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‘Sustainable de-growth’ in agriculture and food: an agro-ecological perspective on Spain’s agri-food system (year 2000)

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ABSTRACT

Traditionally, energy balances in agrarian production have been used to calculate the impact of food on the Spanish economy in physical terms. However, this tool is clearly insufficient. Human diet has undergone significant changes in recent decades. Between production and consumption, previously non-existent or insignificant processes such as transportation, packaging, processing, distribution, preservation, etc. have come to the fore. This article aims to evaluate the energy cost of the Spanish agri-food (AFS) system in the year 2000 with a view to ascertaining the relative importance of each link in the agri-food chain.

This information is essential when it comes to designing any strategy for sustainable de-growth. The results of this research show that feeding the Spanish population is an inefficient process: the Spanish AFS currently consumes 1408 PJ, while all of its residents combined consume only 190 PJ. Agrarian production is effectively the main source of this inefficiency (34% of the primary energy consumed), but not the only one: processes such as the preservation and preparation of food in the home (18%), transportation (17%) and packaging (10%) show that the way we feed ourselves is not sustainable. The paper makes a strong point that a fundamental transformation of the AFS is required. A move towards organic farming and corresponding new consumption patterns (i.e., local, seasonal food, less meat consumption) may considerably reduce resource use in the AFS and contribute to sustainable de-growth in Spain.

1. Introduction

Energy balances in agriculture are used as an important tool to assess the impact agrarian activity has on the environment. They provide information about the depletion of non-renewable resources as well as other environmental problems (Dutilh and Kramer, 2000). In the 1970s, the first research into energy balances in agriculture was published (Leach, 1976; Pimentel and Pimentel, 1979) revealing that new forms of agrarian production were more inefficient since they were increasingly dependent on inorganic inputs derived from the use of fossil fuels, electricity or agrochemicals. In Spain, studies were carried out soon afterwards, offering similar results (Naredo and Campos, 1980; Puntí, 1982; Simón, 1999). These findings indicated that energy efficiency in Spanish agriculture had reduced five-fold in just over two decades, from 6.1 J J^{-1} in 1950–51 to 1.2 J J^{-1} in 1977–78. Reuse levels fell significantly (from 94.3% to 59%) and the use of inorganic fertilisers increased, along with mechanical traction, electricity and phytosanitary treatments.[1]

Since industrialisation, the role of agrarian activities in the metabolism between society and nature[2] has changed. From being the main energy source for society (by harvesting chemical energy stored by plants through photosynthetic conversion), agrarian activity has become a resource intensive sector with high energy requirements. Between production and consumption, new economic processes have gradually developed: transportation, packaging, processing, preservation, distribution and consumption. Therefore, in the 1950s, the discipline of Agronomy proposed the idea of the ‘agri-food economy’, since the provision of food increasingly depended on activities that took place outside of farms (Davis and Goldberg, 1957). The gap between the concept of

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[1] A recent review summarises the different studies about energy balances in Spanish agriculture, in which these estimations can be found (Carpintero and Naredo, 2006).

[2] In relation to the concept of ‘Social Metabolism’ as it is used in this text, see Fischer-Kowalski and Haberl (1998).

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'agrarian product', understood as the output derived from the production of the agrarian sector (Rodríguez-Zúñiga and Soria, 1986) and the concept of 'food product', understood as the final production of goods resulting from the transformation of agrarian products and addition of diverse uses (Lancaster, 1966), has continued to grow in recent decades.

New dietary habits in western countries are the cause and at the same time consequence of these changes. In Spain, average food consumption measured in nutritional energy has increased by almost 30% since the 1960s, mainly due to the increase in the consumption of fats, which has risen from 72 g/cap/day to 154 g/cap/day in 2001-3 (Schmidhuber, 2006). The abandonment of Mediterranean dietary habits (Alexandratos, 2006), replaced by the mass consumption of products derived from livestock farming, is responsible for the fact that 41% of the population is overweight (Schmidhuber, 2006).

This diet has a high territorial cost for the current Spanish agriculture. According to Carpintero and Naredo (2006), producing a kg of vegetables requires an area of 1.7 m^2 whereas producing a kg of meat takes 7 m^2. Hence, since the mid 20th Century, the ecological footprint of Spanish food has gone from a positive balance of 80000 ha to a deficit of 2.4 million ha in agricultural surface in Span in the year 2000 (Carpintero and Naredo, 2006), a pattern that corroborates what has happened in the rest of Europe, where the amount of 'virtual agricultural land' has a negative balance of 35 M ha (Witzke and Noleppa, 2010), an area equivalent to the size of Germany. Feeding European countries, including Spain, requires the mass importation of agrarian products from elsewhere, mainly those that sustain livestock production (González de Molina and Infante, 2010). All of this increases the participation of non-agrarian activities in the agri-food system.

Consequently, the debate about food cannot focus solely on the ecological performance of agrarian production. The environmental pressures exerted on the rest of the agri-food chain can be much more severe (Dutilh and Kramer, 2000; Heller and Keoelian, 2002, 2003) and, as a consequence, a coherent policy for the promotion of sustainable agrarian systems must take the entire agri-food process into consideration.

