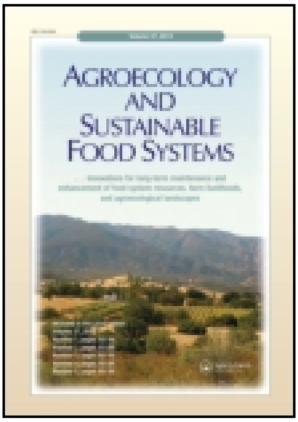

Agroecology and Sustainable Food Systems
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/wjsa21

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Accepted author version posted online: 18 Sep 2013.Published online: 15 Jan 2014.

To cite this article: David Pérez Neira, Marta Soler Montiel & Xavier Simón Fernández (2014) Energy Indicators for Organic Livestock Production: A Case Study from Andalusia, Southern Spain, Agroecology and Sustainable Food Systems, 38:3, 317-335, DOI: 10.1080/21683565.2013.833154

To link to this article: http://dx.doi.org/10.1080/21683565.2013.833154

Agroecology and Sustainable Food Systems, 38:317–335, 2014

ISSN: 2168-3565 print/2168-3573 online
DOI: 10.1080/21683565.2013.833154

Energy Indicators for Organic Livestock Production: A Case Study from Andalusia, Southern Spain

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This work analyzes the energy performance of organic livestock farming in Andalusia (Spain), both as an industry and by type of livestock, through the application of the energy analysis methodology adapted in this article to the study of the organic livestock farming. From this perspective, it is possible to observe that organic livestock farming has a great capacity to use resources and generate outputs in the form of products of animal origin and, especially, manure, which is an important resource for agricultural fertilization. The energy efficiency of organic livestock farming in Andalusia is estimated at 0.08. If the manure reused by agriculture is considered an output, the efficiency of the industry reaches 0.32. Also, 28% of the energy consumed by the industry is nonrenewable and the energy efficiency in relation to the use of nonrenewable energy is estimated at 1.38. By type of livestock, the energy efficiency in relation to the use of nonrenewable energy is estimated at 1.78, 1.62, 0.84, 0.57, 0.22 for goats, cattle, sheep, pigs, and poultry. These results show the capacity of extensive

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organic livestock farming to reduce energy costs and improve its energy efficiency.

KEYWORDS *organic livestock, livestock energy analysis, energy efficiency, energy indicators*

1. INTRODUCTION

Nowadays, intensive livestock farming is an economic activity with a high environmental impact. According to the Intergovernmental Panel on Climate Change (2007) data for 2007, livestock farming is responsible for 14% of the greenhouse gas (GHG) emissions, due to either livestock gas emissions or the amount of energy use in farms. It is, therefore, necessary to reduce the environmental impact of livestock farming in terms of both GHG emissions and energy consumption. The design and development of livestock farming systems whose energy inputs are low as compared to the resulting energy output in the form of food may help reduce GHG emissions (Dalgaard, Halberg, and Fenger 2000; Dalgaard, Halberg, and Porter 2001; Dalgaard, Olesen et al. 2011). In this context, the development of organic livestock farming can contribute to energy saving and energy efficiency (Pimentel & Pimentel 2006; Refsgaard et al. 1998), especially in those livestock farms where there is a high degree of integration between agriculture and livestock farming in terms of energy flows (Nahed 2006). Alternatively, animal production and livestock can also be reduced (Bleken & Bakken 1997). In order to see some progress in relation to these questions, it is first necessary to quantify and analyze the energy use of the different animal production systems (Grönroos et al. 2006; Fluck 1992, 1981; Ministry of Agriculture, Fisheries and Food 2000).

Even if biophysical indicators are internationally acknowledged tools, usually applied to decision making, policy design, and the comparative study of different economic processes (Kumar 2009), they still occupy a totally subsidiary and secondary place in relation to monetary indicators. Nevertheless, in a context of climate change and growing energy shortage as the present one, biophysical indicators (Dale and Beyeler 2001; Corre et al. 2003; Carpintero 2005; Martínez Alier 2008) and, in particular, energy analysis (International Federation of Institutes for Advanced Study [IFIAS] 1974; Pimentel 1980; Carpintero & Naredo 2006; Meul et al. 2007; Garavand et al. 2010) should have an increasing importance in the analysis and decision making of agricultural and livestock farming systems as indicators of environmental sustainability (Meul et al. 2012), energy efficiency, and technical-productive viability.

