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ANALYSIS

Social metabolism in an agrarian region of Catalonia (Spain) in 1860–1870: Flows, energy balance and land use ☆

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Abstract

The energy balance of the 1860–1870 agrarian system in a Catalan county (Spain) shows a 1.41 energy return on energy inputs. This positive figure was achieved despite the high intensive Mediterranean organic agriculture then practiced and its unavoidable dependence on the inefficient livestock bioconversion of biomass to obtain manure and traction. The key feature was the integration between agricultural, pasture and forest lands mainly by means of livestock breeding. The study of past socio-metabolic flows helps to highlight the two sides that have led to a lower energy performance of the agrarian systems in the 20th century: (1) the injection of external energy subsidies coming from fossil fuels; and (2) the functional disconnection between the different land covers inside the whole agrarian ecosystem. This disconnection has brought about a much more inefficient land use from an ecological point of view.

Keywords: Energy balance; Agrarian organic economy; Social metabolism; Land use; Agricultural, forestry and livestock integration; Regional sustainability

The analysis of energy flows provides us with very relevant information for understanding the type of relationship that each society has established with the natural environment that sustains it. It also provides useful information in understanding the ways in which the land is used and the capacity to satisfy their inhabitants needs. Although this is an innovative type of analysis, it draws on the intellectual tradition rescued from oblivion by Joan Martínez Alier (1991, with Schlüpmann, K.; and 1995). Significant here with regard to our purposes is the pioneering work

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of Eduard Sacher [1881], Sergei Podolinski [1880–1883] and Leopold Pfaundler [1902] who drew up the first energy accounting proposals on the economy.

As Martínez Alier has pointed out, that tradition was interrupted until it was taken up again by ecological anthropology and human ecology. The nineteen seventies and eighties saw the appearance of studies by Gerald Leach, David and Marcia Pimentel, José Manuel Naredo and Pablo Campos which improved the methodology of the energy calculations and demonstrated that the spectacular increases in agricultural production achieved in the second half of the 20th century with the subsidy of fossil energy concealed an energy efficiency that was clearly lower than the traditional one. The waste of energy and materials has turned contemporary agricultural systems into a source of widespread pollution which threatens its sustainability.[1] In the last decade, there have been interesting contributions from other authors, such as Vaclav Smil or Mario Giamprieto.[2] Particularly significant for our purposes are those of the IFF Social Ecology group at the University of Vienna.[3] As far as Spain is concerned, we also have the works of Pablo Campos and Javier López Linaje (1998), Xavier Simón (1999:115–138) and Oscar Carpintero (2002:85–125).

Our work focuses on an examination of the energy balance of an agricultural region of Catalonia in the mid-nineteenth century, when it was still almost exclusively based on organic energy obtained from biomass. By computing the energy flows that sustained the region, we have sought a better understanding of the logic behind certain agrarian practices prior to industrialisation, which are all too often lumped together under the description of "traditional" agrarian systems. Our hypothesis is that, from the 18th century onwards, there emerged in most of Europe a number of different agrarian intensification methods, leading to what Anthony Wrigley has referred to as *advanced organic economies*. Without the application of a large-scale external energy subsidy, they succeeded in increasing the quantity of biomass and energy in each unit of land that was directed towards human consumption (Wrigley, 1993, 2004).

It is important to remember the processes prior to the so-called "green revolution" in order to understand fully the deep change brought about by the implementation of current agrarian technologies since the middle of the twentieth century. Having been produced within a framework that was still basically organic, the accomplishments achieved had perforce to be diverse: an advanced *organic* agriculture could not be the same in an Atlantic or continental-Europe environment as in another Mediterranean one.

1. Methodology

Following the methodology established in the aforementioned works, the first step consists in establishing the production of primary energy. As José Manuel Naredo argues, the energy which is made available for successive transformations of the agricultural system is not *produced*, since it is solar energy captured by plants by means of photosynthesis. Yet there is no sense in establishing a balance between solar energy inputs and the final available assets resulting from the agricultural and livestock conversions, given that the resulting amount does not represent any added value but rather the total amount of energy irremissibly dissipated in the process. On the other hand, there is indeed sense in estimating the caloric value of the biomass produced in a given time and place, in order to then evaluate its degree of exploitation in the successive transformations of the agricultural system. The degree of efficiency or inefficiency of such conversions tells us important things about the agricultural and livestock practices, the land management, its capacity for covering the needs of the population, its environmental wastes and impacts, and long-term sustainability (Naredo, 1996:333–364).

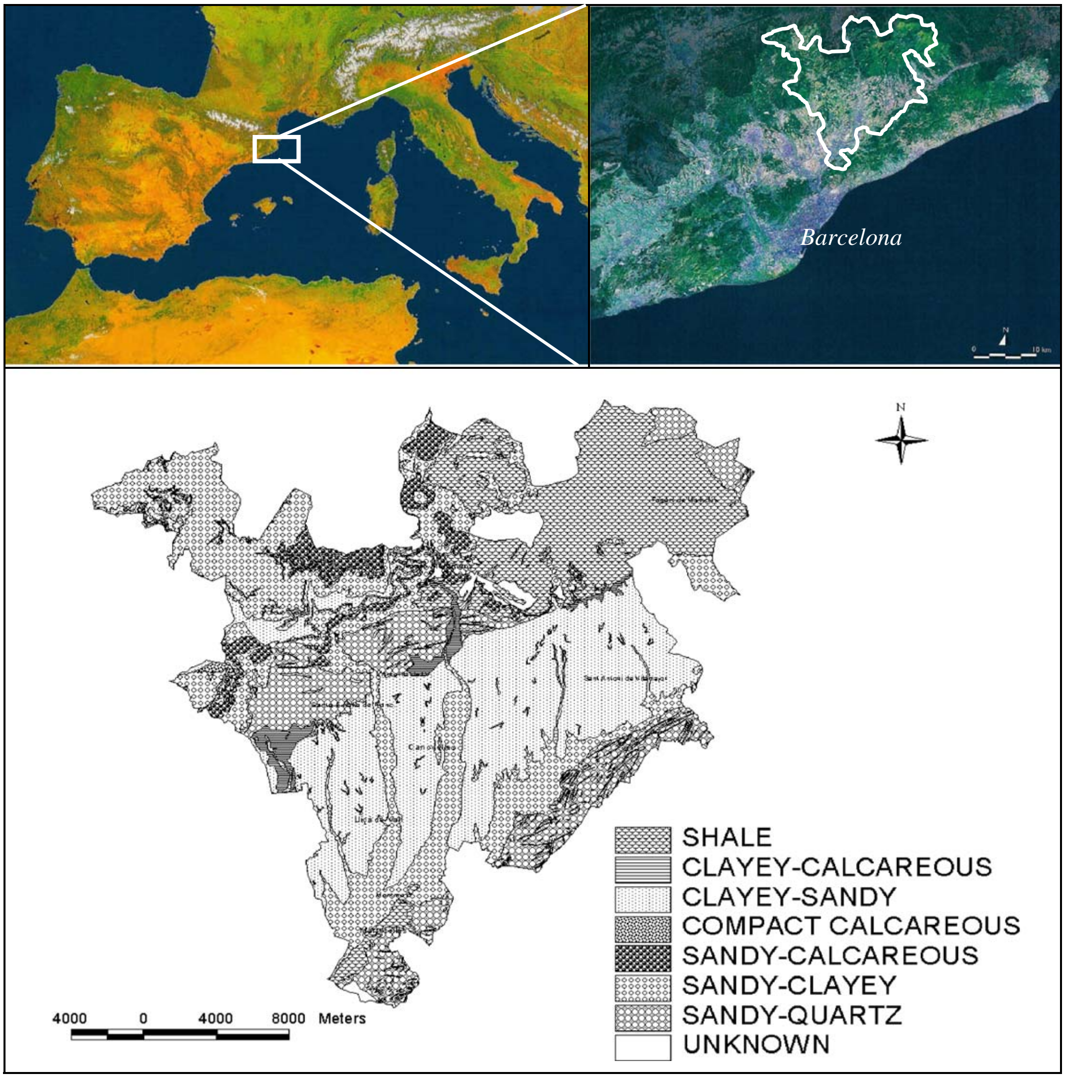
[1] Pimentel, D. and Pimentel, M. (1979), Leach, G. (1981), Campos, P. and Naredo, J.M. (1978:63–72), Naredo, J.M. and Campos, P. (1980a:17–114 and 1980b:163–256), Campos, P. (1981:241–277 and 1984), Puntí, A. (1982:289–300), Naredo, J.M. (1996), López Linaje, J. (1982, 1985a:75–126, 1985b:105–144, and 1990:69–80).

