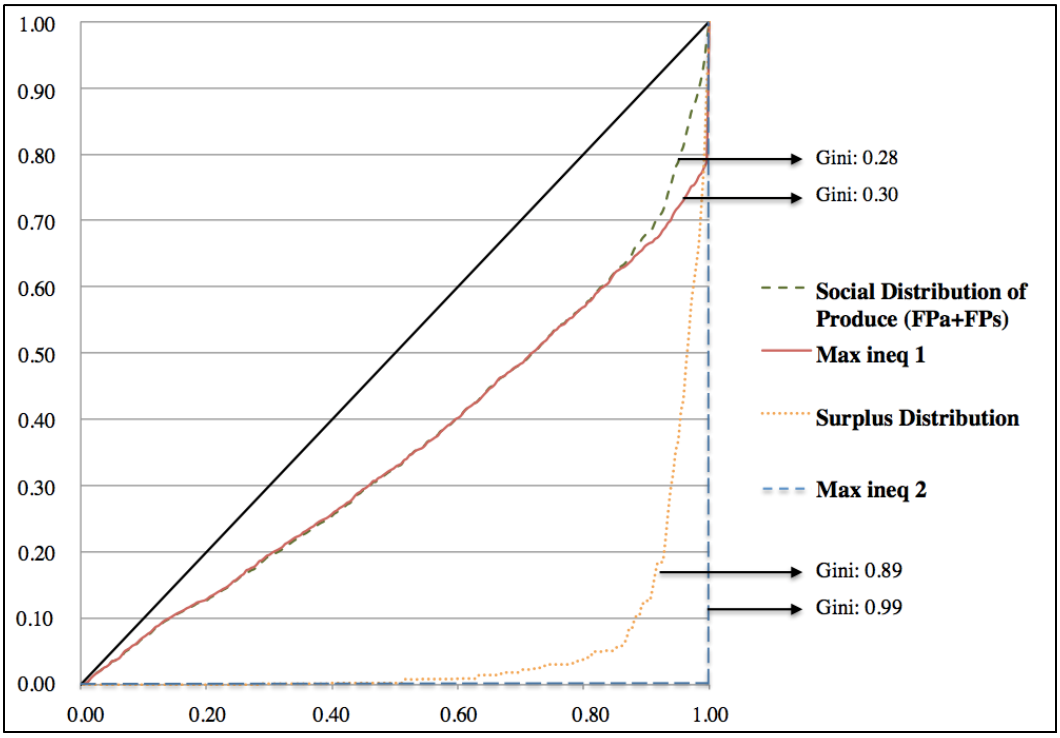
[49] This is one of the tricky consequences of transforming FP to FP_{ECB}, as both are measured in different units (GJ and GJ_{ECB}). Thus, when analysing the different flows (BR and FP) we need to clearly mention which are the measure units we are using.

(Gini 1). The maximum feasible inequality (Max. ineq. 1), where all the population except one household would lived at the subsistence level, raised a Gini coefficient up to 0.30. Accordingly, the Inequality Extraction Ratio was 95%, which meant that 95% of the maximum possible inequality was registered.

The second approximation refers only to the surplus appropriation process, represented by the second line (Surplus Distribution; FPs). The Gini coefficient in this case was 0.89. If we consider that only one landowner appropriated the whole surplus (Max. ineq. 2), the maximum Gini possible would be 0.99. In this case the IER would be of 90%. In the Discussion's Section we will compare our results with those proposed by Milanovic. As his methods are more similar to our first estimated IER (95%), which also includes subsistence consumption, this will be the one that we will use to compare with Milanovic's data.

Figure 5.12 Social Distribution of Produce and Surplus Distribution



Source: Own elaboration.

5.4.5 Subsistence wages

Finally, we analyse the results of the estimation of reproduction or subsistence wages for an average household. An adult male worker annually needed 5.8 GJ of food consumption (equivalent to 147 pesetas) and 11 GJ of fuel consumption (equivalent to 24 pesetas). Thus, the total annual basic consumption is estimated in 16.8 GJ and 171 pesetas. If the average percentage of agricultural worked days of the total available was around 64% (180 working days), the individual subsistence wage should be 0.95 pesetas per day. If we include the basic consumption of the children (for intergenerational reproduction) and the basic consumption of the wife (who ensured the DFW), the consumption of the HH increased up to 1 ECB (a total of 57.5 GJ and 499 pesetas) (see Figure 5.A). If we maintain the percentage of hired working days per year, the household subsistence wage should be 2.8 pesetas per day, which closely fits to the salary registered in historical sources (2.5 pesetas). Even better, 40 female working days (1.25 pesetas per day) would be required to close the HH's cash gap after male income, which means a HH with a total of 220 working days, and 18% of female agricultural labour over the total. Finally, when comparing the average FPLab (0.32 GJ_{ECB} per working day; CV = 19%) and the 'natural price' of work or subsistence wage (0.25 GJ_{ECB} per working day),[50] the difference between the two would be the potential appropriation of surplus during the process of contracting the labour force (22% of labour productivity; 0.07 GJ_{ECB} per working day).

5.5 Discussion

Here we want to focus on three different debates: (i) the estimates of women's participation in the social organisation of labour, (ii) the social distribution of produce and the ensuing social class inequalities, (iii) the maximum feasible inequality and Inequality Extraction Ratio and (iv) the role of reproductive prices.

5.5.1 Women's participation in the Social Organisation of Labour

Although it is a very tentative estimate, bringing to light female participation in agricultural labour is one important contribution of this work. Under-recorded women's work within the nineteenth century statistics has been studied for many European countries (Humphries and Sarasúa 2012). In particular, evidences suggest substantial under-reporting of female agricultural labour (Higgs 1995; Sarasúa 2000; Van Nederveen Meerkerk and Paping 2014), which has been 'the most common and simultaneously the most invisible' (Van Nederveen Meerkerk and Paping 2014:454). In our case, female labour represented 18% of total agricultural labour. Results are consistent with the few similar analysis made for other case studies. Based on local sources, Colomé (2000) estimates that women performed 18.4% of the total required labour for one hectare of vineyard c. 1861 (San Sadurní d'Anoia, Catalonia). Van Nederveen Meerkerk and Paping (2014) compare male and female wage work of labourers not living in the farms for some farms in Groningen (Holland) between 1773 and 1904. The share of women working days over male ones was around 30% (Van Nederveen Meerkerk and Paping 2014:462), while the same indicator for Sentmenat was between 23% (Sample 1) and 28% (Sample 1&2).

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[50] In energy terms, if the annual basic consumption is 56 GJ, and we estimate 220 days of hired annual work, it is necessary to obtain 0.25 GJ_{ECB} per working day.

At national scale, and according to the 1877 census, the female share of the economically active population working in agriculture within the total agriculturally active population was 19% (Sarasúa 2000:86); a score that has been re-estimated to 21% by Maluquer de Motes (2016:58-59). Although our results seem similar, their meanings are different. Our approach estimates that around 18% of total agricultural labour was performed by women, but considers almost 100% of the women living in agricultural HHs as agriculturally actives. Muñoz-Albeledo (2012) provides higher female participation rates for rural Galicia (44%) by contrasting official censuses.

Almost all the research studies on female labour participation exclude DFW, mainly for the difficulties to obtain credible estimations. We emphasise the need to include DFW in order to (i) better understand the total labour required for socio-ecological reproduction (which would be around 54% underestimated if not included); but also to (ii) understand the sexual division of labour and the lower percentage of female agricultural activity. The fact that 184 AWU were devoted to DFW limited the availability of female labour in agriculture. An average of 62% of total female available labour was devoted to DFW, and female agricultural available labour (after deducing DFW) was 46% of the male one. This means that dedication to DFW supposed a work in itself. As an example, it is relevant how, for Groningen (Holland) in the nineteenth century, a strong and negative correlation was found between the amount of available female family labour and the number of servants employed, concluding that 'farmers' wives and daughters performed more or less the same tasks as the live-in female servants' (Van Nederveen Meerkerk and Paping 2014:457).

Considering both DFW and agricultural labour, and even taking into account the minimum of agricultural work participation, female and male labour share within the total labour required was almost identical. The labour performed over the available labour was around 77% per both sexes. This challenges the understanding of women economically active in agriculture, when it is perceived as waged, permanent and continuous labour. Female agricultural participation was complemented by DFW, which makes difficult the interpretation of what *agriculturally active female* meant. Which amount of time devoted to agricultural tasks can be considered enough to label them as agriculturally active? Paping (1995) proposes tentative estimates of average female labour input in the Groningen clay region of around 190 days per year for farmers' wives and daughters, and 115 for female labourers (Paping 1995), i.e. 68% and 39% of a full-time labour status. Similarly, Llovet (1937) proposed for a Catalan municipality to apply a coefficient of 60% to female agricultural labour with respect to agriculturally active male.