Andalusian organic livestock farming represents more than 56% of the livestock production in Spain (Ministerio de Medio Ambiente y Medio Rural y Marino 2011) and constitutes an economically viable industry based on the use of natural resources through pasturing (Soler Montiel et al. 2009). In this sense, this work has the main objective of quantifying and analysing the performance of the organic sector through the use of the energy analysis methodology (IFIAS 1974; Meul et al. 2007), applied and adapted to extensive organic livestock farming. Energy analyses are mostly focused on studying the performance of crop production agriculture, and only to a much lesser extent that of livestock farming. The energy indicators used for the present analysis of agriculture conceal the complex energy performance of organic livestock farming and it is, therefore, absolutely necessary to develop specific indicators capable of reflecting that complexity. In this sense, this work studies the energy performance of the industry in 2005 in relation to its output, inputs (direct, indirect, and capital inputs), energy efficiency and other livestock-specific energy indicators, both aggregated and by types of livestock (beef cattle, sheep, goats [meat and milk], pigs, and poultry), while distinguishing as well between renewable and nonrenewable energy. The selection of the period of reference (2005) has to do with the availability of information and data. The year 2005 was the only year for which complete data on the physical and economic performance of the ecological sector as a whole in Andalusia were available (Soler Montiel et al. 2009). Despite the limitations inherent to the analysis of one sector or economic activity in relation to a single period of time, this study aims to make a first comprehensive view allowing an assessment of the scope and limitations of the energy efficiency of organic farming in Andalusia as a fundamental requirement for environmental sustainability.

2. MATERIALS AND METHODS

The energy assessments presented in this article are based on the empirical data provided by 72 organic farms surveyed in 2006–2007. These data were also the basis for the monetary estimation of the "Economic Accounts of Organic Farming and Livestock Farming in Andalusia in 2005."[1] The sample represented 6.75% of the total population. The information on the energy inputs and outputs of the different types of livestock were transferred to Excel spreadsheets and analyzed with the help of SPSS software. The parameters were estimated with a separate ratio estimator in stratified sampling.

The methodology used in this article is that of process energy analysis (IFIAS 1974; Corre et al. 2003; Meul et al. 2007). In practice, energy analyses make a partial application of the principles of life cycle assessment (LCA), and the calculated system levels vary from one study to the other. These methodological decisions can be justified by various reasons associated

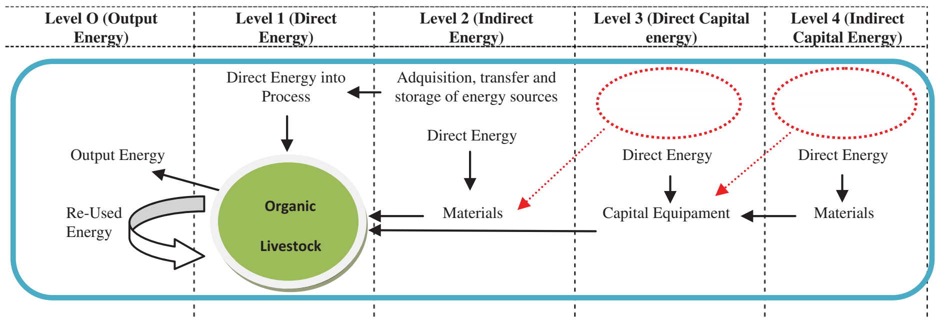

FIGURE 1 Analytical limits of the organic livestock system in Andalusia.

to the relevance and availability of data (International Organization for Standardization 2006; Udo de Haes 2007). The system boundaries defined for the analysis of Andalusian livestock farming presented in this article are summarized in Figure 1 and structured into five levels, four related to the energy inputs and a fifth corresponding to the energy output.

Level 0 corresponds to the energy output measured by the gross livestock production. Level 1 quantifies the consumption of direct energy (DE) inside the farm. Level 2 measures the consumption of indirect energy (IE), particularly the energy cost of producing the inputs used during the livestock production process. Levels 3 and 4 quantify the proportional energy cost linked to the consumption of fixed capital (CE), in particular the consumption of energy associated with the amortization of machinery (level 3) and the repairing and maintenance of the fixed capital (level 4). The consumption of energy related to farm facilities and the transport of inputs and output has not been considered due to the lack of the necessary physical data for its calculation.

