Continuity, change, and geographical differences in Spain's firewood consumption: a new estimation (1860-2010)

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KEYWORDS: **history of energy, forests history, energy transition, firewood.**

JEL CODES: **N53, N63, Q23, Q41.**

Although firewood was the main energy source until recently in most parts of the world, our understanding of its consumption levels is still quite limited, even in regard to recent periods. The powerful impact of fossil energy carriers and their major effects on global ecology, economy and society have led us to underestimate the role firewood has continued to play during the energy transition. This article offers a new reconstruction of long-term firewood consumption in Spain, taking into consideration variables related to supply and demand, which are then used to reconstruct the production, appropriation and energy uses of firewood biomass. This new series distinguishes also between the origins (forest or crop firewood), and between different regional behaviors. The main findings indicate that total and per-inhabitant consumption has been greater than traditionally assumed; that there was major regional divergence, with consumption varying significantly from one area to another; that the decline in firewood consumption was gradual and later than previously thought; and that it increased or declined over time in a non-linear fashion. Moreover, the traditionally neglected estimation of the role of woody crops was found to be very significant in this process, as it represented between 20% and 70% of total consumption for the whole data series.

Continuidad, cambio y diferencias geográficas en el consumo de leña en España: una nueva estimación (1860-2010)

PALABRAS CLAVE: **historia energética, historia forestal, transición energética, leña.**

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Aunque la leña ha sido la principal fuente de energía hasta hace relativamente poco tiempo, nuestro conocimiento sobre su consumo es escaso, incluso en periodos recientes. El impacto de las energías fósiles y sus profundos efectos en la economía, la sociedad y el medioambiente han llevado a descuidar el análisis del papel que la leña ha podido seguir jugando hasta la actualidad. Este trabajo ofrece una nueva estimación del consumo de leña en España, que pretende mejorar las carencias de estimaciones anteriores. La nueva estimación toma en consideración variables relacionadas, tanto con la oferta como con la demanda, que son usadas para reconstruir la producción, la apropiación y el consumo, distinguiendo además el origen genérico de la leña consumida (leña forestal o leña de cultivos), así como las diferentes pautas regionales de consumo. Los principales hallazgos son que el consumo per cápita ha sido mayor de lo que habitualmente se asume; que han existido fuertes diferencias regionales en el consumo; que la caída del consumo ha sido más gradual y más tardía de lo que se pensaba, con algunos periodos de estancamiento y retroceso que otorgan a la evolución un carácter no lineal; y finalmente, que el papel de la leña procedente de cultivos, tradicionalmente no contabilizada, alcanza cifras (entre un 20% y un 70% del total del consumo) que le dan un alto protagonismo en el proceso.

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1. INTRODUCTION

Throughout most of the world and most of history, firewood has been the main source of energy used by humanity (Smil, 1994). Only since the 17th Century in England, over the course of the 19th Century in certain European countries and in the United States, and during the 20th Century for much of the world have fossil fuels begun to replace firewoowd as the main source of energy (Kander, Malanima & Warde, 2014). The study of energy in an historical perspective amongst scholars from different disciplines has grown significantly in recent years (see Wrigley, 1988; Crosby, 2006; Grubler, 2012; Kander, Malanima & Warde, 2014). In fact, several research projects have attempted to estimate comparable consumption series at an international level[1]. Their results have led to improvement in our understanding of the phases and geography of the energy transition. Moreover, they have shed light on very relevant on-going debates including the material basis of modern economic growth (Ayres & Warr, 2010; Wrigley, 2016), the rise of the Antrhopocene (Fischer-Kowalski, Krausmann & Pallua, 2014), the causes of climate change (Allen *et al.*, 2009), and the making of modern socio-political systems (Mitchell, 2011).

However, this new wave of research, which has manifested the formidable importance of modern energy sources in contemporary societies, has paid little attention to the role that biomass and in particular firewood, as the main fuel source in the pre-industrial world, might have continued to play in the modern age. In fact, its usage is implicitly considered to have declined, shrinking back to a marginal role in the total energy consumption of industrialised countries. Because it was not relevant for energy policy and because it was understood to represent a residual part of consumption, official records stopped to provide data on fuelwood use or, when provided, they were dramatically underestimated (see Henriques, 2009: 38). This paper, however, argues that firewood may have continued to play a highly relevant role and that its invisibility is due not so much to its loss of importance but rather to the dearth of reliable statistics capable of tracking its consumption. Since the 1980s, following the oil crisis, there has been renewed interest in studying bioenergies (see Smil, 1983). However, this interest has not fully reached long-term analyses, which continue to focus almost exclusively on modern energies, without looking in de-

1. In addition to the estimations provided by Smil and Grubler, in recent years various estimations have been developed regarding the extraction and consumption of energy sources. The IFF Social Ecology provides reconstructions globally and for a large group of countries from a long-term perspective using Material Flow Accounting methodologies (http://www.uni-klu.ac.at/socec/inhalt/1088.htm). And in the field of Economic History, a recent international project has estimated energy consumption in various European countries since the 19th Century (http://www.fas.harvard.edu/~histecon/energyhistory/).