[2] Smil, V. (1987, 1991, 2001), Giampietro, M. and Pimentel, D. (1991:117–144), Giampietro, M. et al. (1994:19–41).

[3] Fischer-Kowalski, M. (1998:61–78) and Fischer-Kowalski, M. and Hüttler, W. (1999:107–136), Haberl, H. (2001a:107–136, and 2001b: 53–70), Fischer-Kowalski, M. and Amann, Ch. (2001:7–47), Haberl et al. (2001:25–45), Krausmann, F. (2001:17–26), Krausmann, F. and Haberl, H. (2002:177–201), Schandl, H. and Schulz, N. (2002:203–221).

For this we need to know the plant cover of the territory being analysed, which in part depends on its own ecological capacities, and in part on the kind of human intervention practised on it. To this end we can draw on the statistics about the use of land, the distribution and rotation of crops, and the yields from the main crops. Once the primary energy captured in the form of biomass has been established, this goes through a series of transformations before becoming a final usable or consumable energy. The analysis of that and other transformations will allow us to establish a balance of final available energy, composed of consumable plant biomass and the production of livestock in the form of food or animal labour, and raw materials.

The unit of calculation used is the caloric value, or combustion value, which allows us to express in the same unit the input and output flows of the system in order to calculate its balance. However this also introduces bias into the analysis, because the energy calculation does not capture the usefulness or value that the society attributes to different caloric units. Within



Source: Rodríguez Valle, F. L. (2002).

Map 1. Area of study and main types of soil.

the economic subsystem, a kilocalorie or joule of wood is clearly not the same as one of wheat or meat. Yet if we want to broaden the observation window of reality in order to re-introduce into the analysis the metabolic flows that sustain our social life, it is then also clear that we ultimately keep ourselves alive thanks to the renewed cycle of solar energy that moves the materials required in order to satisfy our needs. From the point of view of social metabolism it makes perfect sense to reduce the material flows to their caloric equivalent, in order to compare subsequently different energy systems according to the resulting balance.

In order to establish the balance, the energy flow reintroduced into the system in the form of human or animal labour has to be taken into account, and other inputs in the form of re-use of materials such as seeds, fertilising material and other waste. Subtracting these quantities from the net primary production will give us the final available energy. Once all these values have been established, we can calculate synthetic indicators about the production of energy per surface unit or inhabitant, and their degree of efficiency, in order to contrast them with other historical cases.

2. The study area and sources

The study area is located in the region known as Vallès Oriental, a small plain situated in a tectonic basin between Catalonia's littoral and pre-littoral mountain ranges, whose diversity of geological substrata, together with a rainfall above average for the Mediterranean,[4] have led to the development of a considerable variety of soils with a greater range of agricultural possibilities than in more arid areas (Rodríguez Valle, 2002). The closeness to Barcelona – between 5 and 12 h on horseback according to a timetable map of 1808–1809 – meant that the Vallès was connected very early on with the commercial dynamics of Catalonia's demographic and urban centre of gravity (Vilar, 1964:271). From the end of the lower medieval agrarian struggles, the landowners who held the polycultural farms that were characteristic of the mid-northeast of Catalonia (*masies*), structured into compact units around a rural dwelling, gradually gained control of the rights of access to the main resources over a complex and conflictive transition from feudalism to agrarian capitalism (Serra, 1988; Garrabou and Tello, 2004:83–104).

Map 1 shows the distribution of the soil textures described in the *Estudio Agrícola del Vallès*, an anonymously written manuscript presented in 1874 to the Barcelona Economic Society of Friends of the Country, which forms the main source of our analysis (Garrabou and Planas, [1874]1998:58–74 and 138–139). The *Estudio* establishes seven kids of soil characterised by their texture: 1) those composed of slate and shale, situated in mountainous areas and slopes generally covered in woodland or scrub; 2) clayey-calcareous, with a certain proportion of limestone and fine material, suitable for cereals; 3) clayey-sandy, with a large proportion of clay (*grosses* or *roges* in Catalan), very heavy to work with due to its compacted nature and retention of water, but which could

Table 1
Classification of soils and types of exploitation

Type of texture	Hectares	%	Main soil use around 1860–1870
Shale	11,396.7	19.1	Woodland, scrub or pasture
Clayey-calcareous	1,000.7	1.7	Cereals and fodder (without fallowing)
Clayey-sandy	17,199.4	28.9	Cereals and legumes (without fallowing)
Compact calcareous	309.2	0.5	Vines or scrub and pasture
Sandy-calcareous	2864.4	4.8	Vines or woodland, scrub and pasture
Sandy-clayey	16,379.3	27.5	Legumes, potatoes, cereals, fodder
Sandy-quartzy	8636.8	14.5	Vines or woodland, scrub or pasture
Unknown	1813.4	3.0	Woodland, scrub or pasture
TOTAL	59,600.0	100.0	

Source: Rodríguez Valle, F.L. (2002), Garrabou, R. and Planas, J. eds. ([1874]1998).

[4] Average rainfall varies between some 600 mm in the Vallès plain up to 800 or 1000 mm on the peaks of the pre-littoral range, in comparison to 440 mm in Barcelona. The potential evapotranspiration (Thornthwaite's PET) varies on an opposite gradient from 846 mm in Barcelona to 521 mm on the summit of the Montseny. This makes the slopes of the pre-littoral range a source of the run-off that feeds the river Besòs as far as the city of Barcelona. Its exploitation permitted the development of locally important *huertas* or vegetable gardens, and the cultivation of hemp (Rodríguez Valle, 2003:12–16).

be made into good fertile land with a certain amount of investment in fertilizer and labour; 4) compact calcareous, situated on steeply sloping land and only exploitable for forestry or the planting of vines with a great deal of terracing work; 5) sandy-calcareous, thin soil on slopes (*terres primes* in Catalan), located in areas of contact of the tectonic basin with calcareous outcrops, also exploited for vines and forestry; 6) those described as sandy-clayey, made up of sands and flood silts which give them good drainage and good water retaining capacity, easy to work and very fertile for the growing of cereals or legumes; 7) sandy-quartz, formed from the decomposition of granite (*sauló*) which emerges at both sides of the fault, shallow and with a low water-retaining capacity, largely devoted to vines or forestry exploitation.[5]

The *Estudio Agrícola del Vallès* reproduced the summary of the use of land and livestock for each municipality in the 1860–65 fiscal assessments (Tables 1 and 5). From this, and assigning each crop rotation to the type of soil, we have estimated the total production applying the average yields per hectare. Although some local variations can be seen, for the overall study area the surface area estimated by the 1860 assessments varies little from the 59,600 officially registered at present: 52,020 ha, 12.7% less. A large part of the 7580 ha of difference were found in mountainous municipalities, and corresponded to extensive barren or forested areas. The reliability of the measurement of the agricultural surface areas seems to be reasonably good.[6]

Subtracting the 3404 ha declared to be unproductive – some 6% or 7% of the total expanse used – , our analysis will refer to the 48,616 ha that around 1860 made up the useful agrarian area, with 36% of it cultivated. The then cultivated area of 18,476 ha was substantially more than that of the present.