The idea of 'sustainable development', promoted over two decades ago with the Brutland Report (WCED, 1987), has not been able to articulate responses to halt environmental problems. For some authors, the very idea of sustainable development seemed to be a contradiction in terms (Georgescu-Roegen, 1993). Practice has shown unequivocally that it is not possible to reconcile economic growth with environmental sustainability (a general overview is provided in Krausmann et al., 2009). However, scientific community, including UNEP (IPSRM-UNEP, 2010), thinks that the western lifestyle is damaging not only its own environment but also that of poorer countries and, in general, the planet as a whole. In this context, the proposal of 'sustainable de-growth' has emerged as a strategy that aims to generate new social values and new policies capable of satisfying human requirements whilst reducing the consumption of resources (a theoretical context in Martínez-Alier et al., 2010). 'Sustainable de-growth' is not yet a formalised theory (Latouche, 2006) but rather a meeting point for social movements, academia or politics. In any case, its future success will depend on the capacity it has to generate coherent political responses and empirical results that shore up its proposals.[3] De-growth-in contrast to the idea of dematerialisation, which aims at a reduction of resource use while the economy continues to grow-, in our opinion goes further and means that significant reductions of resource use require fundamental changes in the production and consumption system (Schneider et al., 2010; Spangenberg, 2010).

The aim of this article is to place the current environmental problems of agriculture and food at the centre of the debate surrounding 'sustainable de-growth'. To do this, a change in approach is essential, evaluating the physical cost of feeding the Spanish population as a whole, beyond the agrarian sector. For this purpose, the total energy use of the Spanish agri-food sector (AFS) was calculated, from agrarian production to domestic consumption. Breaking this total figure down into specific processes, we can identify which parts of the chain give rise to the majority of the energy consumed and, consequently, propose alternatives for sustainable de-growth. The first section outlines the methodology used and the limitations of this study. The second section describes the main research results. Thirdly, and finally, the debate is opened about the possibility of reducing the energy consumption of the agri-food sector by promoting organic farming with agro-ecological criteria and responsible consumption.

2. Methodology and system boundaries

LCA methodology is fully standardised (ISO, 1997) as an official tool used to evaluate the environmental burdens of producing certain products or certain activities, attempting to reflect them from the 'cradle to the grave'. It would be impossible to cite all the case studies to which it has been applied, even just within the agrarian sector.[4] The aim here is not to apply its precepts rigidly to the entire agricultural and food sector (AFS), since this would be unachievable. We merely take on board the philosophy of its proposals with a view to estimating the energy use of the sector at an aggregated level from the 'land to the table', offering data that can be used to evaluate the level of sustainability of the Spanish agri-food chain in the year 2000. For this purpose, we are following the methodology proposed by Heller and Keoelian (2002) in their study of the Life Cycle Analysis of the US Food System from the late 1990s. The different Spanish statistical sources mean that our estimations are somewhat different. At the end of this text there is a methodological annex included, detailing the calculations carried out and the sources used.

All AFS are inserted into international markets where they exchange materials and energy with many other sectors and territories. It is impossible to reconstruct the precise boundaries of their biophysical structure with the statistical data and case studies currently available. Spanish agriculture, for example, consumes energy to produce not only food but also other types of goods such as fibres, fuels, etc, which cannot be distinguished. Furthermore, the energy consumption of the AFS transcends national borders in complex networks that make it impossible to evaluate the energy consumed in other territories destined for the Spanish market.[5] Similarly, there is consumption in activities of other sectors, such as the services sector (for example, in advertising) which, with the available statistical data, has been impossible to estimate.

We took into consideration the energy consumption of six main activities included in the Spanish national agri-food chain: agrarian

[3] In the last five years, there has been a boom in the bibliography about 'sustainable growth'. An interesting summary can be found in the special issue published in this magazine: Journal of Cleaner Production (2010), issue 18. See Schneider et al. (2010), Griethuysen (2010) and Spangenberg (2010). Or, in Spanish, a monograph about sustainable growth included in the magazine "Ecología Política" (2008). For a more summarised version, see the recent review of this issue provided by Martínez-Alier et al. (2010).

[4] See the work of Audsley (1997). For Spain, a summary of different studies on LCA and agriculture can be found in: Rieradevall and Antón (2004).

[5] According to the data by González de Molina and Infante (2010) Spain's agrarian production does not suffice to feed its population. In the last decade, Spain has consumed 109 Mt of agri-food products and produced only 98 Mt. Consequently, although Spain exports 20 Mt. it is necessary to import more than 30 Mt. This implies that feeding the Spanish population requires more energy than estimated in this paper.

production, processing, packaging, distribution, transport and domestic energy consumption. The energy used to produce imported food products which are consumed in Spain is not taken into consideration, although some of these products are eventually consumed in Spain. In the case of transport, in addition to the transportation carried out within Spain (transport between farms, processing centres, shops or homes), we took into account the energy consumption involved in the exportation and importation of agrarian and food products on the understanding that these flows are essential in order to maintain the functioning of the AFS (see Fig. 1). On other hand, we take into account the energy consumed to produce food that will possibly be later exported.

For these calculations, we took into consideration the consumption of direct energy by each of these activities including, where possible, the total energy consumed in the production of each product involved by means of life cycle analysis (for the production of fertilisers, treatments or packaging). In any case, even though this proposal presents certain drawbacks, they have been consubstantial to similar case studies that methodologically support our work (Heller and Keoleian, 2002, 2003). They are not, however, an obstacle to providing a general overview of the Spanish agri-food sector and identifying which processes in the chain should 'de-grow' and to what extent (Table 1).