tail at the evolution of traditional energies, their geography, the factors that influenced their abandonment, or possible discontinuities in their trajectory. A detailed historical reconstruction of firewood consumption is historiographically relevant for several reasons: analysis of regional patterns and the forms of firewood appropriation help to open up the black box of the energy transition, by providing new evidence regarding its dynamics and historical discontinuities; in this respect, it helps to gain a better understanding of the mechanisms of energy sustenance and, in short, the material cultures (in a *braudelian* sense) of societies during the energy transition phase, highlighting that many social groups and territories may have continued to depend on traditional energies until well into the 20th Century. Furthermore, a more exact measurement of firewood consumption could alter total energy consumption figures over the course of the transition and thereby alter the timescale of this transition, as well as some of its associated indicators, such as energy intensity. Finally, a better estimation of firewood consumption is essential in order to describe more fully certain environmental impacts, such as greenhouse gas or other types of emissions (Fernandes *et al.*, 2007).

In Spain, various proposals have been made to estimate long-term firewood consumption, but none has been satisfactory. Some have been constructed using assumptions based on firewood production information from public forestry statistics, which only cover a small and changing portion of woodland and forest land (Rubio, 2005; Iriarte-Goñi, 2013), whereas others calculated firewood production data based on land uses, but without subsequently inferring real consumption (Infante-Amate *et al.*, 2014). The aim of this paper is to overcome these limitations and present the reconstruction of a firewood consumption data series between 1860 and 2010, which offers details at the level of Spain's judicial districts (425 in the whole of Spain) and which not only takes into account firewood from forests and woodland areas, but also firewood taken from woody crops (vines, olive groves, and other orchards and fruit crops), which have played a very significant role in total consumption.

For the purposes of this reconstruction, a model is proposed that combines variables pertaining to supply (availability of firewood) and demand (replacement of traditional energy with modern energies according to geography and infrastructures). To this end, an initial estimation of firewood appropriation for the whole of Spain is conducted for the year 1860, which is then broken down into different judicial districts, as detailed in the second section of this paper. Using these figures as a foundation, the evolution of consumption is then calculated up to 1960, inserting various assumptions about demand at different points in time and in different territories. This estimation is developed in the third section of the paper. The reconstruction carried out is based on a methodology that is described in full in an additional working paper, which is complementary to this paper (Infante-Amate & Iriarte-Goñi, 2017), since the details would be impossible to summarise within the context of this study. Finally, section four completes the series by extending it up to 2010, offering a summary of the findings, as well as a discussion thereof.

2. FIREWOOD PRODUCTION AND CONSUMPTION PRIOR TO THE ENERGY TRANSITION

The data series developed in this study begin with an estimation of firewood consumption for energy purposes at the level of Spain's judicial districts in the mid 19th Century. The starting point is a calculation of woody biomass extractions from forests, as well as vine, olive, and fruit crops, calculated on the basis of a reconstruction of forest and woody crop land areas for the year 1860[2]. Extraction coefficients were applied to these land areas, following the same methodology used for the period 1900-2000 by Infante-Amate *et al.* (2014), in which three types of forest areas were defined (high forest, coppice forest, and open forest) as well as three types of woody crops (olive groves, vineyards, and fruit trees) with different coefficients depending on the province[3]. The percentage of firewood used as fuel was then calculated by subtracting from the total biomass appropriated the proportion used for non-energy purposes: wood commercialised in other economic sectors (Iriarte-Goñi & Ayuda, 2006) and wood that has no socio-economic usage or purpose even though it is appropriated[4]. According to this estimation, in the mid

2. The terms *appropriation* and *extraction* are used here indistinctly to refer to woody biomass harvested by people regardless of its ultimate use. Forest areas have been estimated by combining the Woodland surface area data provided by GEHR (1994) at a provincial scale, with the public woodland data provided by the "General Classification of Public Forests and Woodlands" of 1859 at the level of the individual judicial districts. The estimation of woody crop land areas is a transposition of the data provided by the Agronomical Consultation Board (Junta Consultiva Agronómica) for the case of olive trees (JCA, 1891b), grapevines (JCA, 1891a) and fruit trees (JCA, 1923). The land use percentage for each crop in each judicial district for these years is applied to the provincial or national land area available for each case for *c.* 1860 based on the data of Gallego (1986) and Zambrana (1987). See Infante-Amate and Iriarte-Goñi (2017).

3. Extraction data have been taken from a literature review for the case of *monte bajo* (17 reviewed studies), the dehesa agro-silvo-pastoral system (9), grapevines (18) and fruit trees (49). In the case of *monte alto* it was estimated on the basis of Iriarte-Goñi and Ayuda (2006) and in the case of olive trees following the model developed by Velázquez-Martí *et al.* (2011). More details can be found in Infante-Amate and Iriarte-Goñi (2017).