The energy output has been estimated from the energy content of meat and products of animal origin by types of livestock (cattle, goats, sheep, pigs, and poultry), as shown in Equation (1):

$$\textbf{Energy Output (EO)}_{\textbf{(i)}} = \Sigma \text{ Gross Livestock Output (GLO)}_{(\mathrm{pi})} \text{ (unit)} \times \alpha^{-1}{}_{(\mathrm{pi})} \left(\mathrm{MJ\,unit}^{-1}\right), \tag{1}$$

where GLO $= \sum \text{Sales}_{(\mathrm{p})}$ (kg) + $\text{Reuses}_{(\mathrm{p})}$ (kg), p is the type of livestock product (meat, eggs, milk and manure), i is the type of livestock and $\alpha_{(pi)}$ is the energy equivalent of product p of type of livestock i (MJ unit^{-1}). The text distinguishes two different estimations of the EO: EO(a), which is the edible energy output (meat, milk, and eggs) and EO(b), which represents the reuse of manure in agriculture.

The energy assessment of the input by types of livestock has been made through the following equation:

$$\textbf{Gross Energy Requirements (GER)}_{(ji)} = \Sigma\ \text{Inputs (I)}_{(ji)}\ (\text{unit}) \times ß^{-1}{}_{(j)}\left(\text{MJ unit}^{-1}\right) = \Sigma\ \text{Direct Energy (DE)}_{(ji)}\ (\text{MJ}) + \text{Indirect Energy (IE)}_{(ji)}\ (\text{MJ}) + \text{Capital Energy (CE)}_{(ji)}\ (\text{MJ}), \quad (2)$$

where *ji* is the input j (forages, concentrates (grains), fodder, diesel, oil, and lubricants, plastics, tools, electricity, labor, owned machinery and rented machinery) of type of livestock *i* (cattle, goats, sheep, pigs, or poultry) and $ß_{(j)}$ is the energy converter of input *j* (MJ unit^{-1}).

This work does not take into account the energy expenditure associated to transportation or the energy value of noncultivated pasture.[2] Tables 1 and 2 reflect the average energy coefficients ($\alpha_{(pi)}$ and $ß_{(j)}$) used for the assessment of the inputs and outputs obtained from specialized energy analysis literature.

TABLE 1 Energy equivalent of the output (α(pi))

Particulars	Energy equivalent (MJ kg^{-1})	Source
A. Output	Energy level O	
1. Cattle meat	10.6	Leach 1976; Naredo & Campos 1980; Jarach 1985; Fluck 1992; Pimentel & Hall 1984; Moreiras et al. 2005; Nahed et al. 2004
2. Sheep meat (3–4 months)	12.5	
3. Goat meat (sucklings)	11.2	
4. Pig meat	15.8	
5. Poultry meat	6.9	
6. Eggs	6.2	
7. Milk	2.8	
8. Manure[a]		
(a) Cattle	1,2	
(b) Sheep	1,5	
(c) Goat	1,5	
(d) Pig	1,7	

[a]Energy equivalent of manure has been calculated dividing the percentage of "gross energy requirements of the livestock" lost as feces by manure gross production (kg/animal) by types of livestock (cattle, goats, sheep, and pigs) (Pérez Neira, 2010).

TABLE 2 Energy equivalent of the physical and capital inputs ($ß_{(j)}$)

Particulars	Unit	Energy equivalent (MJ unit^{-1})	Energy equivalent (MJ unit^{-1})	Sources
A. Inputs		Energy level 1	Energy level 2	
1. Feed				
(a) Forage				
Hay	kg	12.2	—	Leach 1976; Naredo and Campos 1980;
Silage	kg	12	—	Pellizzi 1992; Pimentel 1993;
Straw	kg	0.5	—	Pimentel and Pimentel 1996; Moreiras et al. 2005
(b) Concentrates (grains)				
Corn	kg	15.4	Production energy cost	Leach 1976; Naredo and Campos 1980;
Peas	kg	13.2		Pellizzi 1992; Pimentel 1993;
Broad beans	kg	14.2	7.98–10.2	Pimentel and Pimentel 1996;
Soya	kg	17.6		Moreiras et al. 2005;
Sunflower	kg	21.4		Ghorbani 2011
Triticale	kg	14.2		
Oats	kg	14.5		
Barley	kg	14.8		
(c) Fodder				
Compound fodder	kg	GEC [(a)]	0.36	Singh 1986; Pimentel 1980;
Flours/oil cakes	kg	GEC [(a)]	0.49	Stout 1980
2. Diesel	kg	39.27	9.5	Pimentel and Pimentel 1996;
3. Oils and lubricants	kg	—	67.2	Yilmaz et al. 2005; Canakci and Akinci 2006; Hatirli et al. 2006;
4. Plastics	kg	—	92.2	Meul et al. 2007; Karimi et al. 2008; Garavand et al. 2010; Higo et al. 2010
5. Tools		—		
(a) Iron	kg	—	84.6	Tsatsarelis 1992; Pellizzi 1992;
(b) Plastic	kg	—	92.2	Baird et al. 1997
(c) Wood	kg	—	2.5	
6. Electric power	KWh	4.05	8.2	Jarach 1985; Kitani 1999; Ozcan et al. 2004; Meul et al. 2007; Mobtaker et al. 2010