5.5.2 Social inequality and wage labour in Catalan preindustrial agriculture

The results found reaffirm the hypothesis posed in previous works on the creation of labour markets through land grabbing (see Chapter 4). The results suggest that the total amount of work exchanged through the market was important, around 40% of the total agricultural labour. This could be one hidden piece of the puzzle about agricultural inequality in Catalonia, as the perception of the importance of proletarianisation in Spain has been much more related to west-southern regions. Research studies on Catalan agricultural cases show that 'for a high proportion of families - which, with some exceptions, ranged from half to two thirds of the rural population - their farmland patrimony did not allow economic reproduction' (Garrabou et al. 2014:136). For Sentmenat, between 37 and 62% of the HHs had annual incomes lower than a male annual wage (Garrabou et al. 2014). Colomé (2000) also argues that a large part of the population probably had difficulties to guarantee their reproduction, and he defines the threshold of necessary farmland for household reproduction below 5 hectares. Padró et al. (*forthcoming*) proposed for Sentmenat c.1860 a threshold of 4.3 hectares from a reproductive perspective (including nutrients replenishment and livestock feeding). Therefore, more research was needed to understand the mechanisms through which many Catalan agricultural families were able to reproduce themselves (that should include sharecropping, rural or urban wage labour and direct natural resources appropriation [i.e. gathering, hunting or theft]).

Our results show how labour demand of large landowners did fit with the income requirements of landless peasants and small landowners, and that this would explain almost the whole subsistence gap. Although this was also dependent on the HHs structure, the thresholds would be around less than 3 hectares (80% of labour supply) and more than 8 hectares (76% of labour demand). While a low share of the HHs (7%), which accumulated 45% of the total farmland, kept a large share of total surplus after taxes (81%), the vast majority of the population only had access to enough resources to cover basic needs (food, fuel and housing). The latter result might be affected by the methods used, as we assumed that the sale of labour force was the minimum to cover basic needs. However the work surplus (around 30%) that was above all estimates of labour demand (see Section 3.1.1) suggests that the capacity to sell more labour (and thus to obtain more resources besides subsistence) was not much greater than the one considered. Furthermore, the strong adjustment of the estimated subsistence wage to the wages recorded in the available historical sources indicates that our estimate of the number of hired wages is close to the annual average of working days.

Despite this, we would like to point out a significant limitation of these results, and propose a new insight emerging from our approach. The lack of available sources that could give us detailed information about land tenure structure (see Section 4.A.1), required us to assume that the whole HH mismatch between labour availability and labour requirements was entirely covered through labour markets. Actually, the same gap could be partially covered through other adjustments that 'mobilised' farmland (i.e. sharecropping or land leasing). Hiring labourers, or leasing lands, were alternative options for the landowners, with important consequences for smallholder families and the social relationships set up in the whole agrarian class structure. This means that our results would probably be overestimating the weight of proletarianization and omitting other relevant forms of surplus appropriation carried out through the land market. Our point here is to suggest the need to rethink the relevance of wage labour within Catalan agriculture in relation to land tenure patterns.

Nevertheless, from a broader perspective, what is certain is that our results show that more than 40% of the labour required by landownership could not be covered by autonomous family labour. Given that the aim of this work is to understand the social conflict around labour and produce distribution, it is important to observe that, in fact, landowners had two possible adjustments (through labour markets or land markets) to extract labour surpluses from smallholder and landless families. Our contribution highlights the importance of the reproductive cost of the labour force, which in any case entailed a small surplus extraction per unit of labour.

The combination between the existing biophysical constraints to labour productivity, and the cost of reproducing the labour force, set an upper limit to every type of surplus appropriation. This led to a small range of Extraction Ratio variation in which all the ensuing outcomes must be kept. As a result, landowners had to control a large quantity of farmland to be able to grasp a significant surplus. We acknowledge that forthcoming researches have to go deeper into the alternative or complementary use of land and labour markets by the landowners. Yet we deem that our present estimates on Inequality Extraction Ratio, currently made only taken the labour market into account, will not vary greatly when other alternatives are considered. Hence, in general terms our interpretation of the role of social inequality in Socio-Ecological Transition would remain.

Another consequence of the small ratio of surplus extraction per unit of labour is the low values of inequality coefficients measured by final income. One of the main contributions of this work is to allow comparing the initial distribution of funds (i.e. farmland), which has been widely analysed by previous research on rural inequality, with the social distribution of produce, which we put forth here. Huge differences between both are clearly related to the redistribution process that was taking place through the labour market, although it might not have been the only way. This also means that Gini coefficients need to be carefully compared with other studies, as they assess different distribution scenarios. Because of a lack of registration of final income levels in preindustrial agricultures, inequality assessment has usually been done through landownership distribution.

Gini coefficients for landownership distribution in Sentmenat have been calculated at 0.71 (Garrabou et al. 2014) and at 0.57 (Tello and Badía-Miró *in press*).[51] Even Garrabou et al. (2014) did not include labour expenses within the estimates of maximum-minimum incomes, which would be probably overestimate the incomes for large landowners and underestimate incomes for smallholders. As has been described in this paper (see Section 3.2.2), labour expenses were an important part of total farm expenses of wealthy landowners. A recent work by Tello and Badía-Miró (*in press*) estimates an average Theil coefficient of 0.20 for the agrarian income distribution in the province of Barcelona in 1852, including a minimum income for all male adults as a proxy for the earnings from labour market.

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[51] Badía-Miró and Tello (2014) show aggregated Gini coefficients for several municipalities of the Vallès County in the nineteenth century. The specific Gini coefficient for Sentmenat has been transmitted through personal communication.

In fact, our Gini coefficient confirm their assumptions. Differences between the Ginis estimated through the access to resources (i.e. farmland) and those calculated through estimated final incomes (including wages) do not mean that one has to prevail over the other. Both give us different qualitative information. In fact, landownership structure would be defining the distribution of labour, and the final redistribution of produce.

5.5.3 Subsistence wages, maximum feasible inequality and socio-ecological transitions

From an overall analysis of actual inequality and maximum feasible inequality it is possible to compare the Inequality Extraction Ratio (IER) here found with other studies. IER in Sentmenat was 95%, which means that 95% of the feasible inequality occurred. Milanovic observes a similar pattern for preindustrial economies c. 1820, where global IER was 97% (Milanovic 2011:8). He finds that the most ‘modern’ preindustrial economies (i.e. Holland and the Netherlands c.1561-1808; France c.1788, and England and Wales c.1688-1801) were the ones with the largest absolute distance between the observed inequality and the maximum feasible inequality (Milanovic et al. 2011:264). Our case study would be situated within the less ‘modern’ preindustrial economies, and this might be related to its agricultural basis, a common feature of the so-called ‘non-developed economies’.

Milanovic argued that ‘as the average income grows, the constraint on the maximum Gini is relaxed’ (Milanovic 2011:9). This could be better understood noting that when the surplus was larger, the maximum feasible inequality increased too. As has been earlier mentioned, Sraffa argued a very similar proposal with the so-called ‘fundamental Sraffian equation’ (Barceló 1994). As has been widely argued, biophysical and economic growth limitations of agrarian socio-ecological regimes, represented in this case by preindustrial agricultures, were due to its dependence on the harvest of solar energy converted by plants, thus its limited available energy (Wrigley 1988). Indeed, working dependence on human and animal bioconverters compelled to a low overall efficiency of the conversion of primary into final and useful energy, which has been estimated at less than 5% (Krausmann et al. 2008b). We argue here that preindustrial agricultures had lower capacity to generate surplus because they relied on live reproductive funds (farmland, human and animal labour) that had high reproductive requirements. We include here the need to consider the total costs of labour force reproduction, including intergenerational reproduction. In its commodified version, we found a strong adjustment between reproduction wages and wage labour productivity (78%). The thin margin between labour productivity and reproduction requirements of labour force affected the capability of landowners to increase the appropriation of produce. Hence, the increase of this surplus appropriation rates had to be obtained mainly through an extensive growth.

We found two relevant implications of the processes mentioned above. First, for our understanding of social inequality as an ‘ecosystem disease’ and second considering the role of social inequality as one of the agents of socio-ecological transitions. Regarding the first issue, higher produce appropriation by elites (i.e. through lower wages) meant higher pressure on ecological funds reproduction (i.e. trough agricultural intensification in order to get higher output flows per land unit), as has been already stated by González de Molina and Toledo (2014). If we consider our case study as a zero-sum game, under the pressure exerted by an increase of surplus flows, there was a necessary reduction of the rest, which could imply (i) a reduction of fertilising biomass (FBR), (ii) a reduction of livestock feeding (LBR) or (iii) a reduction of human food or fuel consumption (FPa1) (see Figure 5.2). This process was similar to the one exerted by demographic pressure on land and as Boserup (1965, 1981) stated, this could also lead to agroecological innovations. As (Padró et al. *forthcoming*) stated for the same case study c. 1860, demographic pressure was not the main driver of pressure over ecological funds reproduction, but could probably be better explained by social inequality. Second, increases in total produce, particularly through technical change (or the development of productive forces), would increase total surplus and would be a shock absorber of social conflict as a consequence of the distribution process between labourers and landowners. In particular, this would mean shifts from relying on reproductive-renewable funds to relying on non-renewable stocks. Thus, could social conflict lead to technical change?

