Energy use in the Spanish Agri-food System (1960-2010). On possible courses for economic degrowth

Abstract

The main purpose of this work is to quantify energy consumption in the agri-food chain in Spain. The years 1960, 1985 and 2010 are analysed, giving an overview of the important changes that have occurred in the sector. Consumption of different forms of energy is estimated (final, primary, distinguishing between direct and indirect consumption and between renewables and non-renewables). The results show that consumption in the agri-food chain multiplied by 10.2 over the period studied, rising from 181 to 1,855 Petajoules. In a first phase, agriculture absorbed most of the new consumption but, since 1985, this stabilised and, since then, other phases of the chain (mainly transport and homes) have sustained total energy demand. Today, one out of every five final energy units consumed in Spain is consumed in the agri-food system (AFS). Transversal energy reduction policies which affect sectors such as agri-foods may be an efficient way of reducing total energy consumption in the country.

1. Introduction

Modern agriculture produces more food, requires less labour input and has increased the productivity of the land. This process of change is long-standing and became accentuated in the final decades of the 20th century with the industrialisation of the sector. It may be seen as a success story of human progress (Bindraban & Rabbinge, 2012; Federico, 2008). However, a large part of the success of modern agricultural systems is due to growing dependence on external inputs, both for direct consumption (fuel or electricity) and indirect consumption (energy required for the production of non-caloric inputs). Although energy output has grown, it has done so to a lesser degree than the inputs used, and so, in the final decades of the 20th century, agriculture lost its traditional energy efficiency (Pelletier et al., 2011).

Today, the high dependence of world agricultural production on external inputs is one of the main threats to its future sustainability. Most of the resources used are increasingly scarce and world demand for them is growing (Krausmann et al., 2008). Food prices have become more dependent on the price of fossil fuels, which has risen in recent years (Headey & Fan, 2008). Furthermore, the generalised use of fossil fuels accelerates the exhaustion of a scarce resource, causes environmental problems such as the emission of greenhouse gases, eutrophication and, in the final analysis, global change (Dutilh & Kramer, 2000).

Motivated by these concerns, several authors published the first works on the energy balance in agriculture in the 1970s (Leach, 1976; Pimentel & Pimentel, 1979), revealing that the new methods of agricultural production were less efficient since they increasingly depended on fossil resources derived from the increased use of fuel, electricity and agrichemicals[1]. In Spain, similar studies were soon carried out (Naredo & Campos, 1980; Puntí, 1982; Simón, 1999). Their results indicated that energy efficiency in Spanish agriculture fell fivefold in little more

[1] A large part of this work came to the forefront in the study of agriculture in the USA and was further analysed in subsequent years (Cleveland, 1995; Dovering, 1985). Today, the USDA continues to promote similar analysis (Outlaw et al., 2005).

than two decades, from 6.1 kcal/kcal in 1950-51 to 1.22 kcal/kcal in 1977-78. Feed and seed re-use fell sharply (from 94.3% to 59.0%) and there was an increase in the consumption of chemical fertilisers, mechanical traction, electricity and plant health treatments.

Industrialisation has not only affected agriculture. It has also radically changed the entire food chain. Over this period, numerous economic activities have been developed between agricultural production and the final consumption of food: transport, packaging, processing, preserving, distribution and consumption. In the 1950s, the idea of an "agri-food economy" was proposed since the supply of food depended increasingly on other activities which took place off the farm (Davis & Goldberg, 1957). The gap has continued to grow over recent decades between the concept of "agricultural product", which is understood to be the output derived from the production of the agricultural sector (Rodríguez-Zúñiga & Soria, 1986), and the concept of "food product", which is the final production of goods resulting from the transformation of agricultural products and the addition of different utilities (Lancaster, 1966).

And so, in the 1970s, two papers were published in Science analysing energy consumption in the US agri-food system (AFS) as a whole (Hirst, 1974; Steinhart & Steinhart, 1974). According to these papers, agriculture represented only a fifth of the energy consumption of the AFS. In the first stage of industrialisation, agriculture grew at a higher rate than other agri-food activities, that is, its role was relatively greater. However, after the Green Revolution, consumption in agriculture was comparatively lower than that in other activities (Heller & Keoleian, 2003) and its consumption even became stabilised (Miranowski, 2005).

Energy consumption related to food has taken an upward trend and represents a large proportion of total energy consumption and so any means of reducing dependence on fossil fuels in industrial companies must address and study in detail the nature of the agri-food sector and its recent transformations (Pimentel et al., 2008; Canning et al., 2010). At a historic moment when it appears that we are close to peak crude oil production in the world (Murray & King, 2012), and at which our decisions regarding emissions are more transcendental and urgent than ever (Hansen et al., 2013), this task becomes even more relevant.

The main purpose of this research is to estimate energy consumption –in its different forms- in each of the links of the Spanish agri-food chain at three historical moments which illustrate the industrial transformation of the sector: 1960, 1985 and 2010.