(*Continued*)

TABLE 2 (Continued)

Particulars	Unit	Energy equivalent (MJ unit^{-1})	Energy equivalent (MJ unit^{-1})	Sources
A. Inputs		Energy level 1	Energy level 2	
7. Labor	h	0.58	2.33	Stout 1990; Gajaseni 1995; Demarcan et al. 2006; Hatirli et al. 2006; Kizilaslan 2009; Pérez Neira 2010; Ozkcan et al. 2011
B. Capital Inputs		Energy Level 3	Energy Level 4	
1. Machinery				
(a) Large machinery (> 50 hp)	MJ kg^{-1}	80.5	41.9	Doering 1980; Fluck 1992; Hetz 1992, 1998; Gajaseni 1995; De et
(b) Small machinery (< 50 hp)	MJ kg^{-1}	53.5	13.9	al. 2001; Canakci et al. 2005; Yilmaz et al. 2005; Hatirli et al. 2006; Guzmán Casado and Alonso Mielgo 2008; Asakereh et al. 2010; Canacki 2010
2. Renting of machinery				
(a) 60 hp	h	13.4	6.9	Doering 1980; Fluck 1992; Hetz 1992, 1998;
(b) 80 hp	h	16.1	8.4	Pelizzi 1992; Yilmaz et al. 2005;
(c) 90 hp	h	19.1	10.0	Hatirli et al. 2006;
(e) 120 hp	h	22.3	11.6	Guzmán Casado and Alonso Mielgo 2008; Karimi et al. 2008; Asakereh et al. 2010

[a]GEC (gross energy crop) indicates energy value of crops incorporated in animal feeds, for example, energy equivalent of corn is 15.4 MJ kg-1 (Moreiras et al. 2005).

The energy analysis of organic livestock farming in Andalusia has been made with the help of synthetic indicators associated to its output, inputs and energy efficiency as defined in the following equations, and by types of livestock (Canakci 2005; Ghorbani et al. 2011; Koocheki et al. 2011):

$$\textbf{Energy Ratio (ER)}_{\mathbf{(i)}} = \text{Energy Output (EO)}_{(i)}\ \text{(MJ)} \times \text{Gross Energy Requirements (GER)}_{(i)}{}^{-1}\ \text{(MJ)} \quad (3)$$

$$\textbf{Net Energy (NE)}_{(i)} = \text{Energy Output (EO)}_{(i)}\ (\text{MJ}) - \text{Gross Energy Requirements (GER)}_{(i)}\ (\text{MJ}). \tag{4}$$

Indicators 2 and 3 (GER and ER) have been calculated in relation to both the total energy inputs (renewable and nonrenewable) and the use of nonrenewable energy inputs (Ghorbani et al. 2011). With this purpose, biomass-derived renewable energy inputs (mainly the gross energy of concentrates and fodder), the energy obtained from labor and the share of energy produced by renewable sources (mainly wind, hydraulic and solar) have all been subtracted from the GER. This text will refer to the resulting indicators as GERnr and ERnr, respectively. On the other hand, for the specific case of livestock farming, two additional indicators related to animal feed have been estimated. The first one (EEF) measures the energy efficiency of livestock when animal feed having an opportunity cost (concentrates and fodder, excluding noncultivated pasture) is transformed into human food of animal origin. The second indicator (EDF) measures the energy dependence on animal feed (concentrates and fodder) coming from outside the farm in relation to the gross energy requirements of the livestock (GEL) (Nahed et al. 2006).

$$\textbf{Energy Efficiency of Feed (EEF)}_{(i)} = \text{Energy Output (EO)}_{(i)}\ (\text{MJ}) \times \text{Gross Energy of Feed (GEF)}_{(i)} \tag{5}$$

$$\textbf{Energy Dependence on Feed (EDF)} = \text{Gross Energy of Feed (GEF)}_{(i)}\ (\text{MJ}) \times \text{Gross Energy Requirements of the Livestock (GEL)}_{(i)}{}^{-1}\ (\text{MJ}) \times 100 \tag{6}$$