4. In this case, we are referring to biomass that has been pruned from crops and is chopped up on the farm, or to the part of the forest biomass that is recycled in the woodland itself. In general terms, the appropriated part can be disaggregated as follows: $WBA_t = WBR_t + T_t + FC_t$. Where for every year t, WBA is the woody biomass appropriated; WBR, the woody biomass that is recirculated in agro-ecosystems; T is the woody biomass used for non-energy purposes (furniture, planks, etc.), substracting 10% of industrial residues that are finally used as biofuels; and FC is the biomass used for

19th Century, 74.4% of total wood appropriation represented energy uses, 3.0% was used as raw material for different purposes, and the remainder was dedicated to other uses, such as bedding for livestock or recycling on the farm.

Table 1 and Figure 1 provide information about the total and per-inhabitant firewood energy consumption at a regional level. The data available for the individual judicial districts have been aggregated into 8 bioregions, which encompass districts with similar geographical features. They were grouped into three coastal regions (Atlantic South coast, Cantabrian, and Mediterranean), and five interior regions based on altitude (0-500, 500-1000 and over 1000 metres) and latitude (north and south) (Figure 1). According to these data, firewood consumption for energy purposes in 1860 was 17.8 million tonnes, which in per capita terms represented an average of 3.1 kg inhab^{-1} day^{-1}. This estimation is higher than the values presented in previous studies (Rubio, 2005; Iriarte-Goñi, 2013), but this increase can be justified on several grounds. Firstly, these prior estimations explicitly acknowledged that the figures they provided represented minimum levels of possible consumption, owing to the way in which they were calculated. Secondly, these new figures are perfectly in alignment with the firewood consumption limits offered in other studies referring to Europe as a whole (Kander, Malanima & Warde, 2014) or to Southern Europe (Fernandes *et al.*, 2007; Henriques, 2009). Thirdly, the estimated consumption is plausible in accordance with presumable energy demand in a country that, in the mid 19th Century, had been growing for several decades in economic and population terms (Nicolau, 2005; Prados de la Escosura, 2017), but which had not yet begun to use fossil energy in considerable quantities (Sudrià, 1987; Rubio, 2005) and which consequently continued to base the majority of its energy consumption on firewood and other traditional energy sources.

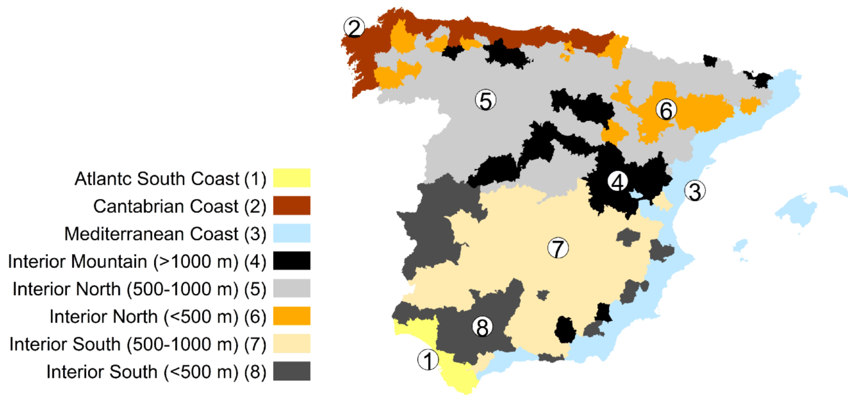
This estimation also flags up broad regional differences corresponding to different geographical and economic situations. In interior areas in the north of the Peninsula and on the Cantabrian coastline, consumption could be around 4 kg inhab^{-1} day^{-1}, in other words similar figures to those of Central European countries (Sieferle, 2001; Warde, 2006). The Mediterranean coastline, on the other hand, presented much lower consumption levels, below 1.5 kg inhab^{-1} day^{-1}, which are closer to the reference figure traditionally given for Southern Italy (Bartoletto, 2004; Malanima, 2006). In between these two, interior areas in the south (also including the Atlantic South coast) presented intermediate con-

energy purposes, in other words, firewood consumption as considered in this paper. The complete model for woody biomass flows is detailed in Infante-Amate and Iriarte-Goñi, 2017) and can be summarised as follows: $WBP_t = WBA_t + \Delta S_t$, where *WBP* is the woody biomass produced naturally and ΔS is the variation in woody stock for each year *t*. Note that *WBA* > *WBP* denotes a process of deforestation, and the contrary case indicates a process of stock accumulation.

sumption of *c.* 2 kg inhab^{-1} day^{-1}. Furthermore, the estimation detects different models for obtaining firewood, which reflect different consumptions based on different land uses. In fact, on the Mediterranean coast and, to a lesser extent, also in the southern interior zone of the Peninsula, firewood taken from grapevines, olive trees, and other woody fruit trees was essential in the mid 19th Century to cover a very substantial proportion of fuel consumption (up to 67.6% on the Mediterranean coast, in contrast to the national average of 20.6%) and partially palliate the scarcity of woodland areas.