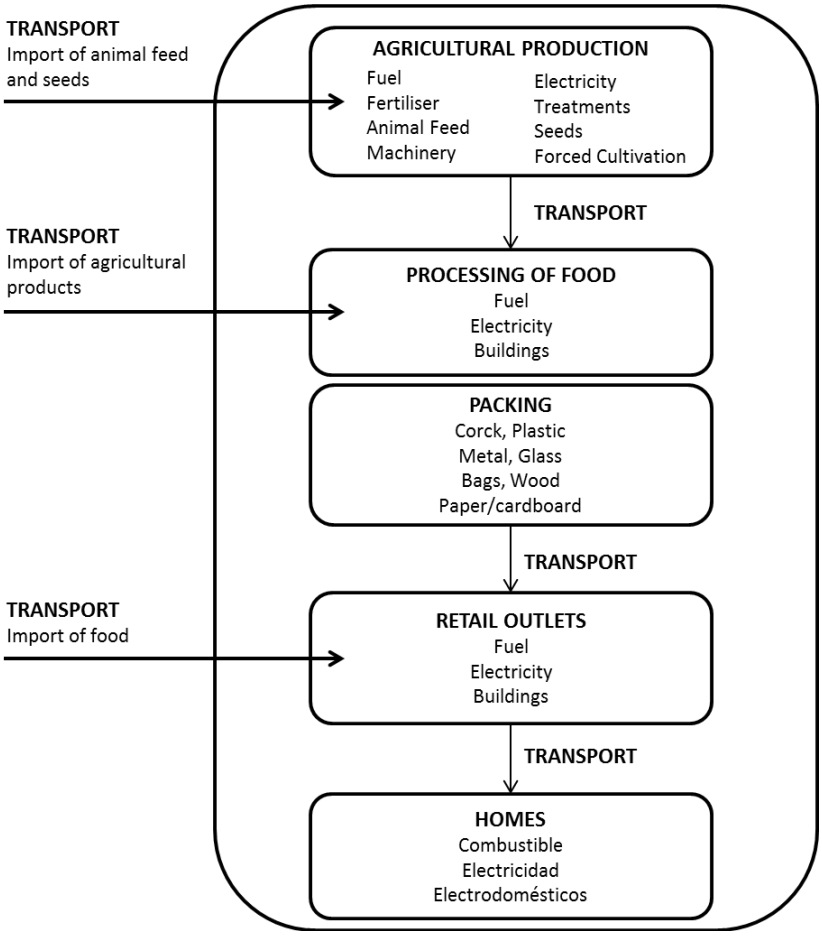
2. Methodology, sources and scope of the study

As has been stated, the main problem regarding methodological proposals, such as energy balances, EROI or any input-output system for the analysis of energy flows in social contexts, is that the absence of a common protocol has prevented valid comparisons between the numerous case studies (Dovring 1984; Giampietro, 2006; Jones, 1989; Mulder & Hagens, 2008; Murphy et al., 2011; Norum, 1983). This has been due to factors such as the difficulty of setting limits to the scope of the study or the variability of energy consumption factors per unit of input.

These obstacles, though, do not invalidate the utility of these methodologies as they still provide very useful indicators on the consumption of resources, the degree of dependence on those resources and the activities which consume them. Nevertheless, they do alert us to the need clearly to specify the scope of the study and the energy flow measurement formulae.

In our case, the scope of the study refers to energy consumption of the Spanish AFS in the years 1960, 1985 and 2010. To this end, we estimate the energy consumption of all of the activities in the agri-food chain (Figure 1). This research, therefore, does not measure the energy cost of food, for which it would be necessary to estimate the consumption of energy associated with all food products consumed in Spain, both those produced domestically and those which are imported. The research analyses the energy consumption of Spanish agri-food activities, allowing us, among other things, to discover what part of final national energy consumption is due to these activities.

Figure 1. Scope of the study. Energy flows examined.



Source: Infante-Amate & González de Molina (2013).

In order not to produce a single indicator which mixes different forms of energy or different methodological approaches, we decided to break down consumption by the different forms of energy. The results are therefore presented in terms of:

Final energy: the energy content of the sources finally used by the AFS, mainly fuel and electricity. It does not include indirect costs or primary energy related to products such as animal feed. It is the usual way of presenting energy balances in official statistics. In this way, we have data which is comparable with the main official sources, detailing AFS-related consumption in the country.

Primary non-renewable energy: the energy content at source, before the transformation processes which generate losses. Under this definition, we quantify not only the direct energy consumed by the energy carriers, but also the indirect energy of all of the goods and services used in the AFS which require large amounts for their production, distribution and maintenance. To do this, using specific life-cycle analysis (LCA) factors, we estimated the total energy costs of the use of fuel and electricity but also fertilisers, packaging, industrial premises, domestic appliances, etc.

Primary renewable energy: this accounts for primary energy from renewable sources. It includes the biomass used as fuel and also the inherent energy of imported seeds and animal feed. It also accounts for non-renewable sources of hydro-electric energy.

Total primary energy: this is the sum of renewable primary energy and non-renewable primary energy.

Table 1 gives a summary of the main sources and converters used in this research, although most cases have been completed with further official statistical information and from literature of the period which is impossible to cite in its entirety[2]. It has been impossible to obtain complete information with regard to two items: agri-food trade in 1960 and a large part of the packaging in 1985. In these cases we have interpolated the results on the basis of representative variables and with the information of the other two years for which data was available. For 1960 (MI, 1961), 1985 (INE, 1991) and 2010 (IDAE, 2013), official statistics were available which offered data on final energy consumption by sector, on which our calculations were based. Statistics regarding electricity were available for all years, broken down by consumption in the main sectors (MIE, 1960, 1985a; IDAE, 2013).

In the case of agriculture, the Annual Agricultural Statistics ("*Anuario de Estadística Agraria*") were used, which offered information on the main items and, in other cases, the Annual Statistics of Spain ("*Anuario Estadístico de España*"), published by the National Statistics Institute. For transport, statistics were available from 1969 on the tons-km transported by road, broken down by type of product, and these were complemented by statistics for rail freight and overseas trade. In general, statistics for trade and industry distinguish consumption by type of activity. We estimated the surface area occupied by trade and industry in order to calculate the energy cost of their production. In the case of packaging, we had complete information in physical terms for 1960 and a recent paper with updated figures. The data for 1985 was inferred. In the case of homes, current information is available and there is partial information available regarding electricity and gas consumption in 1960 and 1985, on the basis of which we have estimated food-related consumption (Table 1).

As regards conversion, we have standardised final consumption in joules. To obtain the primary energy, indirect costs associated with AFS inputs were added, for which we used updated LCA studies, attempting where possible to modify, adapt or use other factors for each period studied. The sources used are also cited in Table 1. Indirect energy consumption was calculated, that is, consumption of energy associated with its production and distribution, both for energy carriers (fuel or electricity) and for non-energy carrying goods (e.g., buildings, plastic bags).

[2] Full methodological details can be found in Infante-Amate et al. (2014).

Table 1 Summary of the main sources used.