5.6 Conclusions

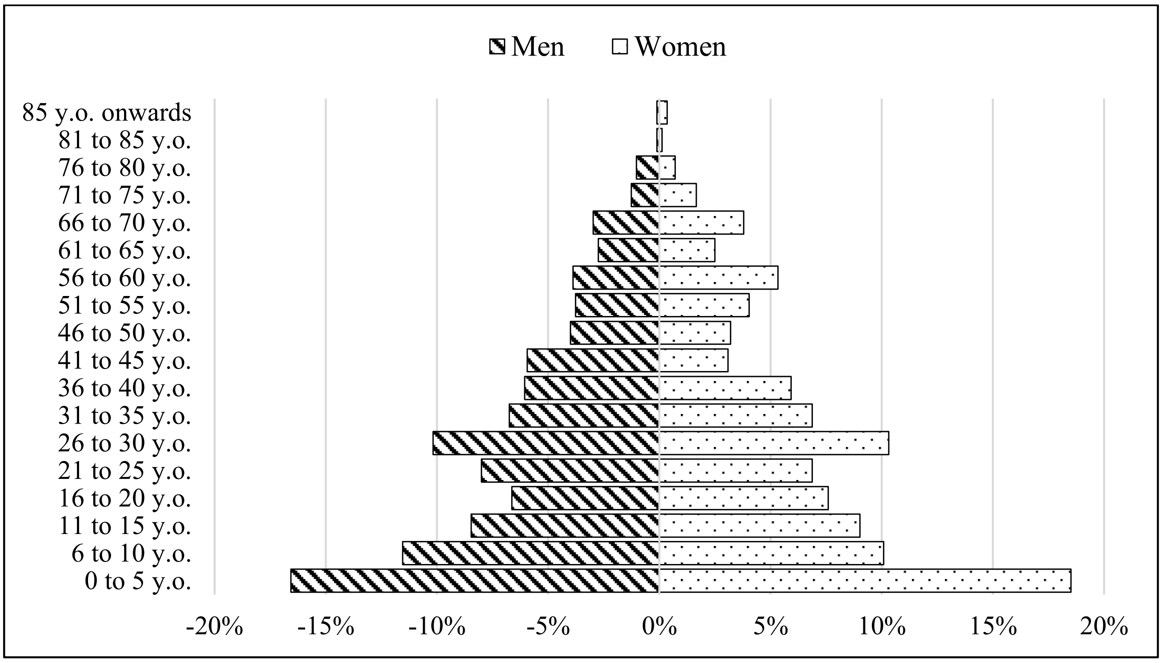
We have tested the methodological proposal to reconstruct socio-ecological reproductive structures of advanced organic agricultures. The methodology of multidimensional balances (biomass, energy, labour and cash flows) presented here allows us to build up a framework where ecological, feminist and social perspectives can be easily related. Through the concept of socio-ecological reproduction we interlink ecological (un)sustainability, invisibility and relevance of domestic and care works, and class inequalities formation through land grabbing. The results obtained show the robustness of our methodology and the coefficients used. From a historical point of view, this methodology has demonstrated its explanatory capacity, and its potential to reveal several aspects of the preindustrial agricultures that are difficult to assess from the available historical sources using more conventional approaches to rural inequality. Thus, biophysical accounting can be used to add some new insights to different on-going academic discussions.

The methodology we followed has been to able to show several different and relevant aspects of the socio-ecological reproduction processes, through the links between energy, material, labour and cash flows. In its application at municipal level we confirmed the hypothesis posed in Chapter 4, which is that trough land grabbing large landowners assured the required wage labour supply and surplus extraction. This also revealed that a significant share of total agricultural labour (40%) could not be performed as autonomous domestic labour, meaning that the mismatch had to be adjusted either through labour or land markets. DFW revealed itself as a substantial flow (37%) too, which also helps us to better understand the features of female agricultural labour. Finally, surplus analysis shows a small capacity to extract surplus from agricultural practices, and to raise the required farmland area to be able to generate surplus up to 18 hectares of farmland. The low development of productive forces entailed a huge Inequality Extraction Ratio (95%), which depicts the strong social conflict over produce distribution. Finally, we ask ourselves whether this could set in motion a dynamics of social conflict that lead to technical change process.

APPENDIX CHAPTER 5

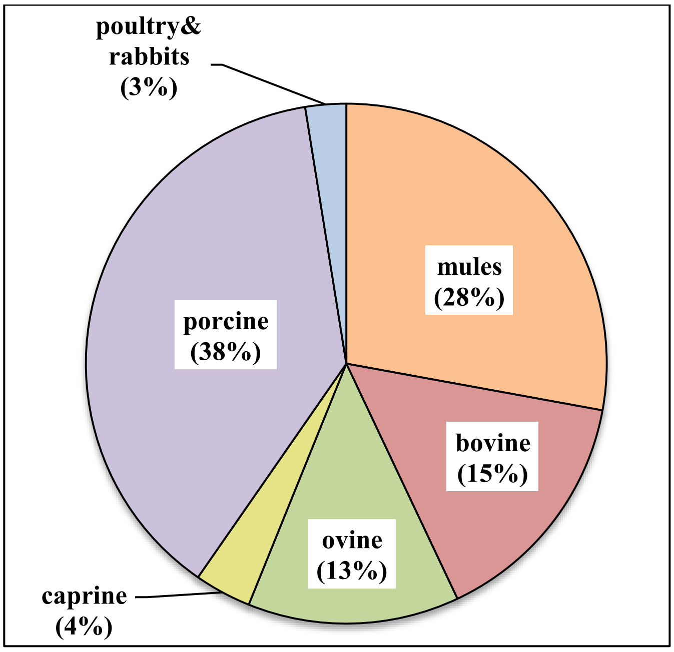
This Appendix include some complementary Figures and Tables.

Figure 5.A Population pyramid (Sentmenat, 1850)



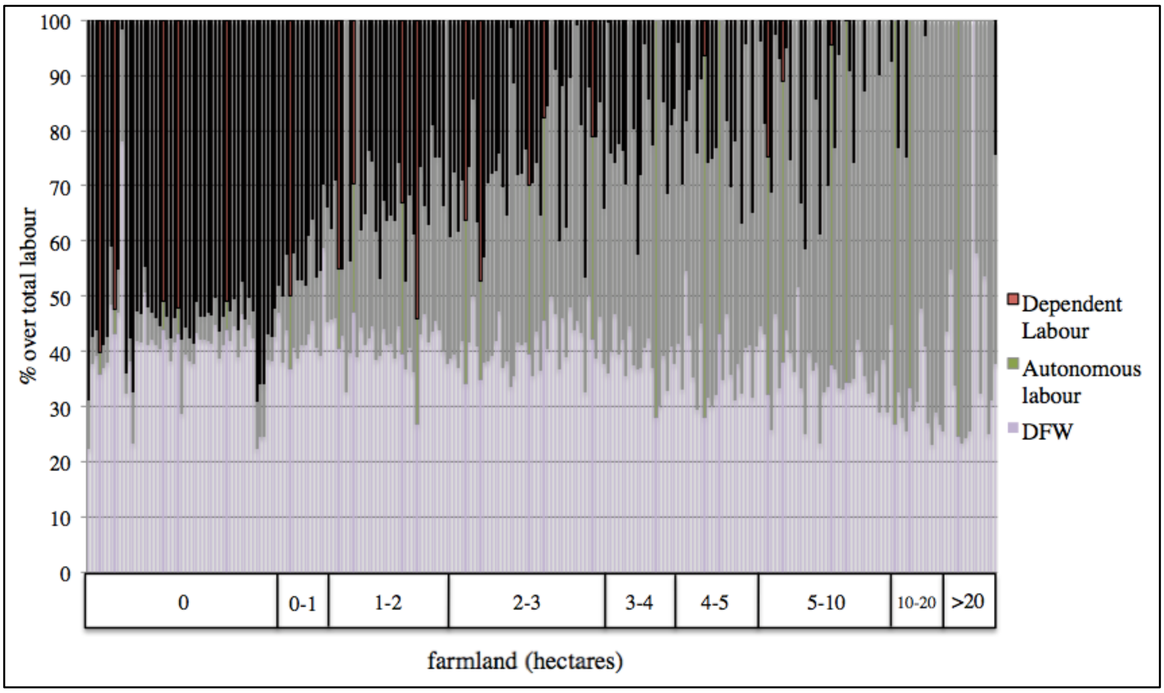
Source: Own elaboration from population census (Sentmenat, 1850).