FIGURE 1

Location and division of the eight bioregions on which our estimations are based



Source: see Infante-Amate and Iriarte-Goñi (2017).

TABLE 1

Estimation of firewood consumption by bioregion in 1860

	Cod	Total [kg/inhab/day]	Forest	Cultivated [000 Tons]	Total	Forest	Cultivated	Total [%]	Cons.Total	Pop.Spain
Atlantic South coast	[1]	2.00	250	50	300	83.30	16.70	100.00	1.70	2.60
Cantabrian coast	[2]	3.80	2,534	266	2,800	90.50	9.50	100.00	15.70	13.10
Mediterranean coast	[3]	1.40	546	1,139	1,686	32.40	67.60	100.00	9.50	21.80
Interior mountain (>1000 m)	[4]	4.30	1,132	55	1,187	94.40	4.60	100.00	6.70	4.90
Interior North (500-1000 m)	[5]	4.30	5,406	765	6,171	87.60	12.40	100.00	34.60	25.40
Interior North (<500 m)	[6]	4.10	1,435	361	1,797	79.90	20.10	100.00	10.10	7.70
Interior South (500-1000 m)	[7]	3.00	1,874	645	2,518	74.40	25.60	100.00	14.10	15.00
Interior South (<500 m)	[8]	2.50	970	398	1,369	70.90	29.10	100.00	7.70	9.60
Total Spain		**3.10**	**14,154**	**3,672**	**17,826**	**79.40**	**20.6**	**100.00**	**100.00**	**100.00**

Note. Recycled residues of industrial wood used for burning cannot be assigned by bioregions, but is accounted at a national level (see Supplementary Data).

Source: see Infante-Amate and Iriarte-Goñi (2017).

Finally, although the data given cannot be presented as a fully accurate snapshot of consumption owing to the lack of direct sources, as well as the impossibility of knowing the true dimension of firewood commerce between different areas, the resulting consumption levels are also consistent with the few estimations calculated on a local scale (Tello *et al.*, 2008; Bernados *et al.*, 2011; Infante-Amate, 2014; Bartolomé & González Mariscal, 2016). The next challenge involves estimating how firewood consumption evolved after this point, seeking to ascertain the changes in demand derived from the growing use of modern energies and the degree of firewood substitution that might have generated.

3. ASSUMPTIONS IN TERMS OF DEMAND

Statistical sources on which to base firewood consumption calculations are fairly unreliable prior to the 1970s. For that reason, having established a starting point in the mid 19th Century, our estimation is based on various assumptions that enable us to calculate the evolution of consumption in the period 1860-1960, and from there on to link the constructed series with the official data given by statistics from the 70s onwards. Following some of the explanatory guidelines given in the literature about the energy transition (Dahmén, 1988; Kander, 2002; Allen, 2012), in order to estimate consumption during the long period between 1860 and 1960, we sought to answer three questions: firstly, where was firewood truly replaced with new energies? Secondly, which energies were able to compete with firewood and what was their rate of replacement? And thirdly, how did firewood consumption behave in areas that continued to maintain this energy source as a core resource?

Although studies into the energy transition have tended to present it implicitly as a homogenous process that occurred at the same time throughout the whole of the country, the reality was very different, since broad areas with sizeable populations may well have been left out of the effective distribution networks of new energies until practically the second half of the 20th Century. As some authors have pointed out (Wrigley, 2010; Mytting, 2016), one of the advantages of firewood is that it is practically ubiquitous in the rural world, which makes it possible to use it in small quantities on a local scale virtually anywhere. As a counterpoint, this dispersal hinders its usage in certain areas that require large quantities of energy, since transportation costs from scattered production points to the point of consumption can be very high. Fossil fuels such as coal and oil present the opposite characteristic. These are energies that could be termed "punctiform" (Wrigley, 2010), since they are concentrated in large quantities in specific points. This was, in fact, one of the features that linked the existence of coal to the first processes of industrialisation (Kander, Malanima & Warde, 2014). However, the distribution of these modern energies for use in small amounts on a local scale was very costly and even impossible in the absence of inadequate infrastructures, which excluded very substantial areas of territory when it came to accessing new energy sources.

To gain an idea of what might have happened in Spain, we have assumed that new energies reached localities that fulfilled two basic criteria: they had to have access to infrastructures that would make this possible (port or railway station) and have a population size that would make supply profitable (we considered 5,000 inhabitants as a minimum). In the case of electricity, the data available suggest that its expansion to the rural world prior to the 1970s was partial and only intended to provide lighting services (Bartolomé, 2007), so there was no direct competition with firewood for other uses.