			1960	1985	2010
Agriculture	Electricity and fuel	(1)	MI (1960), AEA	INE (1991)	IDAE (2013)
	Fertiliser	Bhat et al. (1994), Kongshaug (1998), Nemecek et al. (2007)	AEA (2)	AEA	AEA
	Treatments	Nemecek et al. (2007)	AEA	AEA	ASEPLA (2013)
	Machinery	Audsley et al. (1997), Classen (2007)	AEA	AEA	AEA
	Animal feed and Seeds	Jungbluth et al. (2007), Nemecek et al. (2007)	AEA, FAO (2013)	AEA, FAO (2013)	AEA, FAO (2013)
Transport	Road	Monzón et al. (2009), Spielmann et al. (2007).	INE (1970)	MTTC (1991)	MF (2011b)
	Rail		AEE (3), RENFE (1960)	AEE, RENFE (1980)	MF (2011a), RENE (2010)
	International		AEAT (2014)	AEAT (2014)	AEAT (2014)
	Homes		AEE	AEE	MAPA (2006), Milá i Canals et al. (2007)
Industry	Inputs	(1)	INE (1962)	INE (1991), Infante-Amate & González de Molina (2013)	IDAE (2013), Infante-Amate & González de Molina (2013)
Packaging	Buildings	Kohler (1994)	-	-	INE (2013)
	Cork	Kellenberger et al. (2007)	INE (1962)	-	AEAT (2014), INE (2013)
	Plastics	Hischier (2007)	INE (1962)	-	Infante-Amate &González de Molina (2013)
	Glass	Hischier (2007)	INE (1962)	Fernández-Navarro (1987)	Infante-Amate & González de Molina (2013)
	Paper and Cardboard	Hischier (2007)	INE (1962)	-	EUROPEN (2013)
	Bags	Hischier (2007)	-	-	EA (2011), Marcos et al. (2007), Nolan-ITU (2002), SA (2007)
	Madera	Werner et al. (2007)	INE (1962)	-	-
Trade	Inputs	(1)	-	INE (1991, 2000), FEHR (2005)	IDAE (2013), INE (2000), FEHR (2005)
	Buildings	Kholer (1994)	-	-	INE (2013)
Homes	Inputs	Kholer (1994)	INE (1961), MI (1960), SSE (1960)	MIE (1985a,b)	IDAE (2011a)
	Household appliances	Horie (2004)	Banesto (1965)	Banesto (1981)	INE (2008)

(1). Indirect costs of fuels and electricity based on: Althaus et al. (2010), Dones (2010), Faist et al. (2007), IDAE (2011b), Jungbluth (2007), MIE (1960, 1985a), Milota et al. (2004), Röder et al. (2007)

(2): Anuario Estadística Agraria. Published by the Ministry of Agriculture (which has changed its name several times over the study period). Several years.

(3): Anuario de Estadística de España. Published by the National Statistics Institute (INE). Several years.

"-": Data not available. Figures estimated by linear inferral from other representative variables.

3. Results

3.1. Total primary energy. A macro view

In terms of total primary energy, including the indirect costs of the sector, the Spanish AFS consumed some 181.4 Petajoules (PJ) in 1960. Twenty-five years later, in 1985, consumption had multiplied by 5.5, rising to 986.3 PJ. In 2010, it reached 1,854.9 PJ, which is 10.3 times more than the consumption in 1960. In relative growth terms, the great transformation took place between 1960 and 1985, but in terms of absolute growth, the increase was even greater over the last 25 years, between 1985 and 2010, increasing by almost 1,000 PJ (Table 2).

In 1960, the agricultural sector was the largest consumer of energy, with 25.5% of the total consumption of the AFS. It rose from 46.3 PJ to almost 350 PJ between 1960 and 1985, that is, it multiplied by 7.5. Except for the case of packaging, which was initially insignificant, the agricultural sector was the link in the chain which grew most over this period, with the result that in 1985 its proportion of total consumption was even greater, exceeding 35%. In this first phase, from 1960 to 1985, other agri-food activities also saw high growth rates. In fact, the residential sector, the part of the chain with least relative growth, almost tripled. In other words, the growth in energy consumption in the first phase of the study was largely due to the growing use of inputs in agriculture, that is, the incorporation of the technologies of the "Green Revolution". 38.8% of new energy consumption in the AFS was seen in the agricultural sector between 1960 and 1985 (Figure 2).

The other activity which consumed large amounts of energy was transport, which in 1960 already represented 20% of total AFS consumption. Between that year and 1985, consumption multiplied by 6.1, and the proportion rose to 25.2%. Transport and agriculture alone consumed more than 60% of the total in 1985.

The second period studied, from 1985 to 2010, showed different characteristics: the growth in agriculture was substantially moderated and this was in fact the activity which, in relative terms, grew least over the period, multiplying by 1.3. Energy demand in the transport sector doubled, becoming the highest energy consumer of the entire AFS in 2010. Its consumption came to 479 PJ, 2.6 times more than the total consumption of the AFS in 1960. In this second phase there was also significant growth in home energy demand for food-related uses, multiplying by 2.5, from 123.8 PJ to 307.7 PJ. Today, it is the third largest source of energy consumption after transport and agriculture. Industry, trade and packaging have grown constantly since 1960. In fact, the energy used in all of these activities is today greater than that of the whole chain in 1960. They represent 10-13% of the AFS total.

Two very clear phases can, then, be observed in the evolution seen since the 1960s: a first phase in which the industrialisation of agriculture had a significant impact on aggregate energy consumption of the AFS as a whole, and a second phase in which, after more moderate growth in agriculture, other links in the chain came to the fore, especially transport and home consumption. The internal structure of energy consumption in the AFS has, then, changed since the 1960s.