3. RESULTS

The main results of this work are presented both in absolute terms (GJ) and in relative terms by livestock standard unit (LSU^{-1}).[3]

3.1. Gross Energy Requirements of Organic Livestock Farming

Up to 70% of organic livestock farming in Andalusia (LSU) corresponds to cattle breeding, while sheep represent 23%, goats 3.2%, pigs 3.6%, and

TABLE 3 Number of heads, gross energy consumption and output of organic livestock farming in Andalusia (2005)

Items	Unit	Cattle	Sheep	Goats	Pigs	Poultry	Weighted average
No. of heads	LSU	27,608	9,195	1,245	14,120	182	
Gross energy requirements	TJ	359.8	120.6	16.3	32.4	19.5	548.7
Energy Output (a)[a]	TJ	23.9	10.9	3.96	5.8	1.7	46.3
Energy Output (b)[b]	TJ	150.8	21.8	9.7	12.3	1.7	196.4

[a]Energy output (a) = EO (a) = meet + milk + eggs.
[b]Energy output (b) = EO (b) = energy output (a) + manure reuse.

poultry 0.5% (Table 3). In 2005, the total energy expenditure of this sector was estimated at 548,659 GJ and the average GER were 13,901 MJ LSU^{-1}. As shown on Table 4, the most important energy input of livestock farming is animal feed, which represents 86% of the total energy consumption. Of this 86%, 64% corresponds to the energy content of feed and 22% to its indirect production cost. Far from the figures of animal feed, the second and third most important energy inputs were the expenditure in fossil fuels (8.6%) and the use of machinery (3.2%), with average GER of 11,196 MJ LSU^{-1} and 443 MJ LSU^{-1}, respectively. Electric power (95 MJ LSU^{-1}), energy expenditure on tools (22 MJ LSU^{-1}) and labor (86 MJ LSU^{-1}) represented an average of 0.7, 0.2, and 0.6%, respectively, of the total energy expenditure.

TABLE 4 Energy consumption and energy inputs and output of organic livestock farming in Andalusia (2005) (MJ LSU^{-1})

Items (MJ LSU^{-1})	Cattle	Sheep	Goats	Pigs	Poultry	Weighted average	Average (%)
A. Inputs							
1. Feed	11,139	12,057	9,364	19,755	98,248	12,060	86.8
a) DE of feed	8,371	8,987	7,255	13,711	63,737	8,965	64.5
b) IE of feed	2,768	3,070	2,109	6,044	3,4511	3,095	22.3
2. Oil and derivates	1,381	513	2,199	1,135	—	1,196	8.6
3. Electric power	70	75	369	293	1,353	95	0.7
4. Tools	18	34	29	6	—	22	0.2
5. Labor	57	88	147	540	398	86	0.6
B. Capital							
6. Machinery	369	350	1,023	1,061	7,182	443	3.2
Gross energy requirements	13,034	13,115	13,131	22,790	107,181	13,901	100
B. Output							
1. Meat	771	494	199	4,077	—	808	16.2
2. Milk + eggs	95	692	2,981	–	9,399	365	7.3
Energy output (a)	866	1,185	3,180	4,077	9,399	1,172	23.6
3. Manure reuse	4,597	1,191	4,597	4,597	—	3,804	76.4
Energy output (b)	5,464	2,376	7,777	8,674	9,399	4,976	100

The structure of the energy expenditure varied slightly depending on the type of livestock under consideration. The most intensive livestock, in energy terms, were pigs (22,790 MJ LSU^{-1}) and, especially, poultry. Despite its limited relevance in the sample, the latter had GER estimated at 107,181 MJ LSU^{-1}. On the other hand, cattle, sheep and goats proved to be less intensive in energy terms and their GER were close to the industry's average (around 13,100 MJ LSU^{-1}). Animal feed was the most important energy input in all the five types of livestock studied (oscillating between 70% and 91%), particularly in the case of poultry and sheep (around 90% of the total). Also, pigs and poultry were the groups with a higher expenditure on indirect energy of feed (6,044 and 34,511 MJ LSU^{-1}, respectively), due to the greater purchase of fodder in the market and the lesser production of feed in the farms.