TABLE 2

Population with access to new energies

	Code	Thousands of inhabitants				Percentage			
		1860	1910	1950	1960	1860	1910	1950	1960
Atlantic South coast	[1]	188	352	590	933	40.70	68.50	72.90	94.80
Cantabrian coast	[2]	284	1,196	2,208	4,000	14.50	45.20	58.90	87.40
Mediterranean coast	[3]	717	2,415	4,515	6,696	21.40	53.30	69.10	84.00
Interior mountain (>1000 m)	[4]	0	89	168	344	0.00	10.20	16.40	32.20
Interior North (500-1000 m)	[5]	26	590	962	1,449	2.20	44.20	56.10	69.30
Interior North (<500 m)	[6]	375	1,273	2,767	4,593	9.80	28.60	46.10	62.10
Interior South (500-1000 m)	[7]	110	1,478	2,545	3,513	4.60	46.30	58.30	70.00
Interior South (<500 m)	[8]	307	1,117	2,165	2,863	20.60	57.60	72.60	78.10
Total		**2,006**	**8,511**	**15,919**	**24,391**	**13.00**	**43.70**	**58.60**	**74.40**

Source: Infante-Amate and Iriarte-Goñi (2017).

Applying this criterion dynamically as a proxy for accessibility to new energies (Table 2), in the year 1910 only 43.7% of the population had such access. By the 1950s, this percentage had only risen to 58.6%, and it was not until the 60s that the country's intense process of economic change would bring it up to 74.4%. Put another way, in the 60s, approximately one quarter of the country's population (over eight million inhabitants) still did not have regular access to modern energy sources. The percentages also vary substantially according to the different bioregions. The low density of the Spanish railroad network compared with other European countries (Martí Henneberg, 2013), in addition to the endurance of a sizeable rural population until the 60s (Collantes & Pinilla, 2011), would explain this situation.

Knowing which percentages of the population had real access to modern energies, the next step is to estimate the rate at which said population could gradually replace firewood with new energies. In this respect, the information available about prices might offer an interesting initial clue. Table 3 provides an estimation of the relative price it might have cost to obtain one GJ of energy from firewood, coal, coke, oil, and electricity. The data have been obtained from different sources and probably offer a better reflection of prices in Madrid than in other parts of the country (for more details, see Infante-Amate & Iriarte-Goñi, 2017) but, in general, they mark a comparable trend to other estimations of energy prices available in the literature (Betrán, 2005; Fouquet, 2008; Allen, 2012).

TABLE 3
Price Index per GJ according to energy sources used

	Firewood and charcoal	Coal	Coke	Oil	Electricity
1868	100	29	27		
1913	100	26	58	611	2,217
1922	100	56	67	350	1,296
1933	100	52	43	211	1,372
1948	100	14	12	112	113
1958	100	15	8	45	63

Source: Infante-Amate and Iriarte-Goñi (2017).

The data clearly show that, from the mid 19th Century onwards, obtaining one GJ of energy using coal or coke was much cheaper than obtaining it using vegetable fuels. The difference resulted from the economies of scale permitted by the transportation of coal obtained in large quantities in the mines and in ports, and also because that source of energy could be subject to lower consumption taxes in certain cities[5]. In any case, these differences in price must have been a powerful incentive for energy change where coal was available, and they explain why industry, transport and also a growing part of urban domestic consumption opted for that energy source. With regard to electricity and oil, the data show that until the late 1950s, the price of obtaining one GJ was extremely high in relation to firewood and coal, and that indicates that competition with these energy sources must have been limited to very specific uses in which electricity or oil could truly offer advantages (mainly lighting and locomotion, respectively). However, in the case of electricity, there was one important exception. The prices compiled pertain to the domestic tariffs applied to lighting, and this suggests that, in the domestic sphere, electricity did not indeed compete with firewood and coal to obtain services related with cooking and heating, owing to the lack of voltage for such uses. However, the case of industry was differ-

5. Energy Consumption Tariffs in 1897 published in the *Bailly-Bailliere Almanac* of this year (p. 373).

ent, since it could operate with much lower special tariffs than lighting (Garrués, 2012; Martínez Ruiz, 2016). In fact, from the 1920s onwards, many businesses started using electricity in response to rising coal prices, capitalising on the advantages offered by this energy for many manufacturing processes in terms of supply, cleanliness and adaptability (Sudrià, 1997; Bartolomé, 2007). In any case, the leap made by businesses towards electricity must have happened in the vast majority of cases not from firewood but rather from coal.

On the basis of this evaluation, it seems clear that the great competitor for firewood from the mid 19th Century onwards was coal, and for that reason, in the absence of a direct indicator, which would allow us to know the rate of replacement, we have examined the expansion of the apparent consumption of coal (Carreras, 2005), measured in per capita terms, considering it to be an adequate proxy for the decrease in per capita firewood consumption. On the basis of this criterion, we calculated two coefficients for the decline in firewood consumption per inhabitant. A faster one, which we applied to areas where we know the majority of coal consumption was concentrated in the early 20th Century[6]; and another slower one, which was applied to the other areas with access to modern energies.