Table 2

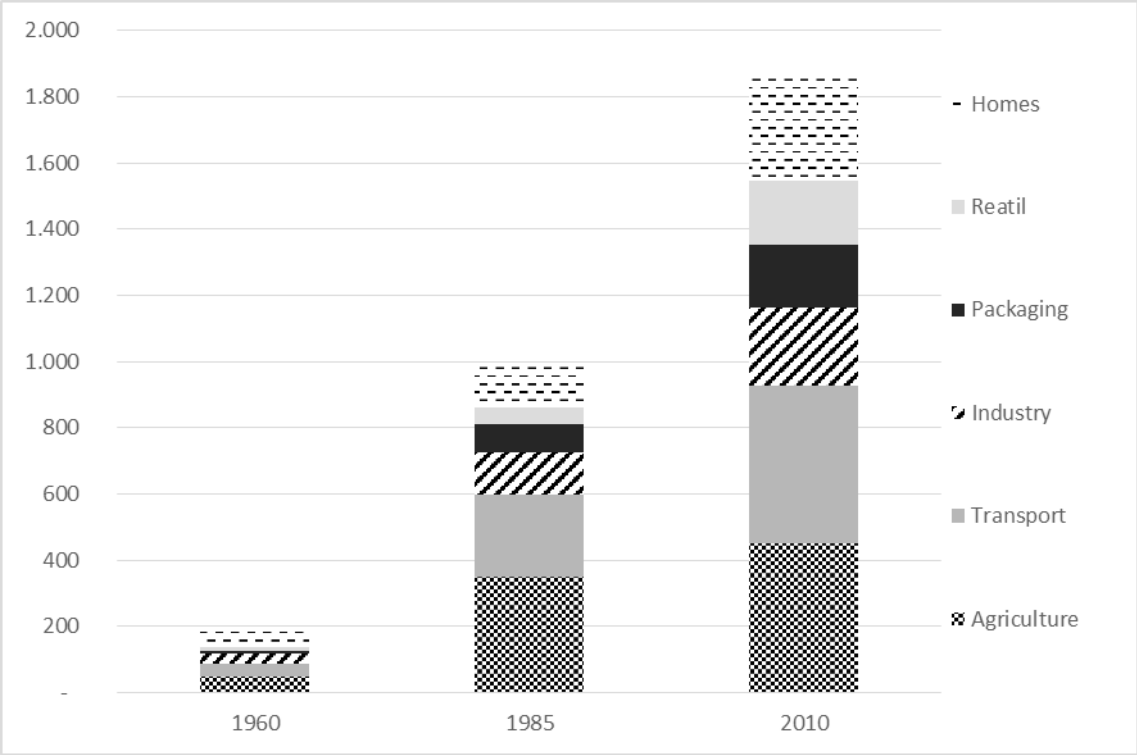
Total primary energy consumption of the AFS.

	Petajoules			Percentage			Growth		
	1960	1985	2010	1960	1985	2010	1960/ 1985	1985/ 2010	1960/ 2010
Agriculture	46.3	348.7	449.1	25.5	35.3	24.2	7.5	1.3	9.7
Transport	40.5	248.8	479.0	22.3	25.2	25.8	6.1	1.9	11.8
Industry	31.5	126.1	235.9	17.4	12.8	12.7	4.0	1.9	7.5
Packaging	4.9	85.7	190.4	2.7	8.7	10.3	20.3	2.2	45.1
Trade	14.5	53.3	192.9	8.0	5.4	10.4	3.7	3.6	13.3
Homes	43.7	123.8	307.7	24.1	12.6	16.6	2.8	2.5	7.0
Total	181.4	986.3	1,854.9	100.0	100.0	100.0	5.5	1.9	10.3

Source: See text.

Figure 2

Total primary energy consumption of the AFS (Petajoules).



Source: See text.

3.1. Total primary energy. A sectoral view

The different elements of energy consumption have changed significantly in each sector analysed and in each period. Furthermore, some very specific items were the source of the main energy demand in some years. After presenting an overview of the consumption results, we shall detail specific consumption in each element (Table 3).

In 1960, in the case of agriculture, the area which consumed most energy was fertilisation, which required large amounts of energy for its manufacture, mainly in the synthesis of

ammonium to obtain nitrogen (Kongshaug, 1998). In this year, the use of nitrogen alone represented over 10% of total energy input into the AFS and, of course, it was the most relevant agricultural consumption. Today, due to stagnation in the use of fertilisers and the development of more efficient ways of synthesising nitrogen, the relative importance of nitrogenised fertiliser production has fallen to represent less than 3% of total consumption. Nevertheless, in agriculture, many other items have risen substantially: fuel, electricity and, above all, imported animal feed. The large amounts of animal feed imported from abroad carry a considerable energy rucksack, both in terms of transport and in production at their place of origin. Today, animal feed alone represents over 10% of consumption in the entire AFS (including its inherent energy content). In relative terms, we have gone from nitrogen as the most significant element of agricultural consumption to animal feed which, in all events, also represents a flow of nitrogen into the agricultural sector (Lassaletta et al., 2013).

The next large section is transport. Although intuitively we think that large-scale imports must consume energy on a large scale, the fact is that international transport today, at a time when it has peaked, hardly represents 5.0% of total consumption. Domestic transport, on the other hand, comes to 20.8%, having been, over the whole of the period of study, the most important variable in the AFS as a whole, with road transport being its most significant element. The reason for such a high figure is that energy consumption, measured in tm-km transported in trucks or vans, is much higher than the energy consumed by ships, the means of transport used for most imports (Monzón et al., 2009; Spielmann et al., 2007). The main problem of transport is not importation *per se*, but the associated domestic network for the redistribution of the goods. Over the entire period studied, the same proportion was seen: something over one out of every five energy units consumed (total primary energy) by the AFS was due to domestic transport of food and agricultural products.

Industry represented a slightly higher percentage in 1960 (17.4%) than in 1985 (12.7%). In any event, its main source was direct consumption of fuels and electricity. The cost of energy related to the construction, maintenance and demolition of industrial buildings hardly came to 3% of the consumption by industry. A similar pattern was seen in the case of trade: its percentage has been between 5-10% of the AFS total and this is mainly explained by demand for fuels and electricity although, in this case, the cost associated with its buildings and facilities is proportionally greater than in the case of industry: shops have a lower final energy demand than industry.

Packaging has risen from only 2.7% in 1960 to 10.3% today. In 1960, paper/cardboard and metal packaging predominated, representing 47.7% and 27.1%, respectively, of energy consumption in the packaging sector. Today, plastics represent 6.4% of the total and 62.5% in the packaging sector with, to a lesser extent, glass and paper/cardboard.

