Supplementary Information to the methods section, 2.2

The estimation of the land areas in 1956 and 2009 is based on cartographic information available at the municipal level, and then aggregated at the county and the BMR levels. For determining at municipal level livestock heads, farmers population and available machinery we have used for year 2009 online statistical information from the Catalan Statistics Institute (IDESCAT). For 1956 we have used the Spanish Statistical Institute (Instituto Nacional d'Estadistica, INE) [1] for livestock heads; for farmers population we have first determined from INE (1956) the ratios of farmers over total population in urban, intermediate and rural municipalities of Barcelona province and then applied these ratios to 1956 IDESCAT population data; machinery power capacity was available for 1969 for each municipality of the province [2]; based on the Spanish growth levels in the 1955-1962 period [3, 4] and knowing Barcelona power capacity for 1962 we have estimated that back in 1956 capacity was 9% of that in 1969. Livestock heads have been transformed into LU500 (units equivalent to 500 kilograms of live weight) by using the same weight coefficients in [5].

Flow estimates (outputs) have been more complex to estimate from statistical sources because of their geographical aggregation at provincial level and their incompleteness related to by-products and unharvested biomass—which are fundamental for our Multi-EROI analysis. As well, extraction from pastureland depends on animal feeding balances at municipal level, in which municipalities with higher livestock densities are expected to extract more from the pastures found within the municipal territories.

In detail, cropland productivity is available from [6, 7] with information for 37 crops grouped in 11 sub-categories: cereals, leguminous, forage, industrial, potatoes, horticulture (they constitute the "green crops" category); citrics, fresh fruits, nuts, olives (they constitute the "other wood crops" category) and vineyard. The information refers mainly to the main produce (expressed in tons/hectare) and for 1956 only some by-products: weight of straw and of pruned branches. Using [8] we convert weight into energy and if not already available from statistics the straw/grain, pruning/fruit or any other residue/product ratios. In this way we have determined the main product and by-product for the 11 sub-categories expressed in GJ/ha. From [2] and IDESCAT (2009) we obtain the county-specific area distribution of these 11 sub-categories, we then define county-specific energy flow values and aggregate them for the 3 cropland categories. Given the distribution of green, vineyards and other wood crops per municipality of each county we can define the cropland energy flows at municipal level. Table 1 below show the relationship between cropland typologies and geographical aggregation of the data.

Table 1. Weighting process for cropland energy flows. Flows per hectare in bold; areas in italics.

Source	**Provincial Level Idescat**	**County level - Idescat**	**Municipal level - GIS**	
Categories (detailed and semi-aggregated)	**GJ/ha (11 categories from 37 crop typologies**)	*Area Distribution (11 categories in %)*		
Categories (aggregated)		**Aggregation of county level energy flows GJ/ha (3 categories)**	*Area Distribution (3 categories in %)*	Spatially explicit energy flows

	Municipality-specific flows (3 categories)

Source: Authors' own elaboration .

We then define which parts of the product and by-product constitute final produce and which constitute biomass reused or unharvested biomass. From [3, 7] we obtain the amount of main produce destined to seed and feed and from [5] we determine the amount of re-ploughed biomass and cereal husks as a percentage of the main product, so that we are able to define biomass reused from cropland back to cropland (seeds and reploughed biomass) and to livestock (straw, husks and feed). As well, we define the amount of unharvested biomass: weeds, from [8] and herbivory from the method employed in [9].

For woodland productivity we obtain information from [6] –data aggregated at provincial scale—, and from [10] with data at county level. Volumes are then transformed into weight and then into GJ. Woodland Net Primary Productivity (NPP) is assumed equal to NPP0 and has been obtained from [11] where the values of Italy have been used as a reference.

To compensate for seasonal variability, the productivity volumes of woodland and cropland (37 typologies) have been adjusted to the average between 1954 and 1958 (based on Spanish aggregated data) and between 2007 and 2011 (based on Barcelona province data).

Pastureland extraction for 1956 has been determined based on each municipality's animal feeding needs once supply from more easily available sources (feed-oriented crops, cropland by-products and domestic residues) has been used up. Since in 1956 it was common that animals were grazing in sparse woodlands (the Spanish *dehesa*) we have assumed that pasture from woodland is also available. For 2009 it is assumed that animals use pasture minimally so that each municipality has excess pasture. The productivity values have been obtained from the method of [5].