To conclude our estimation, mention must be made of the areas that remained outside the distribution channels and networks of new energies. Taking the information available about what happened in rural areas over this long period of time, some data might point to a decline in consumption, whereas others indicate the opposite. The former include the privatisation process of public woodlands and forests, which occurred with particular intensity in the second half of the 19th Century and was accompanied by a parallel process of deforestation owing to the cultivation of new lands (GEHR, 1994). This process clearly reduced the availability of woodland per person, and may have negatively affected the supply of firewood in some areas. Similarly, the control that the forestry administration began to exert over forests might also have impeded access to free firewood for the residents of villages and towns. However, the effects of these two elements are not clear. Although deforestation undoubtedly reduced the availability of woodland per person between the mid 19th Century and the 1930s, if we take into account only the population that, according to our calculations, continued to depend exclusively on firewood, what we find is a level of stability in forest area available per person of around 2.5 hectares

6. To this end we have followed the information given by Coll and Sudrià (1987). The provinces with larger coal consumption and consequently with the fastest firewood replacement rate, in order of importance, were Barcelona, Vizcaya, Asturias, Madrid, Guipúzcoa, Valencia, Sevilla and Zaragoza.

per inhabitant. Furthermore, the rotation of new lands entailed pulling up trees and shrubs that, on account of the non-perishable nature of the wood and timber, generated stocks of fuel available to consume over several years. Furthermore, the control of firewood extraction by the forestry administration did not appear to be accompanied by a decrease in the total firewood extracted from public woodlands and forests, which according to the data available (GEHR, 1991), remained fairly stable over time. It is also well known that on many occasions administrative control and supervision was sidestepped through the fraudulent use of woodlands and forests in which firewood was extracted outside of the new legal framework imposed.

Finally, although no less importantly, in addition to firewood obtained from woodlands and forests, the inhabitants of the rural world were able to access higher quantities of firewood originating from the pruning of woody crops, which doubled their surface area and increased their firewood productivity. There were also episodes of mass uprooting of woody plants (for example in the late 19th Century when traditional grapevines were attacked by phylloxera and were replaced by American disease-resistant vines), which might also have generated important firewood stocks to be consumed over long periods of time. The increase in forestry and woodland exploitation to obtain industrial products, insofar as it generated more forestry waste products, would also have acted in the same direction. Hence, if we take into account that the population that continued to depend exclusively on firewood remained stable over this time period (Table 2) and that the pressure of demand in urban areas decreased with the introduction of coal or other new energy sources, the availability of firewood per inhabitant who exclusively used this fuel source may even have increased.

Running parallel to this, however, other factors may have been generating savings in fuel consumption. Among these, the main one would be the introduction of more effective cooking and heating systems (such as the economic kitchen), as well as the use of building insulation systems through improvements made to construction, which would have retained more heat and allowed more rooms to be heated within a single house with the same fuel. The relative abundance of firewood may well have been compensated by factors that fostered fuel savings, so that, following similar assumptions to those applied by Kander (2002) in the case of Sweden, it could be concluded that in areas that remained outside of the new energy circuits, per capita consumption may have stabilised over time. This obviously does not exclude the possibility that in certain places and under certain circumstances that might have been a scarcity of fuel.

In short, recapping on all the assumptions explained with regard to demand, firewood consumption (FC) between 1861 and 1960 in each bioregion i has been calculated distinguishing between consumption among areas with access (FC_{it}^{A}) and areas without access (FC_{it}^{NA}). In the areas of each bioregion with access, consumption has been calculated as follows:

$$FC_{it}^{A} = FC_{it-1} \cdot p_{it} \cdot m_{it} \cdot r_{ts} \cdot w_{it} \qquad t=1860,1861\ldots 1960 \qquad [1]$$

And in areas without access, as follows:

$$FC_{it}^{NA} = FC_{it-1} \cdot p_{it} \cdot (1 - m_{it}) \cdot w_{it} \qquad t=1860,1861\ldots 1960 \qquad [2]$$

Where p is a factor that accounts for year-on-year population, m is the percentage of the population with access to modern energies, and r a replacement of traditional with modern energies, to which we apply two speeds (s) as stated before. The series has also been adjusted to the average annual temperatures of the different regions, considering that in the coldest years consumption would have been higher. Hence, where w is variation in consumption owing to annual temperature changes[7].

In short, total consumption between 1860 and 1960 can be broken down as follows[8]:

$$FC_{it} = FC_{it}^{A} + FC_{it}^{NA} \qquad [3]$$

From the year 1960 and subsequently we have made use of official statistics to take the data series up to the year 2010 in the case of forest firewood. Strictly speaking, the official statistics have been used since 1973, since prior to that they continued to present reliability problems. We have connected our series in 1960 with the official data in 1973 using the variation rates given in the official statistics but not their absolute values[9]. Hence, the consumption data series between 1961 and 1973 has been calculated as follows:

7. In the case of w, we use a simple criterion to capture annual temperature variability in the series. We assume a percentage variation of total annual consumption in each bioregion equal to its percentage variation in the annual temperature over the historical average temperature (*i.e.*, a -1% variation in temperatures in year t for region i over the historical average temperature of this region modified +1% of total firewood consumption for that year). Annual temperature series have been taken from BRUNET *et al.* (2007).