3.2. Output Energy of Organic Livestock Farming

Considering the Energy Output (EO(a) in Table 3) as the addition of meat, milk, and eggs, the results show that cattle and pig breeding were clearly focused on meat production (90% and 100%, respectively) and had an energy productivity of 8,661 MJ LSU^{-1} and 4,077 MJ LSU^{-1}, respectively. The majority of goat farming in Andalusia was milk-oriented if analyzed in energy terms (94% of the output), although not in monetary terms, while sheep had a double focus (42% meat and 58% milk). Their energy productivities were 3,180 MJ LSU-1 and 1,185 MJ LSU-1, respectively. Poultry was the most productive livestock in terms of EO(a): 9,399 MJ LSU^{-1}.

Manure is the main energy output of livestock. Historically, manure has been the most important source of fertilization in agriculture and still is in organic farming. In a context of environmental crisis and scarcity of oil, manure should recover its agronomic and economic relevance. Thus, it is crucial to include manure as an output in Energy Analysis as well it is a key issue to promote a style of farming based on organic fertilization practices.

Including the reuse of manure, the Energy Output (EO(b) in Table 3) of organic livestock farming in Andalusia is then estimated at 196,392 GJ (4,976 MJ LSU^{-1}). The reuse of manure for agricultural fertilization was the most important energy output of livestock farming, representing 76.4% of the total energy output (EO(b)) and followed by meat (16.2%) and products of animal origin (7.3%). Cattle breeding was the livestock activity most integrated with agriculture as reuse of manure represented 84% of its total output (b). Goats followed as the second livestock in this category. The least integrated livestock in these terms was poultry, where the reuse of manure was null.

3.3. Energetic Inputs of Organic Livestock Farming in Andalusia (2005)

In 2005, the consumption of energy by organic livestock farming in Andalusia was distributed among direct (71.7%), indirect (25.1%), and capital (3.2%) energy and, alternatively, between nonrenewable (28.3%) and renewable (71.6%) energy (Table 5). In all types of livestock, 95–98% of the renewable energy corresponded to the energy content of animal feed (forages, concentrates [grains], and fodder). This is so because fossil energy consumption related to production and packaging of animal feed have been included in the calculation of nonrenewable energy consumptions.

Poultry farming was the livestock activity with the greatest energy consumption per unit, followed by pig farming. The rest of livestock activities (goat, sheep, and cattle breeding), which are the most extensive ones, were also the ones with lesser energy consumptions, all of them very similar. In relative terms, although not in absolute terms, goats were the livestock using a greater amount of nonrenewable energy (41.1%), followed by poultry (39.2%), pigs (36.7%), cattle (34.7%), and sheep (30.3%) (Table 5).

3.4. Energy Productivity and Energy Efficiency of Organic Livestock Farming

The energy productivity and energy efficiency indicators are reflected on Table 6. The average ER(a) and ER(b) of organic livestock farming in Andalusia in 2005 were, respectively, 0.08 and 0.35. When energy efficiency was measured according to the consumption of nonrenewable energy, it increased to 0.32, in the case of ERnr(a), and 1.38, in that of ERnr(b), with an energy balance above 1. This fact points to the industry's capacity to generate an energy output that is greater than the nonrenewable energy consumed in the activity. But it is important not to forget that the net energy (NE) was

TABLE 5 Total energy input in the form of direct, indirect, capital and nonrenewable energy in organic livestock farming in Andalusia (2005) (MJ LSU-1)

Types of energy (MJ LSU-1)	Cattle	Sheep	Goats	Pigs	Poultry	Weighted average	Average (%)
Direct energy	9,512	9,438	8,970	14,844	64,242	9,966	71,7
Indirect energy	3,153	3,327	3,139	6,885	35,757	3,492	25,1
Capital energy	369	350	1,023	1,061	7,182	443	3,2
Nonrenewable energy[a]	4,526	3,976	5,505	8,355	42,003	4,760	34,2
Gross energy requirements	13,034	13,115	13,131	22,790	107,181	13,901	

[a]It includes the direct and/or indirect energy of oil (diesel, plastics, and lubricants), the indirect energy of tools, the capital energy of machinery, the electric power produced by nonrenewable sources, and the nonrenewable indirect energy of animal feed (the energy cost of production and packaging).