Table 1
Main sources for the energy consumption on Agri-food Spanish sector (around 2000).

Group of consumption	Topic	Source
Farming Production	Fuel and electricity	MITC, 2007b
	Nutrients	MAPA, 2000
	Treatments, seeds and Feed	Carpintero and Naredo, 2006
Transportation	Commercial Road transportation	MF, 2006
	Non-commercial road transportation	Heller and Keoelian, 2002
	Transportation by sea	AEAT, 2010; http://www.daloy.com
Processing	Agri-food industry	MITC, 2009
Packaging	Cardboard	http://www.aspack.es
	Plastics	FIRA-CEP, 2008
	Glass	http://www.fever.com
Retail and Hospitality	Hospitality trade	INE, 2002; MITC, 2009
	Retail	INE, 2000; MITC, 2009
Household	Cooking	MITC, 2009
	Domestic Appliances	MITC, 2007b

Source: own elaboration. More details on methodological annex.

3. Results

The latest report about energy consumption in Spain revealed that the amount of final energy used in 2008 stood at almost 4150 PJ. Spain has a clear deficit in this area and must import most of its primary energy requirements, thereby pushing up an energy bill that exceeds 40 thousand million euros a year. Transport (1680 PJ) and industry (1260 PJ) are the sectors that consume the most, whereas others, such as the agrarian sector, account for very low figures that barely reach 3.5% of the total (MITC, 2009). However, these statistics only consider the direct consumption of the agrarian sector that is only fuel and electricity. If we incorporate consumption derived from the use of fertilisers and treatments, or the energy content of imported seeds and animal feed, the figure practically triples, shooting up from 170 PJ to 460 PJ, according to our calculations.

But that is not all; we must also factor in the activities that are essential in order to take food to the table in each home. Taking these activities into consideration, we see that the consumption that takes place in the agrarian sector represents just over a third of the total for the Spanish AFS, with the remaining two thirds originating in the transportation of foodstuffs, their industrial processing, packaging, sale, preservation and consumption (Fig. 2). In total, we

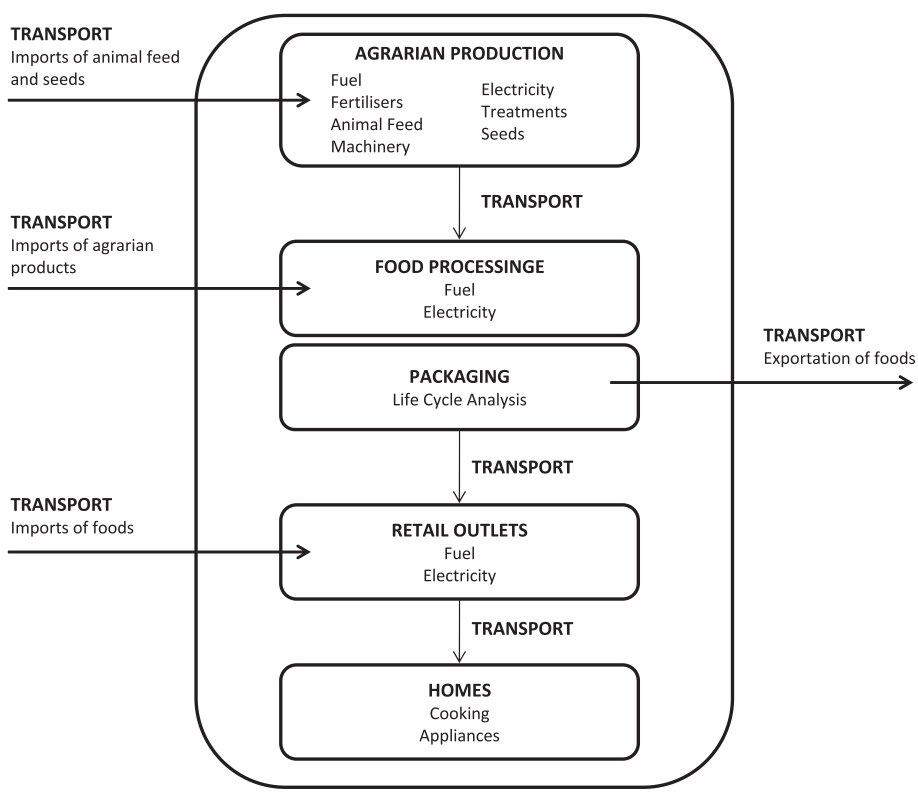

Fig. 1. System boundaries. Activities considered and type of consumption taken into account for each activity. Source: see methodology annex.