We assume scrubland is unharvested land with same NPP as in [5].

Livestock flows are the energy value of slaughtered animals by assuming the farmgate hypothesis: the output flow considered as final produce is the energy content of their weight, and not only the edible part. Slaughter rates have been derived from [5]. For 2009 there are Spanish aggregated data on trade of live animals [1a] which have also been estimated. IDESCAT provides milk egg and wool productivities. All data expressed in weight or litres have been transformed into energy using the coefficients in [8].

Animal feeding has been calculated as in [5]. For 1956 we assume that it was closely integrated with products and by-products of local cropland, pastures and domestic residues and, only in case of a supply deficit there would be imports from eventual surplus in nearby municipalities and counties.

The balance has been determined based on the capacity each animal typology has to metabolize different sources of feed, and on some assumptions of livestock breeding back in 1956—i.e. ruminants better metabolize straw than monogastric which, in turn, are more likely to live in household backyards, while ruminants would more likely be fed on forage and pastures. The table below shows per each animal typology the feeding sources in 1956

Table 2: feeding sources modelled per each animal typology[1]

	Straw (cereals leguminous)	Grains (cereals leguminous)	Forage	Pastures (meadow woodland)	Acorns (woodland)	Potatoes, garden by-products	Domestic residues
Equids	Y	Y	Y	Y	X	X	X
Bovins	Y	Y	Y	Y	X	X	X

Sheep, goats	Y	Y	Y	Y	X	X	X
Swines	X	X	X	X	Y	Y	Y
Poultry rabbits	X	Y	X	X	X	Y	Y

[1] Y = Yes, X = No Source: Authors' own elaboration .

A back-and-forth method has been used to determine the biomass flows from cropland to livestock: first, straw for stall bedding has been defined; then, if excess straw was available, it would be counted as feed for ruminants and distributed proportionally to the feeding demand of each ruminant typology; if not, straw would be imported and local ruminants would not be fed on local straw. Feed-oriented crops (grains and forage) have then be balanced between supply and demand, by being allocated in proportion to each typology's feeding demand and, in case of excess supply, this would count as Cropland Final Produce; if local supply is used up, only then local pastures would be used and its access distributed proportionally. In some cases once the feeding needs were satisfied, there was still pasture productivity in excess of demand, so that the NPP in excess would count as unharvested biomass. In other cases, there was not enough feed or pasture for local demand. Farmers from these municipalities would import straw forage and grains from nearby ones or from other counties. The same process has been done for monogastric animals, where first grains (to chicken and rabbits) then potato and garden residues, then domestic residues and finally acorns in woodland (to swines) were allocated. If demand was still not met in the process, then feed would be imported from nearby municipalities or counties.

For 2009 we assume a more simple hypothesis in which animal feeding is not primarily related to local cropland and pastures but to feeding tables that combine a mix of feed that is cultivated locally and other that is to be imported (such as soybean meals). The method is that proposed in [5].

Note that what can be considered as final produce at municipal level –i.e. feed oriented crops in excess to local feeding demand at county level it could be considered as biomass reused from cropland to livestock. In turn, municipalities that import feed from others in the same county would have these inputs counted as external input while at the upper scale it would count as biomass reused.

According to Tello et al.'s method [12] other input flows refer to: Farming Community Inputs (the exosomatic energy of farmer's work and, for 1956, humanure) and Agroecosystem Societal Inputs (ASI) (imported seeds, with data available from national statistics and from [5] and domestic residues of all households in rural municipalities and of 30% of them in county capitals and urban municipalities). Moreover, for both 1956 and 2009 there are ASI of non-renewable nature: machinery, synthetic fertilizers, biocides and electricity for pumping irrigation water and, for 2009 only, also electricity for running feedlots [13]. Data on fertilizers and biocides consumption is available only at national or Catalan level for time points 1956 and 2009 respectively. Electricity consumption is based on an estimation of energy use per hectare of irrigated land or per animal head [13] for the 1956 time point, and [5] for the 2009 time point.

Biomass reuses notably flow from farmland to livestock. However, there are also flows from livestock back to cropland (known as Livestock Services) which, for the sake of the EROI energy balance constitute double accounting and are not accounted for but that, for the MuSIASEM approach are relevant (i.e. manure is a substitute of synthetic fertilizers) and also for the study of the nexuses between different funds (i.e. work animals vs. machinery) as well as for studying the landscape imprint of agriculture energy flows [14]. Manure flows and draught power have been estimated following [5].