8. The model is validated by estimating the production available in 1930 and 1960 according to the data for the different judicial districts, as detailed in INFANTE-AMATE and IRIARTE-GOÑI (2017).

9. More details can be found in INFANTE-AMATE and IRIARTE-GOÑI (2017).

$$FC_j = FC_{j-1} \cdot a_j \qquad t=1961,1962\ldots 1973 \qquad [4]$$

Where a is the variation in firewood consumption reflected by the official statistics.

In the case of woody crops, we follow Infante-Amate *et al.* (2014), providing an estimation of firewood production and the share used for energy purposes.

We test our new estimation (from 1960) for the single year 2010. IDAE (2011) carried out for this year the largest survey on household energy use (based on *c.* 10,000 personal and phone inquiries), providing data on fuelwood use. Its results validate our estimation.

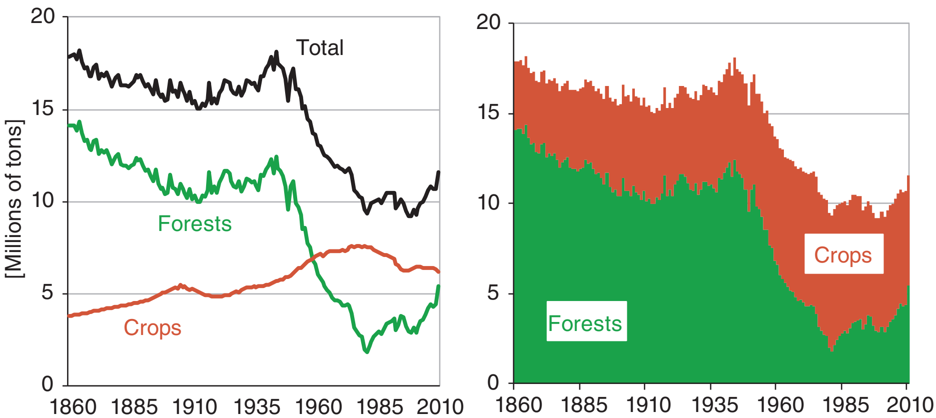
4. THE NEW ESTIMATION: RESULTS AND DISCUSSION

Main results are given in Figure 2 and reveal a three-stage evolution: the first stage runs from 1860 until approximately the First World War, showing a slight decline in total consumption in absolute terms, but a fast decline in per capita terms; the second stage goes from 1914 to 1950, during which time absolute consumption stops falling and even increases at certain points, and in which per capita consumption continues to fall although at a somewhat slower rate; finally, there was a stage of rapid abandonment of firewood in the 60s and 70s, which ended with subsequent stabilisation at lower levels albeit with certain upswings, and with the maintenance of per capita consumption from the 80s onwards.

Figure 3 provides details regarding the decline in firewood consumption on a territorial scale between 1860 and 1960, which help to provide a better understanding of the process. Between 1860 and 1913, firewood consumption fell steadily from 17.8 to 14.7 million tonnes (a decline of 17.3%). The energy transition began to occur guided by the basic elements that were driving it elsewhere in the Western world, in other words urbanisation, relative energy prices and processes of technological change that affected industry (steam-powered machinery, turbines, electric or combustion engines) and domestic consumption (cookers, heaters and heating systems) (see Allen, 2012; Kander, Malanima & Warde, 2014; Fouquet, 2008). In Spain, however, the replacement of firewood up to the First World War was slow for three reasons. The first, and perhaps the most important, was that a large part of the territory that still had considerable population levels during this period remained outside distribution circuits for new energies. In fact, in the year 1913, over ten million people continued to depend exclusively on firewood. The second reason was that, even in areas that gradually gained access to new energies, the adoption thereof was only partial. Hence, although during this period firewood consumption per inhabitant declined greatly in urban areas (from 2.82 to 0.66 kg inhab^{-1} day^{-1}), absolute consumption remained practically constant, and might even have risen slightly during certain moments when the increase rate of the urban population was higher than the rate of firewood replacement for coal (Figure 5c)[10]. Thirdly, focusing on the industrial world, in Spain the synergies between industrialisation and energy change, although they existed, generated a slow growth loop. On the one hand, the country's low coal provisions (Sudrià, 1987) and exterior restrictions (Tirado & Herranz, 1996) prevented a greater supply of modern energy; on the other hand, the slow rate of industrialisation, which was largely focused in Catalonia, generated a relatively low demand in the country as a whole, which impeded a faster transition (Sudrià, 1997). An additional aspect that should be highlighted in this first period is that it saw the timid but steady replacement of firewood from forest sources with firewood taken from crops, which palliated, particularly in Mediterranean areas, the scarcity of firewood generated by deforestation (Figure 4).