TABLE 6 Energy input-output ratio of organic livestock farming in Andalusia (2005)

Items	Unit	Cattle	Sheep	Goats	Pigs	Poultry	Weighted Average
ER (a)[a]	—	0.07	0.09	0.24	0.18	0.09	0.08
ER (b)[b]	—	0.42	0.18	0.59	0.38	0.09	0.36
ERnr (a)[a]	—	0.26	0.42	0.73	0.57	0.22	0.32
ERnr (b)[b]	—	1.62	0.84	1.78	1.2	0.22	1.38
NE[b]	MJ LSU^{-1}	−7,570	−10,739	−5,354	−14,116	−97,782	−8,925
EEF (a)[a]	—	0.10	0.13	0.44	0.3	0.15	0.13
EEF (b)[b]	—	0.65	0.26	1.07	0.63	0.15	0.56
EDF	%	24.3	24.7	17.7	21.4	92.1	24.5

[a]It includes, within the output, meat and products of animal origin.
[b]It includes, in addition to the output, the reuse of manure in agriculture.

still negative, estimated at an average of -8,925 MJ/LSU for the whole sector. At the same time, the EDF was estimated at 24.5%, which means that only this percentage of the GEL of the livestock was covered with fodder and the reuse of crops within the sector. This is an indicator of food independence in energy terms and of the extensive character of organic livestock farming, reflected as well in the average values of EEF(a) (0.13) and EEF(b) (0.56) for the whole organic livestock farming industry.

The results vary depending on the type of livestock under study. The most efficient organic livestocks in terms of ER(a) were goats (0.24) and pigs (0.18), while the least efficient were sheep (0.09) and cattle (0.07). In terms of ER(b), the results were different, with cattle as the second most efficient livestock (0.42) after goats (0.59). The least efficient were sheep (0.18) and poultry (0.09). In terms of nonrenewable energy use, ERnr(b), goats (1.78), pigs (1.20) and cattle (1.62) showed values above 1, while the values of the remaining livestocks, sheep and poultry, were below 1. Finally, goats presented an EEF(b) that was above 1 (1.07), while poultry had the lowest EEF(a) (0.15).

4. DISCUSSION: ENERGY REQUIREMENTS, INPUT-OUTPUT RELATIONSHIPS, AND ENERGY EFFICIENCY OF ORGANIC LIVESTOCK FARMING IN ANDALUSIA

The GER of organic livestock farming in Andalusia in 2005 reached 548,659 GJ (13,901 MJ LSU^{-1}), while the energy productivity of the sector, in the form of meat and products of animal origin, was 46,271 GJ (1,172 MJ LSU^{-1}). Consequently, its ER(a) was below 1 (0.08). Nevertheless, these general data conceal a more complex structure.

First of all, the most important energy expenditure of organic livestock farming corresponded to the energy content of animal feed (DE) (64.5%), followed by the energy expended in its production (IE) (22.3%). These two items were much above the rest of energy expenditures: oil (8.6%), machinery (3.2%), electric power (0.7%) and labor (0.6%). In addition, only 34.2% of the energy consumed was nonrenewable.

Second, the energy expenditure for feed (12,060 MJ LSU^{-1}) was 24.5% of the GEL (EDF). This data reveals a high degree of use of forage, and, therefore, an important saving in the consumption of nonrenewable energy associated to the production, processing and transportation of fodder.

Third, the efficiency results of organic livestock farming in Andalusia (2005), despite their low values, are comparatively better than those obtained by other studies. Thus, Pimentel (2004, 2006) estimated the efficiency of producing sheep meat in the United States at 0.02. The estimations for cattle and goats oscillated between 0.03, in the case of conventional livestock farming, and 0.05, in that of organic systems. The energy efficiency of conventional pig farming was estimated at 0.07 and the production of eggs, both organic and conventional, at 0.03. All the indicators were well below those estimated for Andalusian organic livestock farming in the present work.

It is important to take into account that the measurement of energy efficiency (ER) made by Pimentel on the basis of the industry's edible production (meat and animal products) concealed one of the most important potential benefits of livestock farming: the production of manure and, therefore, of nutrients (N-P-K) that can be used for agriculture. According to the studies made by the Rodale Institute on organic systems during 22 years, one of the most important factors in order to reduce the energy expenditure of farming systems is replacing commercial nitrogen by legume nitrogen and/or livestock manure (Pimentel 2006). If the manure used in agriculture is considered an energy output of livestock farming, it is possible to observe how energy efficiency, measured by the indicator ER(b), multiplied by four times on average (except in the case of poultry): by six times in the case of cattle, by two in that of pigs and sheep and by two and a half in that of goats. Consequently, the indicator ER(b), as compared to ER(a), which does not include the reuse of manure, measures the degree of integration between livestock farming and farmland agriculture. In the case of organic livestock farming in Andalusia in 2005, cattle and goats were the two livestocks with the best results concerning their integration with farmland agriculture, with an ER(b) of, respectively, 0.42 and 0.59.