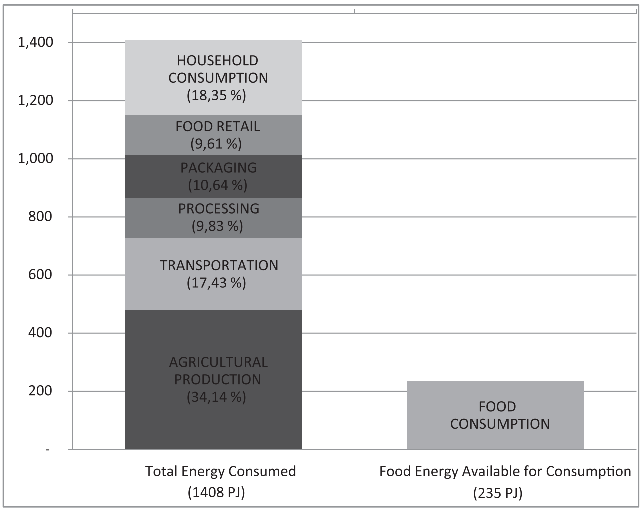

Fig. 2. The first column shows the total energy consumption of the Spanish agri-food sector in the year 2000 by type of activity and the different percentages. The second shows the amount of food available in Spain measured in energy (nutritional values). Source: see methodology annex.

need over 1400 PJ to satisfy the food requirements of the Spanish population, whereas the energy contained in the food consumed barely reaches 235 PJ. In other words, for each unit of energy available in the form of food, 6 units of energy have been consumed in its production, distribution, transportation and preparation. And for every unit of energy consumed in the form of food (excluding losses due to waste and spoiling), an investment of 7.4[6] is required. Where are the roots of this problem?

The industrialisation of the agrarian sector is at the heart of this imbalance. Up until a few decades ago, agriculture provided more energy than it required (Naredo and Campos, 1980). However, currently, this sector is highly dependent on external input. Tractors or irrigation pumps, for example, require large amounts of fuel and electricity. But this is not the only issue. A fundamental element in industrial agrarian systems is the artificial replenishment of fertility. Nitrogen is the most consumed macronutrient in Spain[7] and the main way of obtaining it artificially is to synthesise ammonia in a process that requires high levels of pressure and high temperatures. It represents around 40% of the total energy expenditure for agricultural production in certain developed countries, and up to 70% in developing countries (IDAE, 2007). In Spain, it accounts for almost 100 PJ, according to our calculations, or, put another way, almost a quarter of the total consumption of the agrarian sector and over 7% of the AFS final energy expenditure.

Another salient feature of the Spanish agrarian sector is its strong dependence on grain imported from overseas. Argentina, Brazil or the US, among many other countries, send over 20 million tonnes of grain to Spain, which are mainly used to maintain intensive livestock farming – one of the main sources of non-sustainability in the agrarian sector – and the mass production of meat and dairy produce (González de Molina and Infante, 2010). This amount of grain is equivalent to Spain's total for agrarian exports (20 million tonnes). The energy content of this grain represents a further quarter of the energy consumed in the agrarian sector. Here, we are excluding energy costs derived from the packaging and preservation of products that travel half way round the world.

In fact, one of the main problems of any food system is the energy cost of a transportation network which, as we have seen, in Spain represents the most demanding sector in terms of energy requirements. Apparently, the cost for the Spanish AFS of importing grain from overseas is not excessive. Ultimately, sea transport is one of the most efficient options, measured in terms of energy consumed per tonne transported and km travelled (Pérez and Monzón, 2008). However, this process requires a complex road distribution network to take the freight from major ports to industries, restaurants, shops and homes. In Spain, the transportation of agrarian and food products represents 23% of the final energy consumed by the AFS. The majority corresponds to road transport (almost 20%), both due to industrial and commercial transport and citizens driving to large supermarkets. In short: the final energy consumption required to mobilise these kinds of products stands at 227 PJ, accounting for almost 14% of the total consumption registered for the transport sector in Spain.

During the long miles travelled and the long duration of the distribution and commercialisation process, food must be kept in a good state of conservation and maintain an attractive appearance. This forces the mass usage of packaging in order to maximize shelf life. In Spain, for agri-food purposes alone, over 2 million tonnes of glass are being consumed every year, over 1.5 million tonnes of plastic and over 150 thousand tonnes of carbon derivatives (see methodology annex). In addition to the environmental impacts derived from using these products, which are often highly contaminant, their energy consumption evaluated through their life cycle accounts for around 10% of total AFS consumption, and almost equals the energy content of the products consumed by the Spanish population in a year.

The agri-food industry invests almost 10% of the primary energy consumed by the entire AFS in the processing of agrarian products. Practically the same figure is required by the different points of sale (both retail outlets and establishments linked to the accommodation trade). In comparison with these figures, households consume almost the same as industry and commercial activity put together. Cooking and preserving/storing food require a great deal of energy. Domestic appliances linked to food consume almost the same energy as that contained in the foods themselves (140 PJ in comparison with 191 PJ).[8]

Table 2 also reveals an interesting finding: the disparity between the figures for primary energy and final energy recorded for the different agri-food activities. This means that the efficiency of the energy sources used for each activity is different. Hence, homes and retail outlets, which only represent 10.90% and 5.71% of final energy consumption, respectively, increase their contribution to 18.35% and 9.61%, respectively, for primary energy. In other words, consumption in homes and retail outlets is more inefficient than in other sectors, mainly due to its great dependence on electricity which requires a high primary energy input.[9]

[6] The energy contained in the food available for consumption in Spain in 2001–03 was 3405 kcal/cap/day (Schmidhuber, 2006). The real amount consumed in 1999 was 2768 kcal/cap/day (MAPA, 2000). These figures are the equivalent to a total of 235 PJ and 191 PJ for the national total, respectively.

[7] In the year 2000, Spain consumed 1.30 M tonnes of N, 0.57 M tonnes of P2O6 and 0.74 M tonnes of K2O (MAPA, 2000).