Table 2
Demographic growth and land available

	Inhabitants	Population density inhabitant/Km^2	Area available per inhabitant (ha/inhabitant)	
			(Total)	(Cultivatable)
1718	14,993	25.16	3.98	1.23
1787	20,051	33.64	2.97	0.92
1860	38,342	64.41	1.55	0.48
1900	38,390	63.30	1.55	0.48
1930	56,111	94.15	1.06	0.33
1960	77,039	129.26	0.77	0.24

Source: our own table, taken from data in published censuses and from www.idescat.es. The estimate for *cultivatable* land area is based on that actually cultivated in 1860–1870.

Once one has deducted areas given over to housing or infrastructure, and especially taking into account the abandoning of the countryside which has left unexploited a great deal of land which is undergoing an extensive process of reforestation, the useful agrarian land area registered in the last census of 1999 comes to less than thirty thousand hectares, less than ten thousand of which are cultivated.

Between 1718 and 1860 the population multiplied by a factor of 2.6, going from 25 to 64 inhabitants/Km^2. The available land area was reduced from 4 to 1.6 ha/inhabitant, and that cultivated from 1.23 to 0.5 ha/inhabitant. (Table 2). In an organic based economy, where the people still lived mainly from the land itself, the satisfying of their most elementary needs obliged them to increase the use of land to a maximum. At the same time as agricultural, livestock and forestry exploitation reached their maximum extent, the lower availability of land per inhabitant demanded an increase in the quantity of energy from each land unit directed towards human use.

Need, and also the opportunities presented by the intensification of exchanges, led to the development between 1860 and 1900 of a specific Mediterranean form of advanced organic economy. It is significant that the average population density between 1860 and 1900 remained at the same level of 63 inhabitants/Km^2, despite the existence of important local variations (this was exactly the threshold established by Ester Boserup between a 'medium' and 'dense' human population from an agro-technological point of view).[7] Mountain areas became depopulated as their role as suppliers of

[5] The "unknown" category corresponds to areas with such a variety of outcrops that it proves difficult to fit them into the 1874 classification, located in areas that are little or not at all cultivatable.

[6] We have checked it by GIS using the 1853 cadastral plot map in the municipality of Caldes de Montbui. Other specialists have got the same conclusion in their research on the cadastral cartography and statistical surveys in the Barcelona province during the second half of the nineteenth century (Nadal et al., 2003:37–60). 60% of the 7580 hectares of difference to current measurements can be found in only six of the thirty municipalities, and 30% in two alone, always in mountainous areas.

[7] Boserup, E. (1984:23).

Table 3
Land use and land available

Uses	Classification of the land in hectares			Total existing hectares	%	Total available hectares
	1st class	2nd class	3rd class			
Crops	2824.12	5427.51	10,312.79	18,475.54	35.5	25,392.65
Woodland	2586.63	5156.20	10,229.60	18,564.43	35.7	18,564.43
Pasture	2743.68	3843.24	4989.07	1575.99	22.3	11,575.99
Unproductive	–	–	–	3404.35	6.5	–
TOTAL	8154.43	14,426.95	25,531.46	52,020.31	100.0	55,533.07

Source: "Resumen del Estado demostrativo de la riqueza rústica del Vallés", Garrabou, R. and Planas, J. eds. ([1874]1998:80–81).

timber and firewood was reduced, while the population became concentrated in the lowland centres.

3. Land cover and land use

As a result of demographic growth and the commercial exchanges, there occurred a transference of woodland and pasture into cultivated land, particularly vineyards. According to the assessments of the middle of the 19th century, the 48,616 ha of agrarian land used were distributed in quite similar proportions between wooded area and cultivated land, with a lesser area of uncultivated land set aside for pastures: 55% of the cultivated area was being used for cereals and legumes, with 28% for vines, 4% for olive trees and other fruit trees, and 13% for vegetable gardens and irrigation. The 2300 irrigated hectares represented little more than a ninth part of the area, yet it corresponded to a fifth of the *available* cultivated area, taking into account multiple annual crops. According to the 1874 *Estudio* and the *Cartillas Evaluatorias* (Evaluation Handbooks) published by the Catalan Agricultural Institute of San Isidro (IACSI), the practice of leaving land fallow had practically disappeared, and the predominant rotations in the un-irrigated areas combined wheat and maize with runner beans, broad beans and peas, fodder or potatoes.[8] On irrigated lands two or three crops were obtained annually, alternating the growing of hemp and legumes or potatoes with wheat, other late-ripening fruit, and fodder. In the best un-irrigated lands, durum wheat (*xeixa*) was sown, except in the very cold areas at the foot of the Monseny where it was replaced by rye, and in the worst various mixed bread-making wheats were obtained (*mestalls*). Average cereal yields fluctuated between 10 and 18 hectolitres per hectare, multiplying the seed by between 5.5 and 10 times. The growing importance of vines should be stressed, with their presence continuing to increase until the grapevine fever of the final decades of the 19th century, spurred on by the high wine prices caused by French vineyards being affected by the phylloxera plague.

Taking into account the agronomic capacities evaluated in Table 3, we have estimated the area where more than one annual crop was obtained as 15% of the cultivated land. Given these intensive crop rotations without fallowing, and that in irrigated areas or a certain proportion of un-irrigated areas several annual crops were obtained, the finally available cultivated area came to around 25,000 ha.[9] With a population of 38,342 inhabitants in 1860, the useful agricultural area fluctuated between 1.27 ha/inhabitant, not counting double crops, and 1.36 if these are included. Taking current measurements and without discounting unproductive lands, the level would rise as far as 1.5 ha/inhabitant. The land area cultivated per person around 1860 was between 0.48 and 0.66 ha, depending on whether we consider double crops or not.

These are values lower than the 2 ha/inhabitant estimated by Paolo Malanima for more densely populated parts of Europe towards the middle of the 18th

[8] The 1874 *Estudio* describes various rotations of un-irrigated land, adapted to each type of soil, in which there was no fallowing and where one or two crops were obtained annually. Thus, for example, in clayey soils three crops were produced in two years, the first of legumes and the second year another two of cereals or late legumes; or alternatively, one of potatoes the first year, and the second year another two of cereals and maize, fodder or beans (Garrabou, R. and Planas, J. eds. ([1874]1998:138–139).

[9] In Table 3 the assignment of rotations relies on the identification of soil types carried out from the 1874 *Estudio* by Rodríguez Valle, F.L. (2002).