Table 3
Primary energy consumption in the AFS broken down by activity.

	TJ			%		
	1960	1985	2010	1960	1985	2010
Agriculture	**46,250**	**348,664**	**449,121**	**25.50**	**35.35**	**24.21**
Fertilisers	27,251	72,426	61,844	15.03	7.34	3.33
Nitrogen	*18,773*	*58,696*	*52,324*	*10.35*	*5.95*	*2.82*
Phosphorus	*7,811*	*10,804*	*6,489*	*4.31*	*1.10*	*0.35*
Potassium	*667*	*2,927*	*3,030*	*0.37*	*0.30*	*0.16*
Machinery	523	9,853	12,008	0.29	1.00	0.65
Plant health products	1,265	21,434	24,952	0.70	2.17	1.35
Fuels	3,213	138,927	98,511	1.77	14.09	5.31
Electricity	1,811	27,480	45,766	1.00	2.79	2.47
Imported animal feed	9,832	75,100	191,176	5.42	7.61	10.31
Imported seeds	2,136	286	8,239	1.18	0.03	0.44
Forced cultivation	220	3,157	6,625	0.12	0.32	0.36
Transport	**40,518**	**248,837**	**478,958**	**22.34**	**25.23**	**25.82**
Total Domestic	40,048	233,539	386,317	22.08	23.68	20.83
Domestic Road	*38,908*	*230,306*	*380,891*	*21.45*	*23.35*	*20.53*
Domestic Rail	*1,068*	*1,124*	*390*	*0.59*	*0.11*	*0.02*
Domestic Homes (Car)	*72*	*2,109*	*5,036*	*0.04*	*0.21*	*0.27*
Total International	470	15,299	92,640	0.26	1.55	4.99
International Sea	*271*	*7,527*	*17,398*	*0.15*	*0.76*	*0.94*
International Road	*147*	*4,280*	*47,541*	*0.08*	*0.43*	*2.56*
International Air	*51*	*3,492*	*27,702*	*0.03*	*0.35*	*1.49*
Industry	**31,472**	**126,065**	**235,878**	**17.35**	**12.78**	**12.72**
Inputs	30,380	122,814	230,872	16.75	12.45	12.45
Building	1,092	3,251	5,006	0.60	0.33	0.27
Packaging and Packing	**4,946**	**85,680**	**190,401**	**2.73**	**8.69**	**10.26**
Paper & Cardboard	2,359	12,468	27,707	1.30	1.26	1.49
Metal	1,341	4,335	9,633	0.74	0.44	0.52
Plastic	481	53,510	118,912	0.27	5.43	6.41
Cork	0	4	8	0.00	0.00	0.00
Glass	551	14,964	33,253	0.30	1.52	1.79
Wood	214	-	-	0.12	-	-
Plastic bags	-	400	888	-	0.04	0.05
Trade	**14,468**	**53,289**	**192,902**	**7.98**	**5.40**	**10.40**
Point of sale	9,956	28,193	54,405	5.49	2.86	2.93
Restaurants & catering	4,512	25,096	138,497	2.49	2.54	7.47
Building	2,878	9,672	22,747	1.59	0.98	1.23
Homes	**43,707**	**123,810**	**307,673**	**24.10**	**12.55**	**16.59**
Cooking	42,373	36,325	91,803	23.36	3.68	4.95
Household appliances (inputs)	950	85,781	208,235	0.52	8.70	11.23
Household appliances (production)	383	1,705	7,635	0.21	0.17	0.41
TOTAL AFS	**181,362**	**986,346**	**1,854,932**	**100.00**	**100.00**	**100.00**

Source: See text.

Finally, in the case of homes, 19% of total final energy consumption is food-related. The largest part of total consumption is due to heating (47%), hot water (18%), non-food-related domestic appliances (11%) and lighting (4%). With regard to food, the cooker (40% of food-related consumption) and refrigeration (36%) are the most important elements, followed by the oven (10%), freezer (7%) and dishwasher (7%). That is to say, 50% of food-related energy used in homes is consumed in the preparation of food, 43% in its storage and 7% in cleaning.

In 1960, there were hardly any household appliances and gas and electricity consumption in the home was very low. However, most cookers used coal or firewood, which meant that total energy consumption for cooking was even greater in 1969 than in 1985, falling from 42.3 PJ to 36.3 PJ. Why was this? It was due to the fact that firewood and coal were much more widely used in 1960 and the thermal efficiency of cookers at that time was very low, hardly reaching 8% (Arnold & Jongma, 1978). This means that a significant part of the energy produced in the combustion of the firewood or coal was lost. Nevertheless, new cookers are much more efficient since most of the heat they produce is used. It is, then, paradoxical that in 1960 a large proportion of energy was consumed for this purpose (the energy content of the firewood or coal used) although, in its final use, the amount really exploited was much lower due to this inefficiency. In 1960, just the use of firewood for cooking represented 23.4% of total consumption in the AFS. Today, this figure has fallen to 5.0%, although, even so, consumption in absolute terms has grown and has, in fact doubled. This means that while the new systems are more efficient and we consume much more primary energy for cooking, the amount of energy finally used in the home has increased sharply.

3.2. Renewable vs. non-renewable

The data presented so far is expressed in total primary energy, that is, in caloric values at source of each and every one of the items in the agri-food chain, including indirect costs derived from the use of non-energy goods. It is the aggregate sum of all energy consumption, including renewables and non-renewables. In this section, we present the results breaking down the origin of the energy into renewables and non-renewables.

Figure 3 gives details of the origin of the sources of energy in each activity and year studied. It springs to notice that energy consumption originates mainly from non-renewable sources and that this is a trend which has increased over time. In 1960, 32.3% of total energy consumption was renewable energy[3], while in 2010, this proportion had fallen to 12.2%. It is true that total consumption has increased, from 58.5 PJ to something over 226.0 PJ, however, in relative terms, the proportion has steadily fallen.

The contribution of renewable energy comes from three sources: firstly, the biomass contained in imported seeds and animal feed; secondly, other types of biomass, mainly used as fuel; and finally, electricity produced from renewable sources, mainly hydroelectric (Table 4).