Figure 5.B Livestock composition (Sentmenat, 1850)



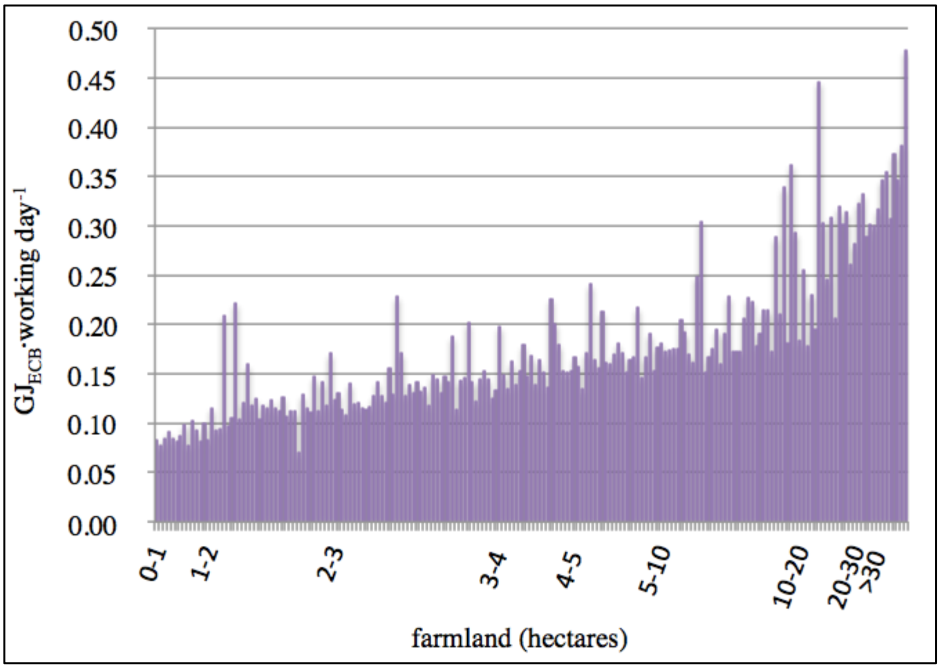
Source: Own elaboration based on sources mentioned in the text (see Section 2.3.4)

Figure 5.C Share of Agricultural and DFW over Total Labour (%)



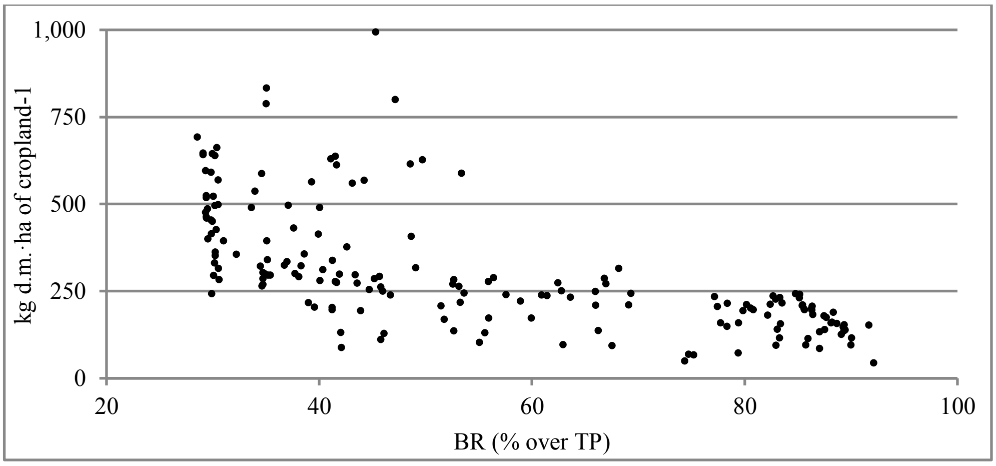
Source: Own elaboration. Note: The figures only include the HHs with access to farmland, although we assumed some subsistence farmland for landless HHs (see section 4.A.1).

Figure 5.D Total Productivity of Labour (TPLab) (Sentmenat, 1850)



Source: Own elaboration

Figure 5.E Manure&Humanure availability and BR weight

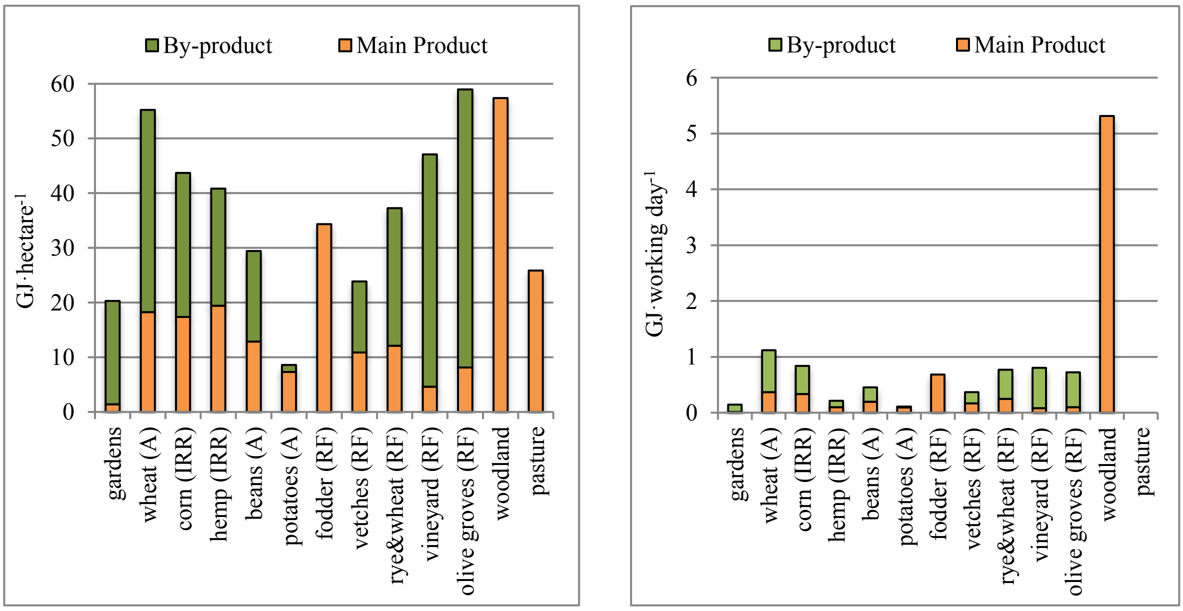


Source: Own elaboration. Note: The figures only include the HHs with access to farmland, although we assumed some subsistence farmland for landless HHs (see section 4.A.1).

5.A.1 Land use pattern effect on productivities

As shown in Figure 5.F, there was a certain variability in total energy yields per hectare, with the most productive crops being woody crops and woodland. The differences could also be due to the different qualities of the soil. We must bear in mind that in the case of rotations of non-permanent crops (irrigated and dry) the effect of crops with higher energy efficiency (i.e. cereals) might be compensated with the lower yields of others (i.e. potatoes and legumes). Finally, the stability of this indicator for the different HHs is quite stable, which indicates that the weight of the different land uses is compensated within each one (e.g. irrigated versus rain-fed). On the other hand, the greatest variations in the energy productivity of labour are greater, mainly due to the presence of woodland.

Figure 5.F Total Productivities (land-left and labour-right) per land use



Source: Own elaboration.

5.A.2 From Final Produce to Final Produce in ECB

Table 5.A Composition of the Equivalent Consumption Basket (ECB)

Basic Basket	Annual Fresh Weigth (kg.)	Cost (ptas)	GCV (GJ)	$GJ\cdot pta^{-1}$	$pta\cdot GJ^{-1}$
FOOD	1,866	401.8	15.2	0.038	26.4
FUEL	3,431	96.1	42.2	0.440	2.3
TOTAL	5,297	497.9	57.5	0.115	8.7

Source: Own elaboration from several historical sources (see Appendix CH-3 and CH-4)

Barceló (1994) pointed out that:

> '(…) from the approach of reproduction and surplus the thesis is held that the price of a good reveals the difficulty (or sum of efforts required) to produce it. And, at least as a schematic approach, it states that this difficulty can be measured by the amount of work embedded in said merchandise, an amount that is an autonomous techno-economic property in relation to the price of the merchandise. So from this point of view any -structural- increase (or decrease) of a relative price is ultimately caused by the increase (or decrease) in the amount of direct and indirect work required to obtain it' (Barceló 1994:24).[52]

We analysed the relationship between the work requirements of each type of crop, its energy productivities per hectare and the prices per energy unit (see Table 5.B). The results confirm the hypothesis that the lower price per unit of energy of the firewood, in comparison with the higher prices of the energy units in the form of food, was linked to the lower labour requirements per unit of product. In the case of wheat and firewood, each working day would be producing a similar monetary value (around 10 pesetas). In the case of wine, the higher price per unit of energy did not compensate for the lower energy yield per hectare, and with the necessary work intensity being similar, the yield per day remains below.

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[52] Translated by the authors from Spanish.