Finally, waste flows have been considered. Following [15] these are considered as resources out of place, namely they are: feedlot slurry in excess of cropland Nitrogen carrying capacity; by-products of pruning burnt on field and burnt biomass from forest and shrub land wildfires due

to lack of management. While the first two have been estimated following the method in [5], the latter has been estimated for year 2009 based on forest fire Catalan statistics and using the same assumptions made on the proportion of biomass burnt in such fires. For year 1956 it is assumed that pruned branches were burnt for cooking purposes and forest fires where not present as woodland was, in general, pastured and still exploited.

1. INE, 1957b. Reseña estadística de la província de Barcelona, Presidencia del Gobierno, Madrid.

2. Consejo económico sindical provincial, 1969. La agricultura en la provincial de Barcelona

3. Ministerio de Agricultura, 1954. El Producto neto de la agricultura española, Madrid.

4. Ministerio de Agricultura, 1963 El Producto neto de la agricultura española, Madrid.

5. Marco, I., Padrò, R., Cattaneo, C., Caravaca, J. and Tello, E., 2017. From vineyards to feedlots: a fund-flow scanning of sociometabolic transition in the Vallès County (Catalonia) 1860–1956–1999. Regional Environmental Change, 1-13. doi:10.1007/s10113-017-1172-y

6. INE, 1957a. Anuario estadístico, Fondo documental del Instituto Nacional de Estadística http://www.ine.es/inebaseweb/pdfDispacher.do?td=127394&ext=.pd

7. Ministerio de Agricultura, 2010. Anuario de estadisticas, parte tercera. Available, at http://www.mapama.gob.es/es/estadistica/temas/publicaciones/anuario-de-estadistica/2009/default.aspx

8. Guzmán, G. Aguilera, A., Soto, D., Cid, A., Infante, J., García Ruiz, R., Herrera, A., Villa, I. and González de Molina, M., 2014. Methodology and conversion factors to estimate the net primary productivity of historical and contemporary agroecosystems. Sociedad Española de Historia Agraria - Documentos de Trabajo https://ideas.repec.org/p/seh/wpaper/1407.html

9. Oerke, E., Dehne, H., Schönbeck, F., Weber, A., 1994. Crop Production and Crop Protection: Estimated Losses in Major Food and Cash Crops. Elsevier, Amsterdam.

10. Centro de la propiedad forestal, 2016 Aprovechamientos forestales en Cataluña. Generalitat de Catalunya. http://cpf.gencat.cat/es/cpf_01_organisme/linies-actuacio-informacio-estadistica/informacio-estadistica/gestio-forestal/

11. Gingrich, S, Niedertscheider, M, Kastner, T, Haberl, H, Cosor, G, Krausmann, F, Kuemmerle, T, Müller, D, Reith-Musel, A, Jepsen, MR, Vadineanu, A & Erb, KH 2015, 'Exploring long-term trends in land use change and aboveground human appropriation of net primary production in nine European countries' Land Use Policy, 47, 426-438. DOI: 10.1016/j.landusepol.2015.04.027

12. Tello, E., Galán, E., Sacristán, V., G. Cunfer, G.I. Guzmán, M. González de Molina, F.Krausmann, S. Gingrich, R. Padró, I. Marco, D. Moreno-Delgado, 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) Ecol. Econ., 121, 160-174, 10.1016/j.ecolecon.2015.11.012

13. Aguilera, E. Guzmán, G.I.,Infante-Amate, J., Soto, D., García-Ruiz, R., Herrera, A., Villa, I., Torremocha, E., Carranza, G. And González de Molina, M., 2015. Embodied Energy in Agricultural Inputs. Incorporating a Historical Perspective. Sociedad Española de Historia Agraria - Documentos de Trabajo https://ideas.repec.org/p/seh/wpaper/1507.html

14. Marull J, Font C, Padró R, Tello E, Panazzolo A (2016a) Energy-landscape integrated analysis of agro-ecosystems: how the complexity of energy flows shapes landscape patterns (Barcelona province, 1860–2000). Ecol Ind 66:30–46. doi:10.1016/j.ecolind.2016.01.015

15. Odum, EP., 1993. Ecology and our Endangered Life-Support Systems. Sinauer Associates, Massachusett