Table 4
Renewable primary energy consumption in the AFS broken down by source.

	TJ			%		
	1960	1985	2010	1960	1985	2010
Seeds and animal feed	9,261	56,524	151,808	15.8	59.1	67.2
Organic fuel	42,990	21,231	25,102	73.5	22.2	11.1
Electricity	6,260	17,950	49,118	10.7	18.8	21.7
Total	58,511	95,704	226,028	100.0	100.0	100.0

Source: See text.

[3] In this work, agricultural re-use has not been taken into account. If it were, the use of renewables in the agricultural sector would be much greater. We have only accounted for imported animal feed and seeds.

In 1960, biomass fuel represented 73.5% of consumption in the AFS, and was the most widely-consumed type of renewable energy. This was due to the fact that the Spanish economy was still highly dependent on traditional energy sources. As the energy transformation progressed, the use of biomass as fuel fell in both absolute and relative terms, representing just 11.1% in 2010.

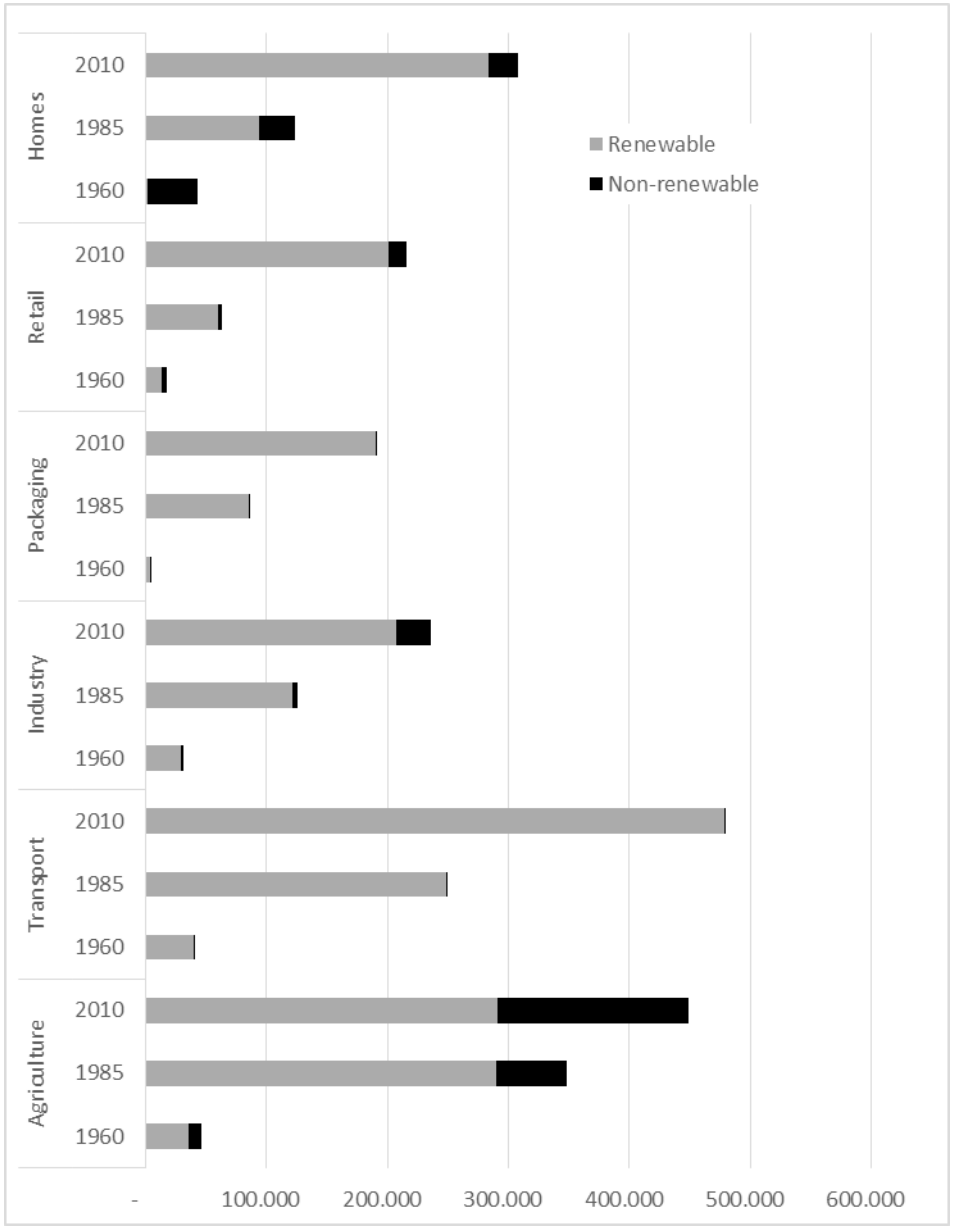
In this process of change, seeds and animal feed, valued by the caloric content of the products imported from other countries and the costs associated with their production, have risen from 15.8% in 1960 to 67.2% in 2010. The growing imports of this type of product mean that consumption of imported grain is a very relevant part of the Spanish AFS today (Lassaletta et al., 2013).

The electricity mix has encouraged the use of non-renewable sources. In 1960, 84% of electricity production was from hydroelectric plants and the remaining 16% from thermal power stations. In 1985, the hydroelectric contribution had fallen to 26%, nuclear production was 22% and the remaining 52% came from thermal power stations. In other words, the growing demand for electricity was increasingly dependent on non-renewable sources. However, absolute renewable energy consumption for electricity production has grown. This is due to the very high growth of total electricity consumption in absolute terms.

This data helps to explain why, in Figure 3, agriculture, homes and, to a lesser extent, industry today appear as the main consumers of renewable energy. The growing importance in Spanish agriculture of imported commercial animal feed and seeds explains why this source of biomass and, therefore, of renewable energy has grown from 20.0% in 1960 to 33.8% of primary energy consumed by the agricultural sector today. This is logical if it is taken into account that, on the one hand, it is, with the exception of homes in 1960, the sector which is most dependent on biomass, because of its very nature, and on the other hand, it is a sector which has become globalised over at the period studied, with a growing proportion of its consumption coming from outside Spain and therefore being counted as inputs in our calculations. Previously, seeds and animal feed mainly came from re-use (Carpintero & Naredo, 2006).