Table 5.B. Embodied energy, labour and cash for different agricultural products (Sentmenat, 1850)

	WHEAT		CORN		WINE		FIREWOOD
	main product	**by-product**	**main product**	**by-product**	**main product**	**by-product**	
working days·hectare	49,4		52,1		58,7		10,8
GJ·hectare	18,0	41,8	17,4	26,3	4,6	36,5	45,5
GJ·hectare (total)	59,8		43,7		41,1		
GJ·working day	0,4	0,8	0,3	0,8	0,1	0,6	4,2
GJ·working day (total)	1,2		1,2		0,7		
peseta·GJ	19,9	3,1	18,2	0,1	42,3	0,9	2,3
peseta·working day	7,3	2,6	6,1	0,1	3,3	0,6	9,6
peseta·working day	9,9		6,2		3,9		

Sources: Own elaboration

In this way, we consider that the proposal to transform the energy content of the production of each HH, depending on the composition of this, through the coefficients of the ECB, does not imply an explicit bias given the characteristics of the markets, and especially of the relative prices of the products, but the result would allow us to approach the objective of cushioning the effects of the diversity of energy qualities. Despite this, we should note that we found different trajectories in the transformation of the original FP to the homogeneous one. In aggregate terms, the FP increases by 1.5%. Despite this, the variations in the different HHs are diverse. For those cases in which the PF is reduced through the transformation, it is mainly due to a greater presence of by-products in the final production (case 1; where ptas/GJ ratio was lower than the average basket ratio [8.7]). In cases where it increases, it depends on the greater presence of wine, with a very high exchange rate of ptas·GJ^{-1} (case 3).

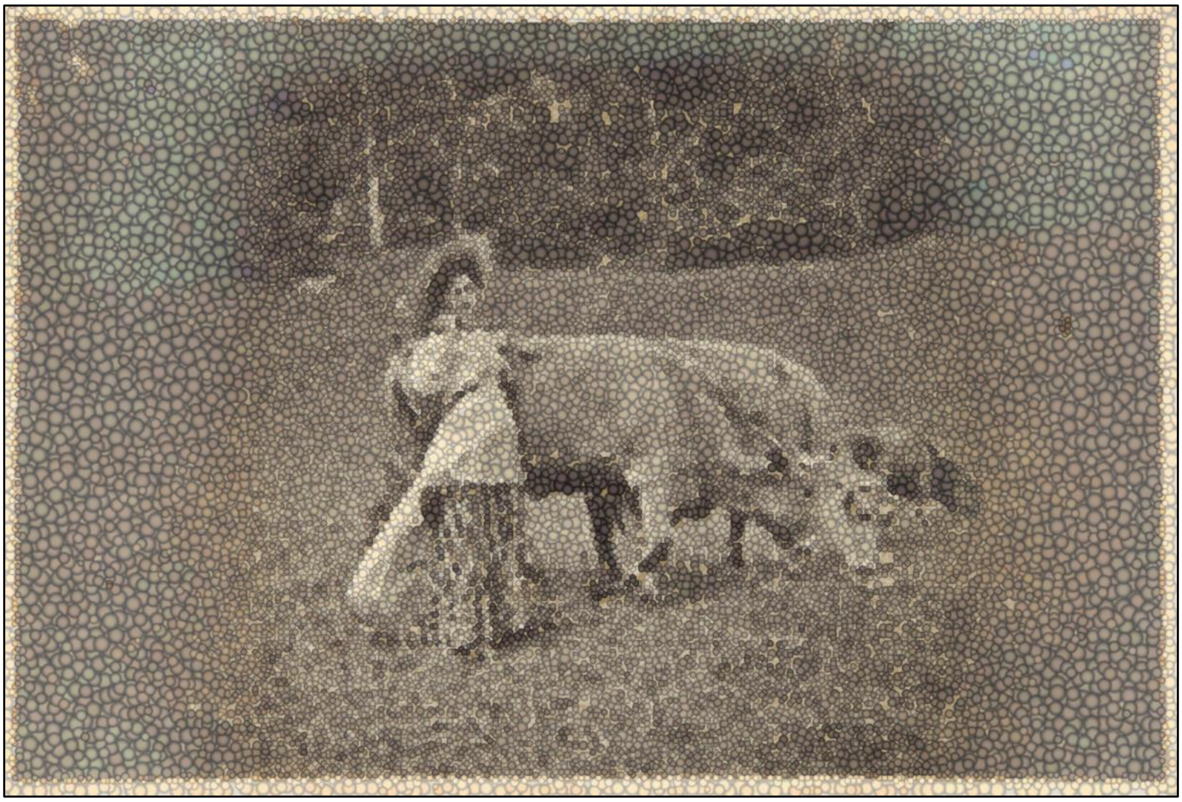
5.C Different patters of change between Final Produce (FP) and Final Produce in ECB (FP_{ECB})

Case 1; 40% reduction					
Products	**GJ**	**%**	**ptas**	**%**	**ptas·GJ-1**
Basic consumption	1.7	2.1	36.1	8.3	21.2
Wine	6.9	8.7	293.6	67.8	42.3
Vineyard by-products	70.6	88.5	65.3	14.7	0.9
Wheat (grain)	0	0	0	0	0
Fodder	0	0	0	0	0
Potatoes	0	0	0	0	0
Olive oil	0	0	0	0	0
Olive tree pruning	0	0	0	0	0
Olive tree replacement	0	0	0	0	0
Meat and eggs	0.5	0.7	39.7	9.2	72.8
TOTAL	**79.8**	**100**	**432.8**	**100**	**5.4**

Case 2; 50% increase					
Products	**GJ**	**%**	**ptas**	**%**	**ptas·GJ-1**
Basic consumption	3.8	8.9	81.6	14.1	21.2
Wine	7.2	16.7	305.8	52.7	42.3
Vineyard by-products	25.5	59,0	22.9	4.0	0.9
Wheat (grain)	3.1	7.2	73.6	12.7	23.7
Fodder	2.4	5.5	39.0	6.7	16.5
Potatoes	0.6	1.5	18.7	3.2	29.3
Olive oil	0	0	0	0	0
Olive tree pruning	0	0	0	0	0
Olive tree replacement	0	0	0	0	0
Meat and eggs	0.6	1.3	38.5	6.6	69.8
TOTAL	**43.2**	**100**	**580**	**100**	**13.4**

Case 3; 256% increase					
Products	**GJ**	**%**	**ptas**	**%**	**ptas·GJ-1**
Basic consumption	4.3	17.1	90.4	16.1	21.2
Wine	9.3	37.2	393.9	70.3	42.3
Vineyard by-products	5.7	22.9	5.1	0.9	0.9
Wheat (grain)	0	0	0	0	0
Fodder	0	0	0	0	0
Potatoes	0	0	0	0	0
Olive oil	1.1	4.4	34.5	6.2	31.2
Olive tree pruning	3.9	15.5	3.5	0.6	0.9
Olive tree replacement	0.3	1.0	0.6	0.1	2.3
Meat and eggs	0.5	1.9	32.5	5.8	69.1
TOTAL	**25**	**100**	**560.5**	**100**	**22.4**

CHAPTER 6:
Conclusions



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CHAPTER 6:
Concluding remarks about the historical analysis and discussion for future research

This Chapter is divided in two sections. Section 6.a focuses on the conclusions of Chapter 3, whereas Section 6.b summarises the main outputs of Chapters 4 and 5.

6.a *Contributions to understanding the Socio-Ecological Transition from past organic to industrial farming*[53]

(i) Chapter 2 represents the first application of the methodology agreed upon in the Sustainable Farm Systems project (Tello et al. 2015, 2016; Galán et al. 2016) to the case study of the Vallès County used as a test bench by the SFS Catalan Team. This paper has a clear methodological relevance, as it represents an effort to describe in detail the steps, procedures and assumptions followed. The diagram described in the Appendix (see Figure 3.B) as well as most of the coefficients used have served as the basis for the following Chapters.

(ii) In the interpretation of the results, I highlighted the role of the nutritional transition and the energy transition as two relevant factors in understanding the socio-ecological transition. On the one hand, the transformation of demand towards different food products had an effect on the structure of land uses, and in its advanced stage it has been based on patterns of strong territorial specialisation. The increase in the demand of cheap products of animal origin as a substitute for vegetable protein gave rise to livestock breeding intensification processes. On the other hand, availability of gas cylinders and other types of modern energy carriers for domestic use led to a process of abandonment of traditional heating practices based on firewood and charcoal. This energy transition went hand in hand with the forest transition, which generated a major process of forest abandonment. Both transitions have entailed a disconnection of human communities and their basic needs (food and fuel) from the territory. While more and more basic needs were covered from other territories (through markets), the territory itself was functionally adapted to the needs of external consumers and markets. The local agroecosystem was then traversed by enormous energy and material flows that simply moved across this territory.