Table 4
Area used and energy value of the crops, woodland and pasture

	Area available in ha	Total production in kg	Energy value of the product in TJ	Output per hectare/ year in GJ	Output per inhabitant/ year in GJ
Crops	18,475.54	75,297,024	551.9	29.9	14.4
Woods	18,564.43	56,103,978	638.5	34.4	16.7
Pasture	11,575.99	20,107,541	72.6	6.3	1.9
TOTAL	48,615.96	151,508,543	1263.0	26.0	32.9

Sources: the same as Table 3 for uses, and for yields the 1874 *Estudio* and the 1879 IACSI *Evaluation Handbooks*, completed with the data on pasture land and woodland from Naredo, J.M. and Campos, P. (1980a,b) and the *Ecological and Forestry Inventory of Catalonia* (CREAF, 2000). The caloric transformation was performed from Mataix Verdú, F.J. ed. (2003[4a]), Moreiras-Varela, O., Carvajal, A. and Cabrera, L. (1997[3a]), and Naredo, J.M. and Campos, P. (1980a,b). Conversion: 1 Kcal = 4186.8 J; 1 MJ = 10^6 J; 1 GJ = 10^9 J; 1 TJ = 10^{12} J. An average human being needed an energy intake of 3.5 GJ/year.

century, or the 2.4 that Fridolin Krausmann calculates for the whole of Austria in 1830–50. While the woodland area per inhabitant was still close to Malanima's levels, the land set aside for pasture was much less (0.3 ha against a range between 0.5 and 1 ha per inhabitant in western Europe, and 0.7 in Austria around 1830–1850). The amount of available agricultural land was also less (0.5–0.7 in the Vallès, against 0.8–1 ha per person in Europe on the eve of the Industrial Revolution).[10]

4. The primary energy output

Once the areas devoted to the various land uses were established, we calculated the potentially useful primary output resulting from the transformation in biomass of the solar energy irradiated in a year onto the biologically productive land. The energy consumed by plant respiration and the majority of underground biomass are excluded, and we consider that forestry exploitation was sustainable. The primary production calculated in Table 4 – equivalent *grosso modo* to the land cover's solar energy retention capacity in the agrarian useful area – distinguishes the energy output coming from the cultivated land, the forestry mass, and the uncultivated area used as pasture.

Primary output exceeded 151,500 t, equivalent to 1263 TJ/year. Woodland generated 50.6%, crops 43.7%, and wasteland set aside as pasture 5.7% of that energy. Given the different water content, the weight percentages are different: crops supplied 50% and woodland 37%. The highest energy output per hectare was obtained in the forested area, although an important part could not be exploited for human consumption. Per area unit, or per inhabitant, the energy output of cultivated land was 13% less than that of the forests, and far higher than the pasture land.

It may seem surprising that the energy product per hectare was less than that of Mediterranean woodland in an area with high agricultural yields. Yet the fact of taking as referent the combustion value, the presence of vinegrowing and horticulture, and productivities that were lower than current ones explain the result. 17% of woodland production were leaves, grasses or woodland undergrowth species that were of limited human use as direct consumption, but partially used as pasture. Timber and firewood came to 28.7 GJ/ha of woodland – below the agricultural 29.9 GJ/ha – and adding other extractions the overall forest final output amounted 34.4 GJ/ha; once deducted the animal consumption as pasture, the forestry output directly derived for human consumption meant 42.6% of the primary agro-forestry conversion (Tables 4 and 13). The comparison with some initial estimates put forward by classic authors like Sacher and Podolinsky leads to certain divergences, yet our data is coherent with that obtained by Pablo Campos and José Manuel Naredo, Fridolin Krausmann, and Manuel González de Molina (Naredo and Campos, 1980a:17–114;

[10] Paolo Malanima considers a mean range from 15 to 20,000 Kcal/inhabitant/day (22.9 to 30.6 GJ/inhabitant/year) that were obtained on some 2 ha/inhabitant in the more densely populated parts of Europe, coming from 500–800 g of cereals per person, 2 kg of timber, and the traction provided by one oxen, mule or horse for every six inhabitants (Malanima, 1996:126–129; 2001:51–68; 2003:74–76).

Table 5
Land area, product and energy value of the main crop component

	Area available in ha	Physical yield in kg or l/ha	Total production in kg or l/year	Unit energy value in MJ/kg	Energy value of the total production		
					TJ/year	GJ/ha	GJ/inhabitant/year
Cereals (kg)	8082.81	925.79	7,482,984.7	12.46	93.2	11.5	2.4
Legumes (kg)	5401.84	662.09	3,576,504.2	12.96	46.3	8.6	1.2
Wine (l)	4996.89	1345.21	6,721,866.4	3.27	22.0	4.4	0.6
Oil (l)[1]	771.12	195.90	151,062.4	37.01	5.6	7.3	0.1
Potatoes (kg)	1429.52	4000.00	5,718,080.0	3.14	18.0	12.6	0.5
Fodder (kg)	3289.59	3478.32	11,442,246.7	3.55	40.6	12.3	1.1
Others (kg)	1970.81	–	–	–	27.8	14.1	0.7
TOTAL	25,392.65[2]	–	–	–	253.5	13.7[3]	6.6
Seeds					25.8	1.4	0.7
Fodder					40.6	12.3	1.1
FINAL PRODUCT FOR HUMAN CONSUMPTION					187.1	10.1	4.9

Source: own compilation from sources quoted in Table 4. Note [1] : according to the data from the 1874 Estudio there were 771.12 ha of olive trees, but given the fact that the majority of these were mixed crops, we have reduced the figure to 257 ha in the sum. Note [2] : accounting multiple crops in the same cropland. Note [3] : only accounting the 18,475.54 ha of cropland.

González de Molina et al., 2002:155–185; Krausmann, in press).[11]

Only 34% of 551.9 TJ provided by crops came from the final useful product for satisfying of human needs. The remaining 66% were seeds, fodder, waste or by-products (straw, stubble, green vine shoots, pruning, etc.) mainly used to feed the livestock. Once fodders and seeds were deducted, the finally consumable output was 3193 Kcal/inhabitant/day or 4.9 GJ/inhabitant/year, a value close to the three thousand Paolo Malanima estimates for the most developed part of continental Europe in the middle of the 18th century. And subtracting the industrial crops we get a figure of an edible final output around 2800 Kcal/inhabitant/day or 4.3 GJ/inhabitant/year, only slightly greater than the 2315 Kcal/inhabitant/day or 3.5 GJ yearly needed to sustain the then mean requirement of every individual in the local area (Cussó and Garrabou, 2001:26–34).[12]

Considering that the Vallès Oriental was a rural area close to Catalonia's main urban system, it is surprising that the final agricultural product was not greater. Yet our results are consistent with the agricultural statistics for production and consumption of the Vallès administrative area in 1862–1864, which endorse the existence of only small and temporarily deficits of cereals compensated for by wine exportation (Planas, 2003:489). In caloric terms, the high water content of vineyard production involved a low energy production per surface area: only one 4.4 GJ/ha, against 11.5 for cereals or 12.6 for potatoes. (Table 5). Nevertheless, the higher relative prices for wine allowed the acquiring of imported cereals with a caloric content 3.8 times greater per weight unit, and 2.6 per hectare cultivated.