The second highly significant activity in the consumption of renewable energies is residential consumption. This is because, in 1960 (and, to a lesser extent, in following years), cooking was largely dependent on firewood and charcoal. In fact, most fuel for food-related activities in the home in Spain came from these sources. In the late 1960s, during the process of change, more than 40% of Spanish kitchens used coal or firewood (Banesto, 1965). Consumption of electricity and gas in the home was insignificant at the time. With increased use of household appliances, homes were electrified and gas was introduced, leading to greater dependence on non-renewable energy sources. However, and in contrast to what might be inferred from the so-called “energy transformation”, traditional fuels continue to play an important role: one sixth of the total final energy consumed in Spanish homes in 2010 came from biomass. Even today, something over 1,000 TJ of renewable energy is used in food preparation (IDAE, 2011a). This fact, together with the increasing role of renewable energies in electricity generation, explains the fact that homes today consume 7.7% of energy for food-related uses (cooking and household appliances) from renewable sources.

Figure 3
Total renewable and non-renewable primary energy consumption in the AFS (Petajoules).



Source: See text.

3.3. Final energy

Lastly, we have estimated the final energy consumption of the AFS using the same methodology as used in official statistics in order to obtain a comparable indicator. And so, in this case, the dimensions of some renewable sources such as seeds and animal feed are omitted and the indirect costs of the production of many other items are not counted. In this way, the indicator allows us to estimate the proportion of final energy consumption in the country which is attributable to the AFS.

Between 1990 and 2010, final energy consumption in Spain rose from 2,457 PJ to 3,719 PJ. Over the same period, domestic production grew at a lower rate. Furthermore, if we consider only fossil fuels, domestic production fell from 519 PJ to 238 PJ, which means that Spain is highly dependent on other countries (MITC, 2011). Transport has traditionally been the highest consumer: in recent years, it has fairly constantly represented around 40% of total consumption. Industry is the second most important sector, although its relative weighting has fallen. In 1990, it consumed 36% and has fallen to 25% due to the fact that total consumption has been fairly stable, but with a sharp fall seen since 2007 as a result of the economic-financial crisis. A similar trend has been seen in agriculture, although this sector has never had a leading role in total energy consumption: its relative proportion of consumption fell slightly from 2.93% to 2.40%. Fuel and electricity requirements in the agricultural sector are today at the same levels as in 1994. Services represent 11% and consumption in the home, the sector which has seen greatest growth, has risen from 6% to almost 20%.

Unfortunately, we cannot fully reconstruct final energy consumption by activity for periods prior to 1990[4]. This means that for 1960 and 1985, although we know the total final energy consumption, data is not available for the different sectors as the statistics until 1990 only distinguish between industry and transport.

Table 5 shows the main results. In 1960, 13.8% of total final energy consumption was attributable to the AFS. In 1985, this figure had risen to 26.6% and, today, it is 19.6%. That is to say, consumption by the AFS is today much greater in both absolute and relative terms than in 1960. In the first stages of the industrialisation of the country, sectors related to agri-food generated a significant proportion of the new energy demand in the country. Since that date, it has continued to be an important consumer but lower in relative terms.

Today, at a time when we can make a more detailed analysis, as well as agriculture which is fully focused on agri-food activities, transport and the trade sector also stand out, in which one fifth of all consumption is agri-food related. That is, of each five energy units consumed in Spain for transport, one is expended on the transport of agri-food products. Likewise, one out of every five energy units consumed in trading establishments and the service sector in general is in the AFS: hotels, restaurants, hypermarkets, etc, dominate this area of consumption. In the case of industry (13.2%) and homes (16.1%), consumption is somewhat lower. In the latter, heating and hot water are the uses which consume most energy (IDAE, 2011a).

[4] The energy balances have been reconstructed up to 1980 and earlier data is available but it only distinguishes between industry, transport and other diverse uses, so we cannot ascertain the amount consumed by agriculture or services. Some statistics offer information in this respect and it is possible that the original sources allow this information to be differentiated but this is beyond our resources.

Table 5
Final energy consumption of the Spanish economy as a whole and of the AFS (Petajoules).

	1960			1985			2010		
	Total	AFS	%	Total	AFS	%	Total	AFS	%
Transport	226.2	26.9	11.9	650.7	165.3	25.4	1,544.9	319.9	20.7
Industry	418.5	25.9	6.2	915.2	77.3	8.4	900.8	119.0	13.2
Homes	n.a.	42.7	n.a.	n.a.	56.7	n.a.	707.9	113.7	16.1
Services	n.a.	10.3	n.a.	n.a.	29.8	n.a.	409.9	82.4	20.1
Agriculture	3.6	3.6	100.0	118.6	118.6	100.0	93.3	93.3	100.0
Other	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	62.3	n.a.	n.a.
Total	793.4	109.4	13.8	1,684.5	447.6	26.6	3,719.0	728.2	19.6

Source: See text.

4. Discussion

The growing scarcity of non-renewable energy resources is an important item on the political and academic agenda (Krausmann et al., 2008; Murray & King, 2012). In response to these concerns, which have been growing since the 1970s, many authors have focused their research on studying how food production is increasingly dependent on fossil fuels (Leach, 1976; Pimentel & Pimentel, 1979; Outlaw et al., 2005; Pelletier et al., 2011), a fact which could endanger world food supplies in the future. However, in recent years, as well as the increasing weight of non-renewable inputs in agriculture, we have witnessed a process which is much more costly in energy terms in the field of food: the development of new activities in the agri-food chain (Heller & Keolian, 2003; Pimentel et al., 2008; Canning et al., 2010; Infante-Amate & González de Molina, 2013).