I want to connect both processes with what was presented in the second stage of this PhD thesis. In the first place, we can link the generalisation of the increase in the consumption of products of animal origin as the effect of a 'positional consumption' (Scitovsky 1976). The nutritional transition started in the late nineteenth century in Spain, with a generalised consumption pattern that was previously reserved for the upper classes, and whose factors included a regular consumption of food of animal origin (Collantes 2010). This 'reference' diet had already spread in many areas of

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[53] Given that the first article of this thesis is also the oldest, I have allowed myself to slightly redraft the thematic thread of what we proposed in the published version.

Europe, including the significant weight of products of animal origin (Montanari 1993; Fernández-Armesto 2004). Second, the transition to the common use of modern energies for domestic use, such as gas cylinders or electricity, responded to other types of logic. Greater ease in the processes of appropriation, storage, management and security facilitated the basic functions of cooking, heating and cleaning, therefore reducing the time spent in a society increasingly less linked to the agricultural sector and the territory. Although positional consumption, linked to social inequality, together with labour savings where the main driving forces at stake, the two transitions also had to become economically viable.

(iii) In the second half of the 20th century a large part of the industrialisation of agriculture also led to specialisation processes, as we have described in other previous works (Gingrich et al. *in press*). The characteristics of our case study are revealing in this regard, given that the territory was organised under specialisation patterns in both the nineteenth and twentieth centuries. In the first case, the constraints on the mobility of materials in advanced organic economies limited the advance of the frontier of specialisation, while a high percentage of the subsistence continued to be produced in the same territory. At the same time, the 'territorially autonomous' functioning implied a strong effort in terms of biomass reuse (and the land costs associated with it) as well as labour requirements. These limitations no longer existed in the twentieth century, when there was practically a total integration of inputs and production in international markets. In addition, the local population almost broke its ties with the territory. Although specialisation processes in general might generate certain imbalances in the functioning of agroecosystems, the specialisation in meat products had more pronounced impacts. The strong imbalance between livestock density and the farmland productive capacities of the territory produced a funnel effect. When, on the one hand it required large amounts of biomass imports, on the other it caused high concentrations of excreta, which became a waste in the territory.

(iv) The foregoing allows us to see more clearly the importance of the funds structure in the socio-ecological impacts derived. In this case, livestock specialisation and its consequences in terms of livestock density entailed an imbalance between two of the agroecosystem's funds. Therefore, together with the analysis of the flows (Biomass Reused, Final Produce) and their dynamic evolution, we observed the joint analysis of the fund-flow structure. In this way, the state and evolution of energy efficiency in the agroecosystems will be determined not only by the structure of the flows, but also by the structure of the funds (which in part defines the flows). Although limited by soil and climate conditions, an integrated structure of funds that allows a certain balance in the interaction between them will promote territorial synergies (and the reuse of products and by-products within the same territory).

I.b

Contributions of the theoretical framework (I): Inequalities-exploitation and Social Metabolism

(v) Acknowledging the limitations of the present work, I maintain that the issue of social inequalities must be a priority in the studies of Social Metabolism and has to be the subject of further work over the coming years. The analysis of social inequalities from the perspective of Social Metabolism has yielded fruits that I consider relevant. My research highlights the need to distinguish between social inequalities and exploitation relationships. While for the former there is no evidence of interaction and interdependence between social groups, the latter places the focus on the unequal exchange and parasitic relationships that occur between social groups. This nuance implies at the same time introducing the key element of *labours* (in plural form), and specifically the social organisation of labour. The social organisation of labour and the recourse to the exploitation of the work of others as a source of expansion of the levels of metabolic appropriation, are both essential to understand the current socio-ecological structures.

(vi) Considering labour in plural form allows us to observe two types of inequality and exploitative relations, those that occur between people of different gender and those that occur between different social classes. The exploitation of domestic and wage work are shown as being similar processes in different spaces. The emergence of households as the first space of power help us to understand how the control of female workforce within households responds to a logic of domination and appropriation not only similar to that of wage labour, but articulated—as shown by the indicators of total productivity of work. The centrality of the legitimating elements, land property and sexual division of labor, also shows their contingency. My proposal is to state that these inequalities, as well as the ensuing processes of exploitation, respond to a biophysical tension derived from the opposition between the end of economic activity (reproduction, consumption and enjoyment) and the required means (labour).

Contributions of the theoretical framework (II): Socio-ecological reproduction

(vii) The analytical scheme represented in Figure 4.1 proved to be very useful to help us think about the nested loops structure that represents socio-ecological reproduction processes in preindustrial agricultural societies. At the same time, it facilitates the integrated comprehension of interpretative proposals with different origins: Social Metabolism, Feminist Economics, Sraffian and Marxist approaches. The possibility of putting into dialogue different dynamics and processes evidenced by each of these approaches has significant explanatory power. The diagram shows the interactions between energy-material flows and time flows, as well as the reproductive needs of each of the funds. The consideration of the fundamental processes that take place within the households as well as between social classes allows to visualise two processes of great importance for the analysis of the advanced organic societies as well as their historical dynamics. On the one hand, the totality of the works necessary for the reproduction of the labour force and, on the other hand, the distributive struggles that generate in some way instability and conflict which foster socio-ecological dynamism. I consider that highlighting the need to include domestic and care work within metabolic studies is an important step to take. From here, the complexity and the huge effort in terms of energy-materials and time to maintain economic activities, which ultimately means maintaining Life, is demonstrated.

Methodology

(viii) I consider that one of the main contributions of this work is the methodological proposal presented and developed in Chapters 5 and 6. In short, I applied the balances approach to the reconstruction of biophysical flows in agriculture, to propose some estimates related to the use of time and the distribution of production. As I have been able to confirm, the analysis through multiple balances allowed us to compare results with much more precision than if I had worked with only one element (monetary, energy, nutrients, time, etc.). The inclusion of cash flows is a crucial element, since it is essential to carry out some of the proposed estimates, especially the needs to sell labour force. Although this novel methodology is still in an embryonic state, and it requires a great effort of adaptation for each of the case studies to which it can be applied, I have been very pleasantly surprised by its quantitative robustness as well as its versatility in the generation of results. As demonstrated in Chapter 5, the use of this methodology allows us to contribute with theoretical insights and quantitative estimates to several important debates that took place during the last decades on agrarian and environmental history.

Historical contributions

(ix) It is worth highlighting the progress of the methodology for the analysis of living standards for the period analysed, mainly due (i) to estimates of the weight of self-production over total consumption, and (ii) to including salary income as a reproductive strategy. The analysis of the distributive income processes based on these estimates offers relevant and complementary information to the analysis of the distribution of land ownership. The results have shown a characteristic that, although it fits with the questions posed by some Catalan researchers, seems quite novel and will probably be subject to debate: the presence of a relatively high percentage of hired work (44-48% of the total).[54] In this way, we suggest that the subsistence gap that had been observed for a large share of smallholders for many Catalan municipalities in the mid-nineteenth century could be linked to the need for large farms to hire external labour.

(x) I believe that the advances made by this PhD thesis on the knowledge of female work in preindustrial agricultures are relevant. It has not been easy to find my own place on a topic that has

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[54] This percentage varies according to whether we measure it as an average for each one of the farms (44%) or from the municipal aggregates (48%).

generated such diverse debates. In the first place, I believe that it is an advancement to have introduced quantitative estimates of these works, which makes them more visible and allows us to compare them with the effort devoted to agricultural work. Secondly, I highlight an element that has already been valued from other academic areas such as Ecofeminism: the centrality of domestic and care work in the processes of socio-ecological reproduction, including not only other works but also ecological processes. For this reason, we reiterate that it is necessary to make households visible as one of the main areas of power, and control over female work in households - in other words, female lives - as a strategy to control production and reproduction. The magnitude of these works, which account for 35% of the total work done, gives us an idea of the importance of ensuring that a social group would be in charge of fulfilling them in spite of the repercussions that this entailed for their lives. Finally, we believe that the understanding of the articulation between domestic work and female agricultural work allows us to better grasp the debates on the female presence in the labour market, and makes us rethink the indicators that have been used so far. The greater presence of urban studies may have defined in some way the perspective with which the issue has been analysed, while the relevance of agricultural self-employment in the rural space lessens the presence of women as 'workers', beyond the domestic scope. Again, the estimates of female agricultural work provided by the methodology, 18% as a minimum value, coincide with some of the few works that provide comparable results.

(xi) One of the surprises of the results of this work is that I expected to find that those households with less access to land had great problems to close the soil nutrient cycles. Despite the fact that at the aggregate level (see Chapter 5) I have not been able to analyse the details of fertiliser material management, beyond observing the effect of biomass burial in the increase of BR, the results of the analysis by household unit (see Chapter 5) indicate that the availability of human excreta and manure covered a large part of the extractions in small farms. Therefore, I have found qualitative differences in the methods of fertilisation, with greater presence of manure for the units with access to livestock and of burial of biomass for the others, which implied differences in the necessary fertilisation work. This issue has thus become one of the priority topics for the further progress of my research.