In Andalusia, the average efficiency of organic livestock farming according to the use of nonrenewable energy, ERnr(a), was estimated at 0.32. Nevertheless, when considering the reuse of manure in agriculture, the energy efficiency, estimated as ERnr(b), reached a value above 1 (1.38). This means that, for each unit of nonrenewable energy introduced in the system, an average of 1.38 units of renewable energy were obtained and used in the form of animal feed or organic fertilizers.

These results varied depending on the type of livestock under study, and cattle and goats were again the ones showing better results, with efficiencies of 1.62 and 1.78, respectively. At the other end, the ERnr(b) of poultry was the lowest in the industry, with a value of 0.22. This result was related to the high degree of dependence on grains and fodder for birds, something that explained the high EDF reached by this livestock (92.1%).

Finally, another one of the benefits of extensive organic livestock farming lies on the fact that it is capable of making the most of the energy resources derived from the net primary production of pastures, grasslands and forests that cannot be directly used as food by the human being. The indicator EEF measures the energy efficiency of using food (grains and fodder) to feed the livestock instead of feeding people directly (opportunity cost). In Andalusia in 2005, the most efficient livestock in this sense were goats and pigs, with an EEF(a) of, respectively, 0.44 and 0.30. This means that, for each unit of edible vegetable energy in the form of grain or fodder, 0.44 and 0.30 units of energy in the form of meat and milk were obtained. These results improved if the reuse of manure was considered as part of the output. Thus, the EEF(b) of cattle was estimated at 0.65, that of pigs at 0.63, while goats were the only livestock with an EEF(b) above 1 (1.07).

5. CONCLUSIONS

From the point of view of energy, organic livestock farming is a complex activity and, consequently, the usual indicators applied to agriculture must be complemented with livestock-specific indicators that take into account the energy role of manure, pastures (Meul et al. 2012) and feed.

The efficiency of organic livestock farming in Andalusia in 2005, measured with the indicator ER(a), was estimated at an average of 0.08, and at 0.24 for goats, 0.18 for pigs, 0.09 for sheep, 0.07 for cattle, and 0.09 for poultry. These results are higher than the estimates made by Pimentel for livestock farming in the United States (Pimentel 2004, 2006). The average energy expenditure of the organic livestock farming industry in Andalusia was estimated at 13,901 MJ LSU^{-1}, 78.1% of which corresponded to direct energy, 18.4% to indirect energy and 3.5% to capital energy.

When considering the reuse of manure in agriculture as an energy output, the results improved substantially. Thus, the ER(b) of the industry increased from 0.08 to 0.36. The ER(b) of cattle, sheep, goats and pigs reached 0.42, 0.18, 0.59, and 0.38, respectively. The ER(b) can be interpreted as an indicator of sustainability in livestock management that can measure the degree of integration between livestock farming and agriculture.

Up to 28.3% of the energy consumed by organic livestock farming in 2005 was nonrenewable, a much lower percentage than that of intensive livestock farming, although it reveals the present inevitable dependence on fossil energy. The energy efficiency of nonrenewable energy use in organic livestock farming measured through the indicator ERnr(a) was estimated at 0.38. If the role of manure was taken into account through the indicator ERnr(b), the efficiency increased and reached an average of 1.38 for the whole industry, 1.78 for goats, 1.62 for cattle, 1.20 for pigs, and 0.84 for sheep. The ERnr(b) of poultry was equal to its ER(a) (0.22), due to the low degree of integration of this livestock with agriculture and the high degree of intensification of the management of animal feed in poultry farming, even in organic systems. The energy dependence of feed (EDF) of poultry (92%) was the highest in the industry, the overall average of which was 24%.

NOMENCLATURE

CE capital energy
DE direct energy
EO energy output
ER energy ratio
GER gross energy requirements
IE indirect energy
NE net energy
nr nonrenewable
GLO gross livestock output
GEF gross energy of feed
EEF energy efficiency of feed
GEL gross energy requirements of livestock
EDF energy dependence on feed

NOTES

1. Research project financed by the Department of Agriculture of the Andalusian Regional Government. The energy analysis is based on the data of this previous project (Pérez Neira 2010).

2. Noncultivated pasture has been excluded from the energy accounting due to two reasons: 1) to prevent double accounting, since pasture is both an output and an input in extensive livestock farms, and 2) because noncultivated pasture has no opportunity cost in relation to human food. The indirect energy associated to the management of pasture has been taken into consideration in the rest of input entries.

3. The livestock standard unit (LSU) is a measure that allows homogenising the different livestocks with the purpose of comparing them. This work considers the LSU values established by the European Union: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:LSU

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