[8] Intended to offer a comparative analysis with other cases studies, the literature provides many works at crop scale but not at national scale, as does this text and the previously cited paper by Heller and Keoelian (2002, 2003). Roy et al. (2009) offer a detailed compilation on different LCA studies of food production. We can verify that depending on the product studied, the energetic consumption varies substantially depending on the different phase of life cycle. For example, in ketchup production packing and transport consume a major part of all energy used (Mintcheva, 2005), but on other hand, in milk production most of the energy is consumed in the agricultural phase.

[9] We employed the coefficients published by the MITC (2007b) to convert from primary energy to final energy. Note that with of some energy inputs of the agrarian sector we have used the same coefficients although knowing that they use different energy sources. This is due to the fact that this source only offers a median value, therefore we were unable to distinguish between diverse energy sources.

Table 2
Consumption of primary and final energy in the AFS broken down by the main activities and specific consumption figures for each of them. Year 2000.

	Primary Energy		Final Energy	
	PJ	% of the total	PJ	% of the total
Farming production	*480.9*	*34.1*	*367.1*	*39.0*
Fuel	161.7	11.5	138.7	16.8
Electricity	28.5	2.0	24.5	3.0
Fertilisation	116.6	8.3	81.8	9.9
Nitrogen	100.1	8.0	70.2	8.5
Phosphorus	10.0	0.8	7.0	0.9
Potassium	6.6	0.5	4.6	0.7
Treatments	10.2	0.7	7.2	0.8
Animal Feed	131.0	9.3	91.9	9.8
Seeds	7.4	0.5	5.2	0.6
Machinery	25.4	1.8	17.8	1.9
Transport	*245.5*	*17.4*	*216.5*	*23.0*
Road	145.2	11.7	131.6	15.9
Inter-municipal	0.8	0.1	0.7	0.1
Intra-regional	22.5	1.8	20.4	2.5
Inter-regional	66.2	5.3	60.0	7.3
International (Imports)	36.4	2.9	33.0	4.0
International (Exports)	17.1	1.4	15.5	1.9
Sea	25.2	2.0	22.8	2.8
Imports	22.1	1.8	20.0	2.4
Exports	3.1	0.3	2.8	0.3
Home	75.1	6.0	62.1	7.5
Processing	*138.4*	*9.8*	*97.1*	*10.3*
Packaging	*149.8*	*10.6*	*105.1*	*11.2*
Paper-Cardboard	6.7	0.5	4.7	0.6
Plastic	119.1	9.6	83.6	10.1
Glass	24.0	1.9	16.8	2.0
Retail Outlets	135.3	9.6	53.8	5.7
Hospitality Trade	59.0	4.7	23.5	2.8
Agri-food retail	76.3	6.1	30.3	3.7
Households	*258.5*	*18.4*	*102.7*	*10.9*
Kitchen	114.7	9.2	45.6	5.5
Domestic Appliances	143.8	11.6	57.1	6.9
Fridge	99.5	8.0	39.6	4.8
Oven	22.1	1.8	8.8	1.1
Dishwasher	11.1	0.9	4.4	0.5
Microwave	11.1	0.9	4.4	0.5
TOTAL	*1408.4*	*100.0*	*942.3*	*100.0*

Source: see methodology annex.

In short, the results reveal an activity that requires the use of a very significant amount of energy, mostly from fossil fuels. In each and every one of the processes involved in the food chain, the consumption of resources multiples, resources that not only make the end products more expensive, but are also responsible for so many other environmental problems, such as the depletion of scarce resources, climate change or acidification.

4. Discussion

In view of the data presented, any strategy for sustainable de-growth in Spain must pay particular attention to farming production, to its transportation, the packaging of foodstuffs and their preservation/storage and preparation in the home. Together, they represent over three quarters of the total amount of primary energy consumed in the agri-food system.

4.1. Farming production

Direct and indirect energy inputs into agriculture and livestock production account for over a third (34.1%) of overall energy consumption of the AFS. Just three areas: fuels, nitrogen fertilisation and animal feed account for over 85% of the 480 PJ of primary energy expended by the agrarian sector. The widespread use of these three resources responds to the predominance of a conventional model of production that uses large amounts of diesel oil and fertiliser (especially nitrogen formulas) to maintain highly intensive production and huge amounts of animal feed to sustain livestock farming. This model is also causing other environmental problems (contamination of surface and underground water, erosion, loss of biodiversity, etc.).

In terms fertilisation, animal feed and mechanical traction offer many of the possibilities for ‘de-growth’ in Spain’s agrarian production. It is not enough to ‘save’ fuel, by modernising the fleet of tractors, or to improve the efficiency of irrigation systems, as proposed by the ‘action plan’ drawn up by the Ministry of Research, Science and Technology. The energy savings measures contained in this plan could give rise to an average reduction in the last five years (2008–2012) of just 11.72 PJ, in other words, only 6.8% of the fuels and electricity consumed by agriculture (MITC, 2007b).

The only way of provoking substantial de-growth in agrarian energetic consumption involves changing the model used, switching to a new model that substantially reduces the three main consumption activities mentioned previously. Organic production would substantially reduce these areas. Studies into energy efficiency show that organic farming consumes less fossil fuel to obtain the same product (Alonso and Guzmán, 2004; Stolze et al., 2000; a review is provided in Alonso and Guzmán, 2010; Guzmán and Alonso, 2008). This is mainly due to the replacement of chemical fertilisers with organic fertilisation. Organic farming reduces greenhouse gas emissions when quantified by unit of land (Haas et al., 2001; Flessa et al., 2002; Mondelaers et al., 2009).