Over the last half-century, we have seen enormous changes in the Spanish economy, among which the changes in the way in which the Spanish people produce, handle and consume food occupy a leading place. Between 1960 and 2010, the population multiplied by 1.5, total food consumption by 1.9, final energy consumption by 4.4, GDP by 8.5 (Infante-Amate et al., 2014). However, primary energy consumption by the AFS multiplied by 10.2, much more than the population, much more than the food consumed and more than twice the increase in total energy consumption. In 1960, Spain produced enough food to cover domestic needs, according to FAO figures, and it was healthier than the food consumed today. It was not for no reason that the generation of that period was one of the most long-lived on the planet, according to the World Health Organisation. Today, Spain has one of the highest child obesity rates in the world (Pérez-Farinós et al., 2013). As well as creating serious dietary problems, we have also created a system which is addicted to fossil fuels, a resource which is in deficit in Spain.

The study of this transformation over the long term helps us to understand the phases and factors which led to this transformation in Spain, which could be a model of what has happened in other developed countries. Between 1960 and 1985, the agricultural sector concentrated most of the growth in energy consumption in the AFS, but since 1985, other sectors have multiplied consumption in an upward trend which has still not slowed down. Between 1960 and 1985, 37.6% of new energy consumption in the agri-food chain was seen in the agricultural sector, but only 11.6% of new consumption from 1985 to 2010. This fact warns

us, firstly, that the problem of the energy dependence of our current food supply does not occur only at farm level, but must be addressed in the whole of the agri-food chain. In fact, today, only 24.2% of primary energy consumption of the AFS takes place in agriculture. The fact that agriculture occupies a falling place in consumption in the food chain was already illustrated in countries such as the USA in the 1970s (Hirst, 1974; Steinhart & Steinhart, 1974) and this situation appears to become consolidated in the later stages of industrialisation, due to the stagnation of consumption in the agricultural sector (Outlaw et al., 2005) and to the growth of inputs in the rest of the chain (Heller & Keolian, 2002, 2003).

The main causes of these increases have been due to the mechanisation of most of the activities involved in the AFS. In the early days, this was due to the industrialisation of agriculture, but also to the greater use of transport, the transport of packaging and greater use of household appliances. Since 1985, a fact which has had decisive importance in Spain has been the growing dependence on imported food, mainly grain for animal consumption. This phenomenon has required greater inputs in different parts of the agri-food chain, mainly agriculture, transport and packaging. This process has changed the diet of the Spanish people, multiplying consumption of animal proteins (Lassaletta et al., 2013; González de Molina et al., 2013) and it has meant that associated energy consumption has continued to grow (Muñoz et al., 2010).

According to our results, today, 19.6% of total final energy consumed in Spain is in agri-food activities, or in other words, in feeding ourselves or in producing and handling food. This figure is greater than in 1960 (13.8%) and somewhat lower than in 1985 (26.6%). This fact invites us to believe that an efficient way to promote the reduction of energy consumption should be a transversal action. A change in the AFS could potentially reduce consumption in all of the country's economic activities.

Spain is increasingly energy-dependent on third countries (MITC, 2011) and, according to the data given in this paper, the country's eating patterns are increasingly dependent on non-renewable energy resources. The consumption of energy in the country, especially in the AFS, has grown in parallel to this increasing dependence on external energy supplies. In fact, all of the activities related to the agri-food chain have increased their energy consumption. Although consumption of renewable energy in the AFS has increased, it is proportionally lower today than in 1960.

The Spanish administration has for several years been concerned about reducing final energy consumption in the country. In general, government plans for reducing consumption have been drawn up in accordance with the sectoral distribution shown in Table 5[5], but they do not have a transversal or inter-sectoral focus, such as an agri-food focus, which could potentially help to reduce consumption of all energy-demanding activities.

For example, a more vegetarian diet or lower consumption of meat and dairy products would allow a reduction in livestock, which would lead to lower consumption of animal feed (reduction in transport and agricultural production at source) and, therefore, of energy (Eshel & Martin, 2006), but also of land (Kastner et al., 2012), water (Vanham et al., 2013), lower greenhouse gas emissions, as well as a positive health effect (Van Dooren et al., 2014). Moreover, there would be a fall in inputs into the processing and marketing of animal products (reduction in logistics for preservation, especially energy for refrigeration) and also in the

[5] See, in this regard, the energy efficiency and savings plans designed by the Institute for Energy Saving and Diversification (*Instituto para la Diversificación y Ahorro Energético*) (IDAE, 2011b).

home: the cost of preparing and preserving food is greater in a meat-based diet (Kramer, 1996). This proposal may serve as an example of the potential which other measures may have for the transversal reduction of energy consumption.

In the light of these results, the next step in the research should be the analysis of future scenarios for food in Spain and the impact they may have on the reduction of energy inputs which, in turn, involve high CO2 emissions and heavy economic dependence on foreign countries.

5. Conclusions

The Spanish AFS has undergone a significant transformation over the last 50 years. Since 1960, primary energy consumption in the Spanish agri-food chain has multiplied by 10.2, a higher rate than other variables in the Spanish economy. As has been described in this paper, during a first phase (1960-1985), the agricultural sector absorbed most of the new energy consumption in the AFS. However, in more recent years (1985-2010), the agricultural sector has moderated its consumption while other new activities related to agri-food have grown at a greater rate.

Today, transport (25.8%) and the agricultural sector (24.2%) are the highest consumers of energy in the agri-food chain, followed by homes (16.6%), industry (12.7%), trade (10.4%) and packaging (10.3%). The agricultural sector and transport have traditionally been the highest consumers of energy in the AFS.

Renewable energy consumption has increased in absolute terms due mainly to growing imports of animal feed and seeds but its relative importance has fallen.

If we consider only final energy, our results indicate that, today, 19.6% of total consumption in the country is related to agri-food activity. This percentage is greater than in 1960 (13.8%). That is to say, the process of industrialisation of the AFS has been even greater than that seen in the economy as a whole.

Spain is increasingly energy-dependent on foreign countries and this is viewed with concern in many organisations. A modification of the general practices of the AFS as a whole could be a measure to achieve a transversal reduction of consumption in the country. New research is required to model future scenarios that guarantee the food supply and employment in the sector while reducing inputs which, as well as generating dependency on a resource which is not available in the country, also generates environmental problems.

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