(xii) A debate that appears in a collateral way, but that I believe is of great relevance, is the systematic attainment of a great adjustment between the reproduction prices and the market prices. This means that there was an internal framework that linked and adjusted the prices of basic products and labour prices. On the one hand, the minimum wage was established based on the minimum food and fuel household requirements. On the other hand, it could not exceed the annual productivity of agricultural labour. Therefore, the relationship between the price of labour and the price of basic products had a physical nature behind, and prices only acted as mediators of a set of biophysical flows which could only move within some narrow ranges. We have observed how the differences between food and fuel in terms of price per unit of energy can be explained by analysing prices as a reflection of the incorporated labour. The fact that work was one of the main economic costs would also explain this relationship. Thus, in this case the commodities market did not play a fundamental role as redistributor, given that the prices were controlled by the reproduction cycles. The smaller the margin between the minimum needs of a unit of work and the productivity of that unit of work, the smaller was the capacity to generate and appropriate a surplus, either by the peasant family itself in a model of family farming or between different social classes in an exploitative model of exchange. The fact that 'the minimum needs of a unit of work' must include, according to quantitative estimates, the need to reproduce the work force from domestic and care work to ensure intergenerational reproduction, empirically reinforces my initial theoretical proposal on the importance of including domestic and care work within the analysis of socio-ecological reproduction.

(xiii) This is connected to what has been observed in different ways in both Chapters. In the first place, the differences between the productivity of autonomous work and that of wage labour were approximately 12%, which would be considered as the retribution to land ownership or the energy surplus value of agricultural wage labour. In fact, the latter is what we have defined as Social Productivity of Labour (see Chapter 6), that is, the productivity of labour after the subsequent exchanges in the labour market and the markets of products. This allows observing processes of appropriation of a surplus. The results indicate that the capacity to accumulate a substantial surplus was very limited at that time, and was highly concentrated in the larger farms (the 18 largest HHs accumulated 80% of the surplus). Given that the margin of surplus per unit of hired work was small, 0.04 h-GJ per day of work, it was also the total amount to be accumulated, 81 ECB. We have described how this small margin was defined by the reproductive condition of labour force, its requirements for domestic and care work and intergenerational reproduction. This also implied a low maximum level of income inequality, which is estimated with a Gini coefficient of 0.28, very close to the highest possible level of inequality, with a Gini of 0.30. The above entailed a high Inequality Extraction Ratio of 95%, very close to that proposed in literature.

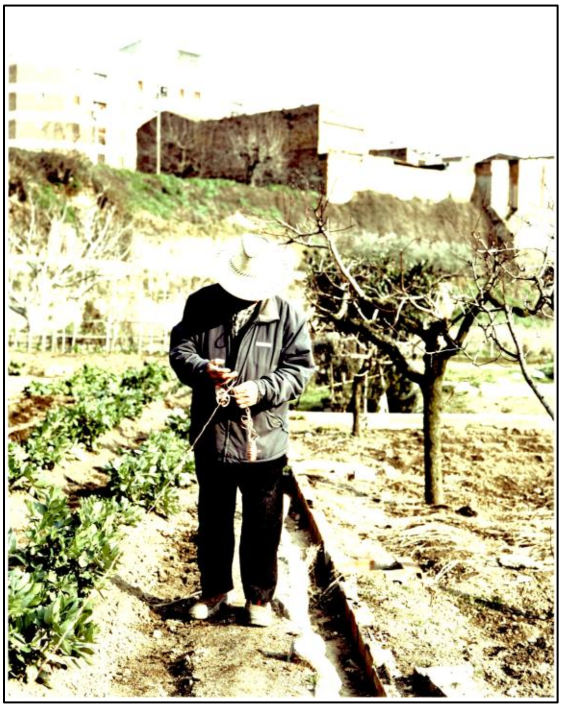
(xiv) Although the data obtained throughout this work does not allow me to affirm it conclusively, I believe that we have provided new theoretical and empirical evidence to support the hypothesis that the process of industrialisation of agriculture was linked to the effects of class inequality. First, globally, the industrialisation of agriculture meant in an abstract way the release of two blocking elements that existed in organic agriculture; the recirculation of biomass necessary to keep the fund element of soil fertility, and the necessary application of large doses of human labour. Both processes were mediated by class inequality. We have observed that for the elites, the transition towards fossil fuels supposed a greater capacity to appropriate a surplus, from reducing the costs of labour force from a self-reproducible source to a non-renewable source. On the other hand, control over fertilisation techniques was also mediated by inequality, although it is the least studied element. The farms that appropriated the surplus used to have access to livestock, and therefore to fertiliser. In turn, the use of labour-intensive techniques generated pressure on the development of technologies that reduced the workload derived from fertilisation. Although this hypothesis remains open, [the research described in] this thesis aspires to contribute with some new elements to the debate that will allow us to continue working in the future. In this PhD dissertation we offered a methodology and preliminary results that support our initial hypothesis. This methodology allows us to connect the studies on inequality and exploitative relations through the Social Metabolism approach from a historical perspective. The connection between biophysical and cash flow analysis, which is proposed here, could be fruitful in the future.

CHAPTER 7:

Final thoughts:

Applications to the present challenges

(some [pessimistic-realistic] insights)



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CHAPTER 7:

Final thoughts: Applications to the present challenges: some (pessimistic-realistic) insights

> ‘The future human society will have to be ecologically sustainable and egalitarian if humanity does not want to destroy the conditions of its own existence as a species or become even more oppressive as environmentally privileged sectors take advantage of resources and the labour force of others and others’
>
> Mary Mellor (2000:270)

This section will be brief, given that the present dissertation is not focused on present times, and the author is not an expert on it. However, as I laid out in the introduction, the main objective that has led us to analyse history was to collect those elements that can be inspiring to understand reality, as well as being able to define realistic and informed strategies for the future. Here I will gather some personal ideas in this regard, that aim to convey certain controversial issues that in our opinion would help to have a more honest debate in the face of the necessary socio-ecological transition.

What I propose next has several limitations. The main limitation is a strong techno-pessimism, which is based on a theoretical/abstract basis (given the biophysical limits to the use of materials-energy) more than on the concrete knowledge of technological development in the search for transitions towards sustainability. In spite of that, I assume that there will be a necessary reduction in the material base of the economy, that is to say, regarding the societal metabolic size. As Ramón Fernández Durán raised, ‘[t]here is no alternative energy source, alone or in combination, that can replace conventional oil and, much less, all fossil fuels’ (Fernández-Durán 2014:103).

In the following narrative one question will repeatedly arise: which technological level can we support in a sustainable society? I think that this question is one of the key elements, since it is at some point uncertain but of significant relevance. Finally, I am aware that I am presenting here some personal insights. The processes of systemic change are too complex, and our ability to understand them is still too limited to be able to ascertain future paths. Notwithstanding this, I propose to contribute to the debate with some open questions, more than firm statements, knowing that social processes are always richer and deeper the more diversity of knowledge is part of them. I hope that some of the reflections here will enrich the debates and proposals.

To begin with, I want to warn that our proposal is not to return to the state of agriculture that we have described in our nineteenth century case study. It would not be the first time that we are accused of it, as this happens frequently. This frequency increases in the case that the person with whom I dialogue lives in a Northern country. Although it sometimes might seem that academics need to complicate some simple issues, in the following paragraphs I consider how this relates to one of the questions I am interested in: what are the barriers to a transition process towards sustainable societies and why do they occur? It should be noted that I will be referring to the challenges faced by countries in the 'Global North'.

The first obstacle is that there is a strong reluctance to accept and understand the existence of biophysical limits. Particularly, this means to accept three kinds of statements. It implies, first of all, recognising that the transition from preindustrial societies to opulent societies has been possible thanks to the generation of socio-ecological chains of exploitation (mainly of nature, but also based on gender and class). Second, this means that the short stage since the Industrial Revolution has been an illusion within the history of humanity. But there is an even more complicated element in understanding the existence of biophysical limits: it would mean accepting that there are (maximum) limits in terms of the availability of basic products for life, as well (minimum) limits in terms of the amount and forms of necessary labour to obtain them. The third aspect is probably the most complicated. A very common position with which we find ourselves confronted is that we have reached a level of development in which we will find the (technological) way to maintain levels or reduce them only slightly. Without doubt, as expressed with great lucidity by Brieva (2017:93): 'The truth becomes particularly difficult to see when one takes advantage of its concealment'.[55]

Although the reduction of energy and material consumption levels is inevitable, these barriers will affect the way in which socio-ecological transition will take place. The conclusions of this dissertation allow us to underline the links between ecological constraints and social inequalities. Thus, the reduction of energy-material consumption levels under criteria of social justice would entail the acceptance of adapting these consumption levels to the existing capacities of the territory and the labour capacities. Nonetheless, the latest is not incompatible with a certain level of exchange, but it seems that we should tend towards predominance of locally produced consumption goods (see Padró 2018). In other words, this process would mean to internalise the territorial and labour costs that have been gradually outsourced since the Industrial Revolution. But, at the same time this would mean waiving relations of privilege and exploitation established with the rest of territories. This perspective could help us to understand why changes are going so slowly, when they happen. Possibly, expecting this to happen voluntarily and peacefully is naive. This is not incompatible with the fact that some groups (with varying degrees) have the will and capacity to (partially) do so. What I question here is that the latter position could become hegemonic.