In addition, there are possible savings with the production of biofuels on the farm or the introduction of photovoltaic solar energy to increase irrigation water. Substantial de-growth requires a drastic reduction of intensive livestock activity, which will only be possible if the regulations of the agri-food market and public policies that favour the consumption of meat and dairy products are changed. However, extensive livestock farming, particularly organic farming, can only sustain part of the demand for foodstuffs from livestock, hence a change in patterns of consumption towards a more vegetarian diet is essential in this regard (Erb et al., 2009; Dutilh and Kramer, 2000; Jones and Kramer, 2009; Kramer, 1996).

4.2. Transport

Transport is the sector that consumes the most energy in the Spanish economy (over a third of final consumption), with the added problem that 100% of this consumption comes from non-renewable sources. In the Spanish AFS, this activity consumes 17.4% of total primary energy, particularly commercial transport by road (10.3%), private transport by final consumer (5.3%) and, finally, sea transport (1.8%). In any case, the main driver for the high energy consumption in food transport is the recent process of economic globalisation which has seen transnational mercantile networks grow exponentially in recent decades. It is true that the international trade of food represents just over 5% of the total primary energy consumed by the AFS and a third of the total consumed for transport. However, the internationalisation of farming multiples the need for intra-national transport, as the millions of tonnes of foods and agrarian products that arrive at Spanish ports require a formidable road transport network to processing centres or retail outlets, with smaller vehicles (lorries, cars…) and much lower energy efficiency per load transported. This process does represent the highest percentage of oil consumption in the AFS.

The measures proposed by the Ministry in its ‘action plan’ to encourage energy savings would to some extent mitigate commercial consumption in the agri-food sector, by encouraging the use of public transport or renewing fleets of vehicles. These measures would help to mitigate 6% of the consumption represented by road transport between homes and retail outlets. But it will be difficult to resolve the expensive logic of a global commercial system based on the mass importation of agrarian products from anywhere in the world and their subsequent transportation towards thousands of towns around Spain. Only a structural overhaul of agrarian organisation can mitigate the costly energy consumption derived from long-distance transport (Jones, 2001; Pirog et al., 2001; Raven and Lang, 1995; Subak, 1999), consequently forcing a shift towards regional or local agriculture which, as well as mitigating the energy consumption of long-distance transportation, would also provide us with a seasonal diet (Cowell and Parkinson, 2003; Morris and Buller, 2003; Winter, 2003). Organic production is also usually structured around short commercialisation circuits or channels, offers traditional varieties more in line with local tastes, and signifies a recovery in the consumption of seasonal foods. The studies carried out by Lobley et al. (2009) and Milestad et al. (2010) show, although not definitively, a certain relationship between organic farming and the localisation of economic activity. Milestad et al. (2010), in a study about Austria, reflect a widespread reality in the EU and also in Spain (González de Molina, 2009): the existence of a *continuum* between organic farmers, whereby they combine the distribution of their products between a local market that gives them a certain degree of security and satisfaction for the farmers, with long commercialisation channels that mobilise higher volumes. This phenomenon, however, does not usually occur in conventional farming, whose markets are barely local.[10]

4.3. Processing and packaging

Both processes account for almost 20% of the total consumption of primary energy. The increase experienced in recent decades indicates that their relative importance in the system's energy consumption will continue to grow. In the US, for example, food processing now accounts for 16.4% of the total consumption (Heller and Keoelian, 2002, 2003). According to our data, the packaging process alone consumes 150 PJ, 11% of the primary energy consumed by the AFS. This is related to the long distances travelled by the foods and, therefore, the need to guarantee their preservation and food safety. Although the reduction of these processes is not usually built into the political agenda (action plan), there is some scope to reduce their consumption by favouring local and seasonal products that reduce the need for processing, preserving and, therefore, packaging of foods.

4.4. Households

In Spain, household energy consumption in general represented close to 20% of the total final consumption in 2008 (MITC, 2009). Of this domestic consumption, between 20% and 35%, on average, are related to food in some European cases (Kramer et al., 1994). In Spain, according to our calculations, this figure is as high as 45%. Of the 238 PJ of final energy consumed by households, 105 PJ are attributable to activities related to food, such as cooking, or the domestic appliances required to prepare and preserve/store food. This is due to the low relative energy cost dedicated to domestic heating in Spain. In turn, households are the second highest consumers of primary energy (18.4%) within the agri-food system. Activities related with the preparation of food account for over 8% and the electricity consumed domestic appliances represents 10%. The type of food prepared has a major effect on domestic energy consumption (Table 3).

Table 3
Consumption of energy in cooking according to the type of food.

Type of food	Energy consumption (MJ/kg)
Potatoes	1
Vegetables	1–4
Fruit	2–5
Milk	10
Eggs	20
Fish	20–40
Meat	30–70

Source: taken from Kramer et al. (1994).

Table 2 shows that the foods that consume the most energy in terms of their production and transportation are also those that require the largest amounts of electricity or gas for their preparation. Cooking vegetables can be 70 times less costly than cooking meat products. It is precisely the consumption of meat that has increased the most in the last three decades (EEA, 2005). This trend has been completed with a generalisation of the mass consumption of out-of-season products, packaged, processed and transported from distant places. The change in the diet of the Spanish population, which is increasingly moving away from the virtues of the Mediterranean diet (Alexandratos, 2006), as well as having negative impacts on their health (Schmidhuber, 2006), multiplies the energy costs of the agri-food system, increasing intermediate consumption (EEA, 2005).