[11] At the end of the 19th century Eduard Sacher evaluated in 18×10^6 Kcal or 75 GJ/ha/year the energy obtained from the wheat fields and forests of Austria and Prussia. Sergei Podolinsky reduced the figure to 8.1 and 6.4×10^6 Kcal or 33.9 to 26.8 GJ/ha/year for wheat and pasture in France (Martínez Alier and Schlüpmann, 1991:65–95; Martínez Alier, 1995:65–142). Fridolin Krausmann estimated values around 1830–50 of between 26 to 39 GJ/ha/year for the crops in various Austrian villages, between 34 and 44 GJ in the forests, and between 17 and 36 GJ in the pasture (Krausmann, in press). For all crops, and including fallow land, Manuel González de Molina, Gloria Guzmán and Antonio Ortega obtain 6.1×10^6 Kcal or 25.5 GJ/ha/year in 1856 for the Granada plain of Santa Fe (2002:155–185). In the countryside around the Guadalquivir river Pablo Campos and José Manuel Naredo obtain a mean value of 5.9×10^6 Kcal or 25 GJ/ha/year (corresponding to 6.3 GJ in the fallow pasture, 21.8 GJ in the seeded fallow land, and 46.1 GJ in that of wheat). The energy value of pasture land which we use in our work (1.497×10^6 Kcal or 6.268 GJ/ha/year), together with that used for Santa Fe, also comes from Naredo, J.M. and Campos, P., (1980a:17–114).

[12] In Santa Fe (Granada) 2975 Kcal/inhabitant/day or 4.5 GJ/year were obtained in 1856 (González de Molina et al., 2002:155–185).

Table 6
Livestock and the production of manure

Animal converters				Manure production			Energy value		
Type	No.	kg/unit	Total weight MT	Per head in kg/year	Total MT/year	kg/ha in cultivation	Unit energy value MJ/kg	Energy value of manure in GJ	Energy value of manure in GJ/ha
Horse	2227	326	726.0	5500	12,249.0	662.9	0.6590	8071.8	0.437
Mule	1017	326	331.5	5500	5593.5	302.7	0.6590	3686.1	0.200
Donkey	1146	172	197.1	1850	2120.1	114.7	0.6590	1397.2	0.076
Cattle	1553	371	576.2	6500	10,094.5	546.4	0.3349	3381.1	0.183
Sheep	11,170	30	335.1	240	2680.8	145.1	0.7921	2123.6	0.115
Goats	3457	34	117.5	222	767.5	41.5	0.7921	607.9	0.033
Pigs	11,478	77	883.8	1450	16,643.1	900.8	0.4626	7699.8	0.417
Fowl and rabbit	40,000	2	80.0	5	200.0	10.8	0.4187	83.7	0.005
STANDING	6495 LU500		3247.3	–	50,348.0	2725.0	–	27,051.2	1.464
Transhumant	18,500	30	[277.5]	[120]	2220.0	120.2	0.7921	1758.6	0.095
TOTAL	7050 LU500		3524.8	–	52,568.0	2845.2	–	28,809.8	1.559

Source: own compilation from the 1865 livestock census, statistics from the General Livestock Association (AGG,1923), and other sources from the late 1920s and early 1930s. All transhumant contracts were settled orally, and we have had to deduct the number of transhumant sheep comparing the 1865 livestock census with the 1860–1870 forage and pasture potential in the region. [The transhumant sheep only stayed six months grazing winter pastures in the Vallès county, so only half their weight has been added to obtain the total livestock amount in LU500 and the same with their manure.]

Market insertion allowed more to be made of the area's ecological possibilities, and enabled a reduction of the bottleneck in the obtaining of organic fertilizers. Vines were planted in poor soil, and except at the time of initial planting, no manure was applied. Partial winegrowing specialisation allowed cultivators to concentrate manure on the better land devoted to vegetable gardens, cereals, legumes or hemp. The vineyards pruning and green shoots even went towards fertilizing other crops, either directly as compost or indirectly as fodder. These were the responses to the challenge of feeding a population which had doubled between 1787 and 1860, with an organically based intensive agriculture on a land subject to the water restrictions typical of the Mediterranean environment, where the keeping of livestock and the obtaining of fertilizer became a severely limiting factor (González de Molina, 2001a:43–94; and 2001b:87–124).

Counting the whole area available due to multiple crops, cereals and legumes take up 52% of the cultivated area, followed by 20% for vineyards and 13% for fodders. The rest were potatoes, olive trees, vegetables and fruit, or hemp (Table 5). The 10,896 Kcal/day or 16.7 GJ/year of fuel and timber extracted per inhabitant from woodland exceeded by over 50% the mean 7000 Kcal/day or 10.7 GJ/year of woodland origin estimated by Paolo Malanima for continental Europe around 1750, but were comparable to those that Fridolin Krausmann considered to have been extracted in Austria around 1830 (Malanima, 2001:51–68; 2003:40–80; Krausmann, in press). The product from pasture land was however much less. This forced people to get all they could out of agricultural sub-products in order to sustain livestock, and also from the possibilities offered by woodland undergrowth and scrub. In woodland firewood and timber contributed the majority of the energy: 532.3 TJ, 51% and 32%, respectively. However, the role of leaves, chestnuts, acorns, grass, edible fungi, asparagus and other plants for animal and human food should not be forgotten.[13]

[13] For the calculation of timber and firewood we have used the data from the *Cartillas Evaluatorias* of the IACSI and the 1874 *Estudio Agrícola*, corrected in some cases downwards considering a compatible exploitation rate with the sustainability of the Mediterranean forest mass of the area (CREAF, 2000).

5. Bio-converters and re-uses

A 38.8% of the available vegetable biomass, 491.2 TJ was transformed by livestock into traction power, meat, milk, wool, hides, manure and other sub-products. In the 1865 livestock census, that only counted the standing animals, stock came to a total of 6495 standardised 500 kg livestock units (LU500). Comparing the feeding needs of this standing livestock with the 1860–1870 forage and grazing potential, we have estimated a number of 18,500 transhumant sheep that only stayed half a year grazing winter pastures. Adding their 555 LU500 equivalent value, we get a stock of 7050 LU500 for the whole of the area under study. This meant a livestock density of 12 LU500/Km^2 – or of 15 LU500/Km^2 if we only take the useful agrarian area – , 30% less than the 17 LU500/Km^2 for Austria in 1830–1850 (Krausmann, 2004:735–773).[14] Local meat production rose to 30.7 kg/inhabitant/year, equivalent to 84.2 g daily per person (256.6 Kcal/day or 0.39 GJ/year), and 87% came from pigs. The availability of milk – largely from goats – and eggs was low: 73.7 g per person daily (56.8 Kcal/inhabitant/day or 0.09 GJ/inhabitant/year).

Manure was the main energy consignment of the livestock sub-system: 45%, followed by 25% for draught animal power, 24% for meat or 6% for milk and eggs (Tables 6 and 8). Uniformly distributed in cultivated land, the 52,568 t of manure meant a scant 2845 kg per hectare per year. Depending on the intensity of use and the performance of the soil, the cultivation of cereals and legumes on un-irrigated land could require from three to nine times more (from 10,000 to 25,000 kg/ha).[15] As well as being complemented by vegetable fertilizers coming from woodland and wasteland, the manure was concentrated on irrigated areas, or on land where the most intensive rotations were practised.