In a second stage, I would like to discuss which potential scenarios could derive from a socio-ecological transition. This is an exercise aimed to show some of the possible challenges of the current transition that have not been frequently highlighted, and it will also help us understand why an uncontrolled transition would entail some very relevant social threats. A clear example is the possible

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[55] Translated by the author from Spanish.

effect on the reduction of transportation capacities, one of the uses of energy that seems more complex to substitute in a scenario of depletion of fossil fuels. Lower capacity to mobilise biomass would put pressure on a large part of subsistence production to occur nearer in the same territory where consumption takes place, which means a relocation of production. Economic relocation is a strong demand of many social movements and some political parties. The environmental crisis also offers the possibility that favourable conditions to the need for these relocation processes can be foreseen. As with other aspects of the transition to sustainability, relocation is not intrinsically positive or negative, but rather a complex process which implications should be analysed.

Relocation inevitably leads to an economic restructuring, from which some of the sectors that have been reduced to the minimum must recover, while the existence of other sectors may no longer make sense. In a context of limited mobility, the recovery of agriculture should be prioritised. The relocation of agricultural activities might pose two types of challenges. A first challenge would be the pressure on land. Moreover, if we assume not only that human food would need to be internalised, but also that external inputs' availability will be limited (mainly chemical fertilisers, and also livestock feed), there would be an uncertain Land Cost of (*forced*) Sustainability (Guzmán and González de Molina 2009).56 It is in this context that transformation in diets, with a reduction in processed products together with a reduction in animal-based food intake, would become imperative. In short, in a readjustment scenario to the local capacities of each territory to feed the population, it would make sense to optimise the territorial cost of diets (see Padró 2018).

The effects of this process on the organisation of labour force are even more uncertain, and would depend to a large extent on the levels of mechanisation that can be assumed (in physical but also in economic terms). Despite the high level of uncertainty, I would like to highlight two issues. First, we must bear in mind that the 'modernisation' and 'economic development' processes in the Global North countries entailed the outsourcing of the labour-intensive and low-paid sectors, not only in agriculture, but also in other sectors linked to basic products such as textiles. A potential limitation of maintaining current levels of mechanisation could led to a greater use of human labour force. Our second point refers to this issue. Although reducing high levels of mechanisation could be considered as an opportunity, it seems to be a taboo. From the terminology used in this work, it seems that Global North societies are highly reluctant to assume the Time-Labour Cost of Sustainability.

I believe that several aspects make this issue very complex. Firstly, as I already mentioned, the current socio-ecological transition will entail for the first time an energy availability reduction. Thus, an open question is whereas we could maintain an increasing tendency of rise or stagnant labour productivities in physical terms. Secondly, an even more complex question is about the consequences of labour productivity trends within the whole socio-ecological system. As a first hypothesis, connected with some of the insights of this dissertation, lower physical labour

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56 I include here the term *forced*, that does no appear in Guzmán and González de Molina (2009), to emphasise the inevitability of the internalisation of the territorial costs.

productivities would lead to an increase in general prices. All these are the complications corresponding to a process of internalisation of externalities. If, as I have stated in this PhD thesis, the biophysical limits have an effect on the balance between (i) the processes of appropriation of natural resources, (ii) time use, and (iii) consumption levels, it seems logical that in a readjustment process between local produce capacities and consumption levels, some disadvantages may occur.

Finally, we might ask ourselves if these pressures would be neutral in terms of class and gender. I have argued in this PhD thesis that the development of the productive forces made it possible to alleviate internal social conflict, even though it has been transmitted to other territories and human groups as well as to future generations. If so, we might be aware of the implications of a reduction in productive capacity due to depletion of the material base, and relocation of economic activities. This could potentially lead to an increase of the internal tensions in the production processes and labour distribution. As I have repeatedly cautioned, the question about the sustainably possible mechanisation level is open. This means that we cannot ignore the possible increase of pressure over the organic energy carriers, including human labour. Moreover, the female workforce could be affected, both by a greater need to control the reproduction of the labour force as well as by a greater pressure on the performance of domestic and care work.

Ultimately, the aim of this section was to emphasise the potential challenges of the inevitable reduction in the societal metabolic size. Without wishing to present a catastrophic scenario, the aim is to raise some of the open questions resulting from the historical study of agricultural metabolism. In my opinion, a reduction in the size of societal metabolism can be an opportunity to rethink novel structures that will allow adjusting economic activities to the possibilities of the ecosystems in which they are carried out. But, at the same time, they pose new challenges derived from the unavoidable transformation in the structures of exploitation relations. Therefore, I suggest to take these elements into account in the debates on planned transitions towards ecologically and socially fair societies. I warn that these projects should include stronger efforts to guarantee a fairer redistribution of production along with the distribution flows of the works, as well as to pick up on the debates about the access to productive means as a key element in both processes. For such a task, I deem that the new conceptual approaches and accounting methods proposed in this PhD thesis can be valuable.

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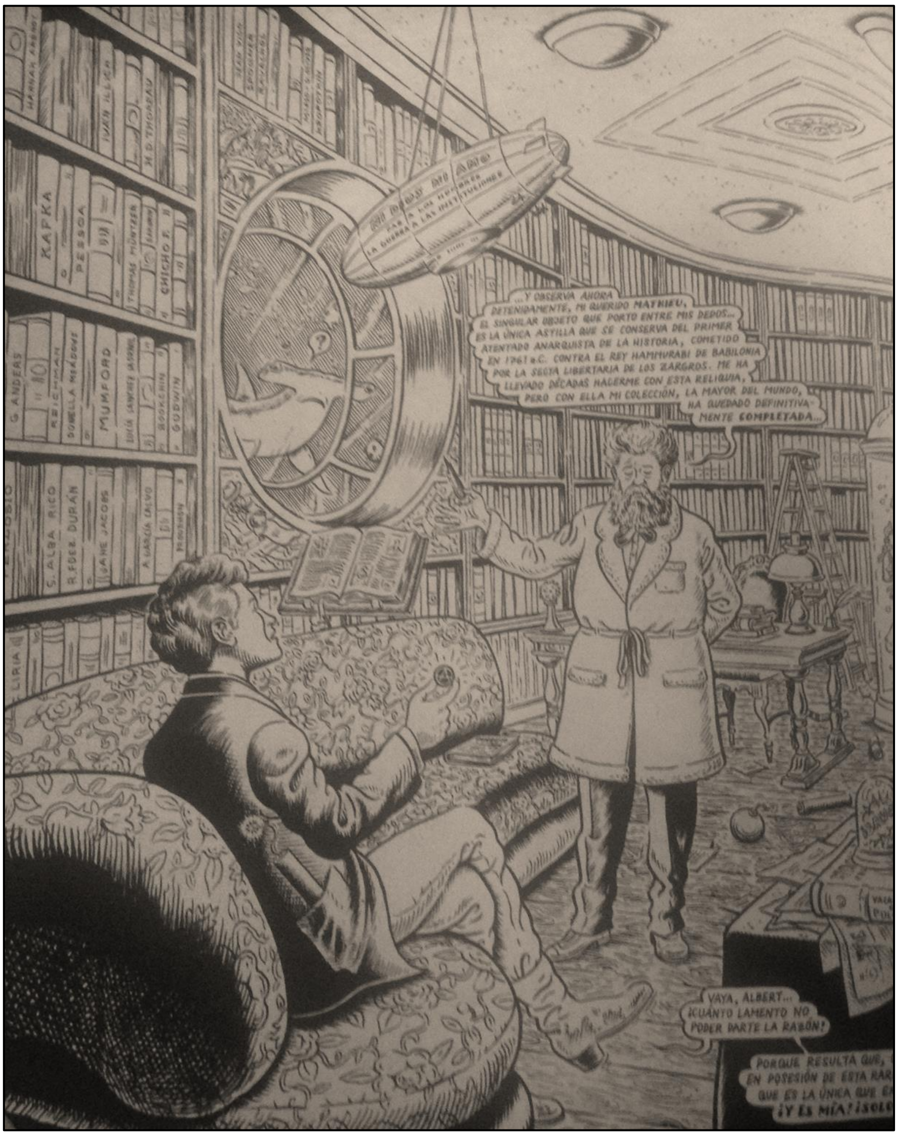

Fragment of the book *The Great Human Adventure* of Miguel Brieva (2017:30)

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La gente dice:
«Pobres tiene que haber siempre»
y se quedan tan anchos
tan estrechos de miras,
tan vacíos de espíritu,
tan llenos de comodidad.

Yo aseguro
con emoción
que en un próximo futuro
sólo habrá pobres de vocación.

Gloria Fuertes (1917-1998)

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