5. Conclusions

By evaluating the energy costs of the Spanish agri-food system, this article has shown that the way in which the endosomatic metabolism of the Spanish population is currently satisfied is one of the main sources of fossil fuel consumption and the severe impacts this is having on the environment. Agrarian production is responsible for more than a third of this invested in the entire food system. The processes involved in the transportation, processing, packaging, sale in food retail outlets, and the preservation/storage and preparation of food in homes are responsible for the remaining two thirds of the energy invested in the entire food process.

Economic de-growth, in order to be sustainable, must pay particular attention to how this process is carried out. We think that only a shift towards organic farming and corresponding changes in consumption patterns can contribute to substantial reductions of resource use in the food system and to sustainable de-growth. The way in which it can be achieved, even improving the quality of what we eat and without reducing agrarian income and employment, is to switch to organic farming, and to change over to a more vegetarian diet, with the emphasis on seasonal products produced locally. Spain is currently leading Europe in terms of organic production (MARM, 2010). Its territorial development, the agrarian management approaches it promotes, its association with local markets, the consumption of fresh and seasonal produce, make it particularly suitable to achieve significant de-growth in the metabolism of the Spanish economy whilst also increasing the quality of food.

An alternative which, paraphrasing Serge Latouche, is based on the strategy of the “4 Rs”: re-territorialisation of production,

[10] The question of globalisation of organic markets requires more attention in the context of de-growth. They are affected by globalisation and conventional economic strategies and it should be analyzed with more detail. However, the scarce literature that has been written in this field highlights that there is a stronger relationship between organic farming and local agrarian production than in the case of conventional production (González de Molina, 2009; Lobley et al., 2009; Milestad et al., 2010).

re-localisation of markets, re-vegetarianisation of diet, and re-seasonalisation of food consumption.

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Methodology appendix. Calculating the energy consumption of the AFS

For all activities accounted in this study, we used the coefficients published by the MITC (2007b) to make the conversations from primary energy to final energy (and vice versa). Furthermore, this project has aimed to take the year 2000 as a temporal reference. However, the statistics available for each estimation carried out did not always have figures for that year; hence, on occasions, it was necessary to take data from the closest years available. In each case, the date is provided.

1. Farming production

In this activity, we take into consideration the direct consumption of energy (fuel, electricity, animal feed and seeds) and indirect consumption pertaining to the use of fertilisers, other treatments, or the depreciation of machinery. We did not take reuse or human labour into account.

The final energy consumption figures for fuel and electricity have been compiled directly from the "Action Plan 2008–2012" (MITC, 2007b) in its "Energy savings and efficiency strategy for Spain". Although there are discrepancies between different sources (see p. 76 of the aforementioned document), the data cited constitute a study carried out, *ex profeso*, to estimate the real energy consumption of the sector (discriminating between consumption for livestock, fishing, farming machinery and irrigation).

To estimate the primary energy consumption derived from the application of inorganic fertilisers, we have taken Helsel's coefficients (1992). According to these calculations, the production of each kg of nitrogen, phosphorus and potassium consumes 78,230, 17,500 and 13,800 kJ, respectively in the stages of production, packaging, transportation and application. They are all included in our estimations. The amount of nutrients consumed in Spain in the year 2000 is available in the "Annual of agri-food statistics" (MAPA, 2000).

In the case of treatments, seeds and animal feed, we have taken data from the study carried out by Carpintero and Naredo (2006) which updates the balances for Spanish farming to the year 1999. Only imported seeds and animal feed were taken into account. We consider the use of domestic feed and seed as an internal flow of the AFS.

2. Transportation

We only considered the transportation of food and agrarian products by road and sea, taking into account that they represent over 99.5% of international trade in Spain according to the statistics compiled by the Spanish Tax Agency. For this purpose, we took into account all inland transportation by road as well as the consumption derived from importing and exporting these products (by sea and road). We understand that the importation of agrarian products is incorporated into the processing activities of the Spanish agri-food industry and that importation of food products is incorporated into the activities of distribution and commercialisation, therefore constituting another element of energy consumption for the Spanish AFS. Similarly, we took into consideration the consumption derived from exports (transport) since they have direct repercussions on the Spanish energy bill as they are required by its AFS.

In 2005, commercial road transportation (national and international) represented 85% of all the tonnes transported per kilometre in Spain. Thanks to the "Ongoing Survey of Goods Transportation by Road" carried out by the Ministry of Development (MF, 2006) we know the number of tonnes per km covered in Spain per type of goods. Specifically, we took into consideration the data from 'group 0' (agricultural products and live animals) and 'group 1' (food products and fodder) with figures from the year 2006. Although other calculations provided higher values, we applied the principle of prudence considering an energy consumption of 1.7 Mj/t-km in accordance with the EMCT estimation (2007). A bibliographic review of these coefficients can be found in Pérez and Monzón (2008).

For non-commercial transportation by road (families travelling from their homes to retail outlets to buy food), we used the data provided by Heller and Keoelian (2002) assuming for Spain a similar pattern to that observed in the US, since no specific statistics are available.