Traction power was another contribution of livestock conversion fundamental for the reproduction of the agricultural system. Around 1860–1870 there were some 29 head of different livestock available in the Vallès Oriental for every 100 ha under cultivation: 11.6 horses, 5.4 mules, 5.9 donkeys and 6.1 oxen. If – following Anthony Wrigley – we suppose that only 55% were used in agricultural work, that three oxen did the same work as two horses in the same period, and a donkey the third of a horse or mule, the draught power available would be around 12.7 equivalent horses per 100 ha cultivated: a figure lower than the 14.3 in Britain around 1820, but higher than the 8.9 estimated for France by Wrigley during the same period (Table 7).[16]

Disregarding donkeys and milking cows, there would have been a draught horse, mule or ox for every 8.2 inhabitants, against the six that Paolo Malanima estimates for the central European area around 1750. However, considering that three donkeys could do the same work as a mule or a horse, in 1860–1870 there would have been a draught animal in the Vallès Oriental for every 7.1 inhabitants. It is likely that this relatively high provision of draught animal power was related to the haulage of timber and charcoal from the mountain slopes of the Montseny to the coastal cities. Whatever the case, its social or territorial distribution was far from being homogenous (Table 8).

6. Energy inputs reintroduced into the system

The functioning of the Vallès Oriental agricultural system required several energy inputs that, as in any organic-based economy, were obtained through re-uses of biomass, fertilizers and seeds, and human or animal labour. Their substitution by sources from outside the system itself, such as inorganic fertilizers or machinery driven by fossil energy, was insignificant around 1860–1870.

Among re-uses, the greatest was the biomass flow for animal feed. In order to obtain the final livestock product, it was necessary to invest nearly forty percent of the primary energy output. This reveals the enormous loss involved in passing from one flow to another by way of livestock conversion: for every 100 vegetable energy unit invested as fodder, only

[14] Fowls and rabbits, which do not appear in the census of 1865 nor the 1874 *Estudio*, are our own estimates.

[15] B.H. Slicher van Bath proposed 10,000 kg/ha, a figure congruent with other data from the second half of the 19th century from the Mediterranean area (Slicher van Bath, 1978[2a]:383). For Britain Robert Shiel suggests an optimum of 10 t per acre, equivalent to 24,700 kg/ha (in Campbell and Overton, 1991:70–71).

[16] Wrigley, E.A. (1993:55–56).

Table 7
Availability of animal traction power

Number		Hours of work per year	MJ/h	Joules/year per head	Energy value of the animal work (GJ/year)	Value/hectare cultivated (MJ/year)
Horse	2147	1800	1.8804	3384.68	7266.9	393.32
Mule	994	1800	1.8804	3384.68	3364.4	182.09
Donkey	1097	1800	0.8059	1450.58	1591.3	86.13
Cattle	1119	1800	1.8804	3384.68	3787.5	204.99
TOTAL	5357	1800	–	11,604.60	16,010.0	866.53

Source: own compilation from sources quoted in Table 6.

some 13 energy units of animal origin were obtained in the form of food, traction, fertilizer or raw materials (Tables 8 and 9). A key feature of organic agricultural systems was the impossibility of substituting from other sources the functions that livestock performed as a motive power and a concentrator or accelerator of the nutrient cycle. This is the difference from agricultures after the so-called 'green revolution', and also from any new ecological agriculture.

We have estimated that the agricultural and forestry labour required an average of 45 working days per inhabitant per year for the region as a whole, meaning some 68 working days per annum per active agricultural worker according to the distribution by occupations, sex and age reproduced in the 1874 *Estudio*, or some 95 working days per year if we discount those under 10 years of age and over 70 (Garrabou and Planas, [1874]1998:154 and 159). If we add the human labour employed in livestock, 57, 86 and 121 annual working days are required respectively. Although this aspect requires a specific study in greater depth, everything points to the fact that work capacity was one of the surpluses in that model of advanced organic agriculture. Estimated in 860 Kcal per working day (or 1.31 GJ/year) human labour accounted for 1.5% of the energy inputs invested, while animal feed accounted for 90% (Table 10).[17]

7. Energy balance and efficiency

Adding the primary output (1263 TJ) to the final livestock product (63.4 TJ) we obtain a total output of 1326.4 TJ. If we subtract the part re-used in livestock feed to obtain animal food, other by-products, traction or manure, together with vegetable fertilizer and seeds, we obtain a final net output – or the energy content of the final agrarian production – of 743.5 TJ, equivalents to 15.3 GJ/ha/year, and 19.4 GJ/inhabitant/year (Table 11).

The total output and re-uses in Tables 10 and 11 include some double counting: the obtaining of the livestock output required the high cost of animal feeding, but if we add to it the power services supplied by animal traction, or the material re-using of manure, we are counting twice the same flow. We have to deduct them, and add the human labour, in order to get a total amount of inputs consumed in the process so as not to fall into double counting. Then we can strike a coherent balance from our data to measure the efficiency of the agrarian system, once we have put

Table 8
Summary of the energy output from livestock conversion

	TJ/year	GJ/inhabitant/year	%
Meat	15.03	0.39	23.7
Milk and eggs	3.33	0.09	5.3
Wool, feathers and hides	0.21	0.01	0.3
Animal fertilizer	28.81	0.75	45.4
Traction power	16.01	0.42	25.3
TOTAL	63.39	1.65	100.0

Source: own compilation from sources quoted in Table 6.

[17] Following Pablo Campos and José Manuel Naredo, we have established the energy value of human labour as the daily average of the energy *working* activity performed by an active adult in all agrarian tasks during the year, which they estimated at 860 Kcal/day or 1.31 GJ/year (Naredo and Campos, 1980a:17–114). To count *all* the 2700 Kcal eaten daily by a male working adult or the yearly intake of 4.13 GJ, as we do with livestock, would imply considering that human beings only consume energy *to work*, forgetting any other activity that also requires energy to be done.

Table 9
Inputs invested in livestock conversion

	TJ/year	GJ/hectare	%
Horse	85.1	1.8	17.3
Mule	38.9	0.8	7.9
Donkey	26.3	0.5	5.3
Cattle	59.3	1.2	12.1
Sheep	68.3	1.4	13.9
Goat	21.1	0.4	4.3
Pig	96.5	2.0	19.6
Fowl and rabbit	24.5	0.5	5.0
STANDING	419.9	8.6	85.5
Transhumant sheep	71.4	1.5	14.5
TOTAL	491.2	10.1	100.0

Source: own compilation from Table 6.

aside any change in capital stocks (Table 12).[18] An input of 526 TJ was used to obtain a net final output of 743.4 TJ, with an efficiency of 1.41 per every energy unit invested. Considering human labour as the only relevant external input, the energy yield reached 94.5 for every energy unit invested from outside.

A flow diagram shows in a clearer way the whole picture, and helps to attain a better understanding of the two key factors that allowed to maintain these high energy yields in such an intensive organic-based agrarian system: 1) the strong integration between cropping, livestock breeding and forestry; and 2) the small amount of external inputs coming from outside.

The energy balance described in Table 13 allows us to observe the intensive, and at the same time integrated, nature of the agro-ecosystem. Cultivated biomass accounted for 44% of the primary agro-forestry conversion, and the forestry mass another 42%. Pastures in wasteland and woodland only represented the remaining 14%, an insufficient flow to obtain enough draught power and manure. The lack of pasture was made up for with an intensive use of agricultural by-products, which directed 27% of the cultivated biomass towards livestock conversion.

The integration between cropping, livestock breeding and forestry explains why the caloric equivalent of the final agrarian product still represented 59% of the solar energy fixed by photosynthesis, although re-uses and losses from livestock conversion or combustion of vegetable fertilizers consume 41%. In 1950–1951 the Spanish final agrarian production only accounted for 38% of the energy contained in the biomass, while the other 62% were re-uses and transformation losses. In 1977–1978, in spite of the replacement of animal traction and manure by tractors and chemical products, 68% of the primary agro-forestry conversion continued to be devoted to livestock conversion. The energy value of the final agrarian product accounted for 47% of the primary output, due in reality to

[18] We do not have enough historical data to estimate the annual investment and consumption of capital stock. So, we are in fact assuming a steady state in which internal investment would equal the capital consumption within the area and during the period analysed. If annual crops would receive enough fertilization and caring to prevent soil degradation, this assumption could be considered more or less realistic, as it would be the case with a sustainable forestry. But it was not the case in the plantation of vineyards or olive trees, in livestock breeding, or in terracing and other capital-land investments like irrigation ditching and lane building. We thank Pablo Campos for this observation.

Table 10
Re-uses and human labour introduced into the agricultural system

	TJ/ year	GJ/ useful hectare	GJ/ cultivated hectare	GJ/ inhabitant/ year	%
Seeds	25.8	0.53	1.40	0.67	4.6
Animal feed	491.2	10.10	26.59	12.81	87.3
Animal traction	16.0	0.33	0.87	0.42	2.8
Manure	28.8	0.59	1.56	0.75	5.1
Vegetable fertilizers	1.1	0.02	0.06	0.03	0.2
RE-USES	562.9	11.58	30.47	14.68	100.0
Human labour in livestock	1.5	0.03	0.08	0.04	18.7
Human labour in agriculture and forestry	6.4	0.13	0.35	0.17	81.3
HUMAN LABOUR	7.9	0.16	0,43	0.21	100.0

Source: own compilation from Tables 4 and 6–9.

Table 11
Total energy output, re-uses and final net output

	TJ/year	GJ/useful hectare	GJ/inhabitant/ year
Crops, woodland, pasture	1263.0	26.0	32.9
Livestock	63.4	1.3	1.7
TOTAL OUTPUT	1326.4	27.3	34.6
Re-uses	562.9	11.6	14.7
Combustion losses in vegetable fertilizers	20.1	0.4	0.5
FINAL NET OUTPUT	743.4	15.3	19.4

Source: own compilation from Tables 4, 8 and 10.

Table 12
Total inputs consumed, final output and agrarian system yields

	TJ/ year	GJ/ useful hectare	GJ/ inhabitant/ year
TOTAL OUTPUT (TO)	1326.4	27.3	34.6
Total re-uses (R)	562.9	11.6	14.7
Internal services (IS = traction + manure)	44.8	0.9	1.2
Human labour input (LI)	7.9	0.2	0.2
TOTAL INPUTS CONSUMED (TIC = R − IS + LI)	526.0	10.8	13.7
FINAL OUTPUT (FO)	743.4	16.5	20.9
Energy return on total inputs (FO/TIC)	1.41		
Energy return on labour inputs (FO/LI)	94.5		

Source: own compilation from Tables 4, 10 and 11, following the Pablo Campos and Javier López Linaje definitions and criteria (Campos and López, 1997; Campos et al., 2004:201–230).

imported feedstuff whose caloric total was equivalent to 11% of the solar energy fixed by photosynthesis in Spain (Naredo, J.M., 1996:328–329).

8. A high intensive organic system

In a collection of notes entitled "*Trade Observations of England*", William Petty [1623–1687] described what we might consider to be a first outline of the idea of an "ecological footprint":"*A man's country is the circuit of Land Whose Radius is halfe a days journey from his house. Trade begins when men need more variety of Commoditys than their own home and country can best produce*" (Petty, W., 1967:209). Our study area's 59.6 Km^2 comprised a territory of these characteristics, one which could be covered on horseback in one day. Though only a small area, it held within it a variety of agricultural and forestry resources that were sufficient to satisfy the greater part of its inhabitants' necessities around 1860–1870, and to generate small surpluses.

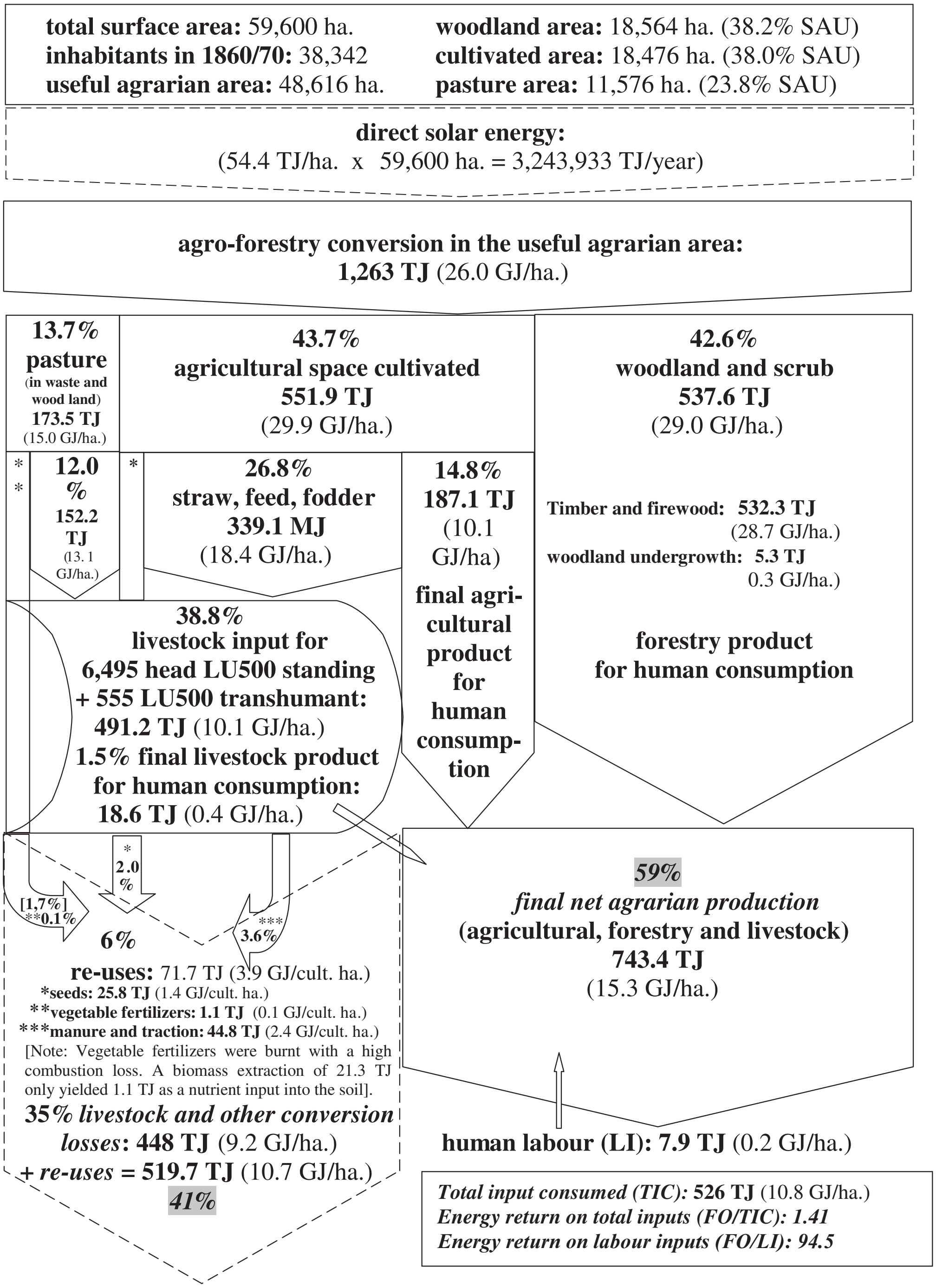
William Petty estimated the land required by each inhabitant in England in 1650 as 1.25 ha (Petty, 1967:xxxvii). In 1830 for the whole of Austria there were still 2.4 ha/inhabitant, but only 0.5 cultivated (Krausmann, in press). These were ecological footprints similar to the one and a half hectares, and half cultivated, that were available in the Vallès Oriental in the 1860–1870 period. Yet as Petty sensed, its inhabitants only managed to reduce that territorial requirement by an insertion in commercial networks that allowed them to optimise their local resources, and to reduce the scarcity of fertilizers. Oscar Carpintero has calculated that in Spain in 1955 the food and timber supply also required 1.3 ha/inhabitant, and half a hectare cultivated: almost the same level that we discovered in our study area (Carpintero, 2002:120–125). This confirms that the energy balance of the Vallès Oriental in 1860–1870 corresponds to one of the highest levels that could be attained in a Mediterranean environment with a highly intensive organic agriculture.