We do not include transportation from farms to factories so as not to fall into double accounting, bearing in mind that that most of the time this transportation is carried out with fuel bought by the farms.

To calculate the energy consumed by the international transportation of food and agrarian products by sea, we have compiled the figures, firstly, for trade that falls under these headings with the most important geographical areas in the world (all based on the trade statistics compiled by the Spanish Tax Agency (AEAT, 2010) in its "datacomex" database). Then, we have estimated the distance between the main sea ports and each area to obtain the figure for tonnes per km (http://www.dataloy.com, viewed on 10.03.2010). To these data, we have applied the coefficient of 0.2 MJ per t/km compiled by different case studies for the EU and the rest of the world (in Pérez and Monzón, 2008).

For sea trade with Europe, we assumed that all exchanges take place between the ports of San Sebastian-Rotterdam. For trade with Asia: we took the route Algeciras-Singapore. With Oceania: Algeciras-Melbourne. With North America: Lisbon-New York. With the rest of the Americas: Lisbon-Santos. All these suppositions are grounded in two principles: firstly, we take from each area the closest route, avoiding overestimations. Secondly, the choice of port is conditioned by its relative importance in international trade according to the number of Twenty Foot Equivalent Unit (shipping container TEU) transported, based on the reports published by *The Journal of Commerce*.

The specific case of Africa prevents such generalisations from being made. Its commercial relations are not channelled through a single port, and the long distances between Spain and the different ports on this continent force a distinction to be made for the t/km of each country. We have only carried out estimations for those that represent a flow of exports or imports above 10000 t. For the rest, whose trade was insignificant, we have applied the distance to the country with the lowest relative energy consumption in transport: Morocco. In all cases, the Spanish port of reference was Algeciras (leader in commerce with Africa).

Table A.1
Distance from Algeciras to the main African ports taken into consideration.

Country	Port	Km to Algeciras
Angola	Luanda	6329
Algeria	Algiers	675
Benin	Cotonou	4988
Cameroon	Douala	5670
Ivory Coast	Abidjan	4345
Egypt	Suez	3238
Ghana	Accra	4712
Guinea	Conakry	3190
Libya	Tripoli	3281
Morocco	Casablanca	317
Mauritania	Nouakchott	2178
Namibia	Walvis Bay	7259
Nigeria	Nigeria	5072
Senegal	Dakar	2470
Seychelles	Port Victoria	8164
South Africa	Durban	9533
Tunisia	Bizerte	1212

Source: authors' own data based on the figures detailed in the text.

3. Processing

Under this heading, we reflected the amount of final energy consumed by the agri-food industry. The 'Annual Report of Energy Consumption' (MITC, 2009) breaks consumption down into industrial subsectors, including 'food, beverages and tobacco'. We took the figure for final energy directly, which in this year totalled 2428 ktep.

4. Packaging

According to the webpage of ASPACK, the Spanish Association of Packaging and Transformed Cardboard Manufacturers (http://www.aspack.es, viewed on 13th January 2010) the total production for the sector in 2001 stood at 324,000 t. A total of 42.7% was allocated to the food sector. According to the Spanish Plastics Centre, the consumption of plastics for packaging in Spain in 2008 reached 2,550,000 t. Of that figure, 60% was used for food (FIRA-CEP, 2008). In 2005 in Spain, 2,143,971 t of glass were produced for food uses, according to the European Container Glass Federation (FEVE).

The calculations for energy consumption per material produced are based on Heller and Keoelian (2002) which adapt the data produced by SAE (1998) about the coefficients applicable to packaging for the estimation of LCA. This gives us the indirect primary energy consumption for the life cycle of AFS packaging in Spain.

5. Retail and hospitality

The 'Annual Report for Energy Consumption' (MITC, 2009) provides the final energy consumption figures for the services sector. It distinguishes between consumption in retail outlets in general but does not differentiate agri-food retailers. To resolve this problem, we turned to the 'Annual Commerce Survey', drawn up by the INE (2000) which provides, among other variables, the amount of money spent on the "consumption of materials and other supplies' by different commercial subsectors. We selected the percentage of those subsectors related directly with the sale and management of foodstuffs (groups 7, 8 and 14) and assumed that percentage in the expenditure in order to attribute it to energy consumption. We know that agri-food outlets consumed 26.55% of the budget on expenses for materials and other supplies and, therefore, we understand that they will also have consumed a similar figure in relation to the total final energy required by the retail sector as a whole.

For the hospitality trade, we used the same report on energy consumption (MITC, 2009) which provides the consumption of final energy among hospitality businesses and hotels without making a distinction between them. In accordance with the INE (2002), we calculated the participation percentage of hospitality over hotels on the basis of the mean values of three indicators available (number of employees, turnover and number of establishments). We understand that, of the total energy consumed by hotels and the hospitality trade, the latter accounts for 72.57%.

6. Households

The energy consumption report (MITC, 2009) reveals an exact figure for the energy consumed by Spanish households for cooking purposes (with gas or electricity).

Similarly, the 'Practical Guide to Energy' drawn up by IDAE (MITC, 2007a) indicates that of the total energy consumed in Spanish homes, 18% is for the fridge, 4% for the oven, 2% for the dishwasher and 2% for the microwave. Hence, in addition to the energy consumed for cooking, we add 26% of the electricity consumption attributable to the appliances required for the preparation of food.

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