In order to estimate the real range of possibilities for the whole of the Iberian Peninsula, we need more studies that examine the lower levels that characterise many other areas that are submitted to more severe water restrictions, that have less woodland, and a more difficult access to commercial networks. Only with a sufficient number of representative samples will it be possible to generalise several key benchmarks for very large territories as a whole. It has nevertheless been useful to have evaluated one of the highest levels attained in those conditions, in order to situate historically the starting point of the contemporary globalisation process which has disconnected the satisfaction of basic human needs from the flows and local uses of the land itself.

9. Driving forces towards unsustainability

To get a coherent energy balance, without counting the net additions or reductions in capital stocks, a steady-state hypothesis has been adopted. Thus, the annual flows in our balance are those that *could* be obtained *as if* the system were a static one, i. e. with neither growth nor decrease in forest cover, no addition or reduction in vineyards and tree plantations, no changes in livestock numbers, and no soil erosion. Although this is an unrealistic assumption, it helps to highlight the two main forces that could have led the agrarian system towards a greater local unsustainability. The first one being deforestation and the second one the lack of manure to sustain crop yields in a high intensive organic agriculture.

Table 13
Summary of the annual energy flows of the agrarian system



Source: own compilation using the scores quoted in Tables 4 and 12. Conversion: 1 Kcal = 4186.8 J; 1 MJ = 10^6 J; 1 GJ = 10^9 J; 1 TJ = 10^{12} J. An average human being needed an energy intake of 3.5 GJ/year.

Towards the end of the XVIIIth century several reports were written advocating coal imports in order to preserve the Montseny forests which were considered overexploited at that time (Jaume Caresmar [1780]; Josep Comes [1786]; quoted in Martí Escayol, 2002:5–20). Although we do not have enough historical data on timber and firewood cutting to prove that trend, photographs taken in the Vallès county during the first half of the XXth century did show a picture of intense deforestation and rejuvenation apparent in the surviving forest. This explains why we have had to reduce somehow the figures coming from our historical sources in firewood and timber extractions in order to get a sustainable forestry energy flow according to present data.

If deforestation was in fact the main driving force towards unsustainability, we might assume that overgrazing and soil degradation could have reinforced it. According to the *Estudio Agrícola del Vallès* in 1874 there were several local businesses which tried to recycle as fertilizers almost any useful animal, human or industrial by-products. Their existence confirms the need to fill the important gap in organic fertilization shown by our steady-state balance. The *Estudio* also mentions the local use of small quantities of guano, although we have no specific figures to include these external sources in our balance. Likewise we have not included two other possibilities to fill this fertilizer gap: 1) a greater use of the traditional slash of brushwood, which having previously covered it with earth was burnt to add potassium and other nutrients to the soil; 2) a greater transhumant pasture. Owing to the fact that all transhumant contracts were settled orally, there were no census of the number of sheep that every winter came down from the Pyrenees. We have deducted this figure comparing the 1860–1870 forage and pasture potential, with the 1865 livestock census that only counted the standing local animals. Thus the livestock flows in our energy balance are once again sustainable by definition. But actually they could not be, and probably were not. This may have fostered overgrazing and soil degradation.

If we had been able to measure this unsustainable dynamic tendencies, they would have diminished the performance indexes obtained from the unrealistic assumption of a steady-state agrarian system. We know that these tendencies could have been counterbalanced intensifying human labour, at the cost of deteriorating again the energy return to external inputs. The growth of vineyards and olive trees offered a substitute for firewood or forage shortages through the use of their leaves and pruning. Although vineyard planting was a labour intensive activity that often required soil terracing, the opportunity cost of the pruning or of the grazing by-products may have reinforced the waves of high wine prices fostering new plantations. In 1840–1850 the oidium plague raised a first wave of wine prices stimulating the investment in vineyards. Our energy balance reflects the spread of vineyards which took place in 1860–1870, although the Vallès agrarian landscape still remained a polycultural one.

The second wave started in 1867 when the phylloxera plague hit French vineyards, causing Catalan wine relative prices to soar. This grapevine fever suddenly displaced polycultivation, provoking the first episode of environmental and economic globalisation that linked the fate of that area to the international value of a single export product. This ended abruptly with the arrival of the disease in the Vallès Oriental in 1883. By 1890 it had killed the old vines, and the region's agriculture swung towards the production of fresh milk and vegetables for daily delivery to the nearby cities. The widespread use of petroleum put an end to the role of the mountains of the Montseny as suppliers of firewood and charcoal, though during WWI and the Spanish Civil War periods the demand for forestry products enjoyed a short-lived increase. The new model was consolidated circa 1930, when the available land had been reduced to one hectare per inhabitant, with only one third of it arable.

During the first half of the 20th century the land required for consumption by the population had already outstripped local availability. Since then the globalisation of economic networks has been sustained by the growing globalisation of social metabolism and its ecological footprint. It is interesting to notice that even in such a globalized context the Spanish food ecological footprint has remained during the second half of the 20th century practically the same as in the Vallès county circa 1860–1870: half a hectare per inhabitant. Since then the main difference with a previous advanced organic economy is the big energy footprint resulting from the combustion of fossil fuels (Carpintero, 2002: 85–125).

Studying the past land uses in those organic advanced agricultures that could attain the highest energy yields, may help to get a better understanding of the two sides that have led to a lower energy performance after the so-called 'green revolution': 1) the injection of an external energy subsidy mainly coming from fossil fuels; and 2) the functional disconnection between the agricultural, pasture and forestry spaces inside the agrarian ecosystem, brought about a much more inefficient land use from an ecological point of view. It is worth distinguishing both sides, because the solutions to overcome their ecological effects must be different. An energy subsidy that substitute the animal work power, or help to make less painful human labour, should not be considered a problem in itself if provided by clean, nearer and renewable sources. The true problem is that at present it comes from fossil or nuclear fuels, and because the overcoming of past dependency on bioconverters has led to a dysfunctional and ecologically unsound land use that is causing serious environmental pathologies.

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