FIGURE 2

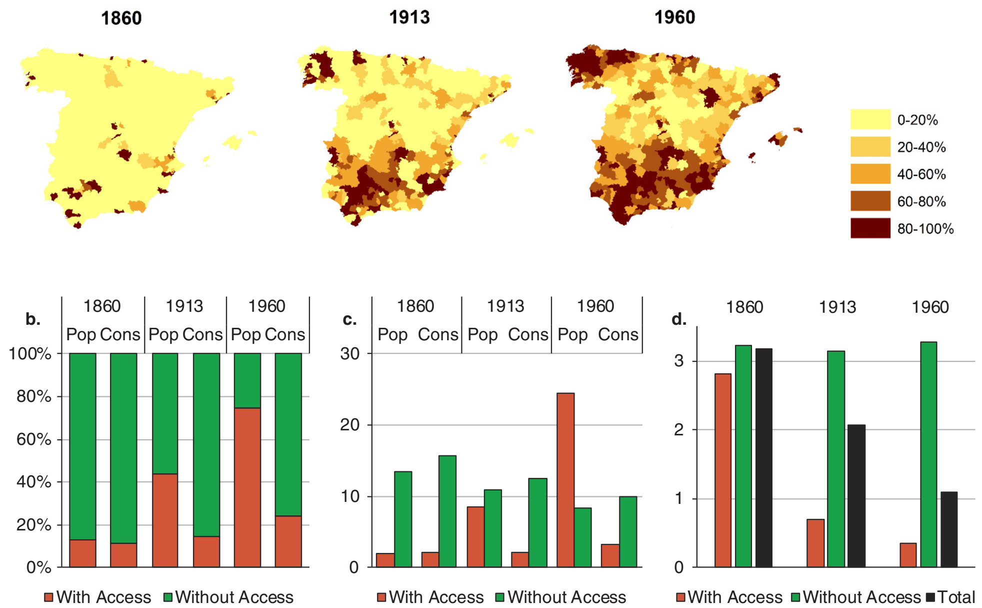
Total firewood consumption in millions of tonnes



Source: Infante-Amate and Iriarte-Goñi (2017).

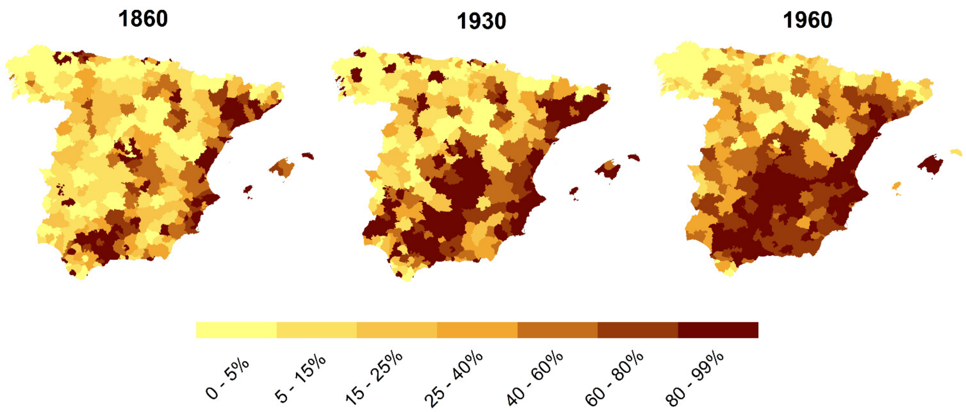
10. To put it another way, when, in equation 2, variable *p* is higher than variable *s*.

FIGURE 3
Maps of 1860, 1913 and 1960 showing populations with and without access to new energies (a); population and consumption with and without access to new energies in percentage terms (b); in millions of inhabitants and tonnes (c); and in consumption per inhabitant (d)



Source: Infante-Amate and Iriarte-Goñi (2017).

FIGURE 4
Percentage of firewood appropriated from cropland over total firewood appropriation



Source: Infante-Amate and Iriarte-Goñi (2017).

In 1914, the trend in firewood consumption in Spain unmistakeably changed, and for over four decades it either increased or remained stable. It was not until 1955 that the level of absolute consumption (14.5 million tonnes) fell to the level of 1913 (14.7 million), although per inhabitant consumption continued to fall owing to population growth. The reasons for this behaviour can be found in the shocks created by the First World War and the Spanish Civil War. In the first case, although Spain was not involved in fighting directly, it was affected by its inflationist effects, which also affected coal. In fact, the prices of coal skyrocketed, and although they fell at the end of the war, they never returned to pre-war levels. Several studies have associated this shortage of coal from the 1920s onwards with a leap forwards in the energy transition towards electricity (Sudrià, 1997; Bartolomé, 2007; Betrán, 2005), but the data series developed here highlights a second effect on the transition, which has thus far been neglected: a return to firewood as an alternative energy source. This trend intensified owing to the second shock produced by the Civil War in Spain and the immediate post-war period. Bearing in mind the energy shortages during this period with almost no coal or oil imports, and the difficulties faced maintaining the basic electricity supply, it is easy to understand the upturn in firewood consumption, which in the most drastic times was even used to power cars using wood gas generators (Gómez Mendoza, 2000).

Figure 5 gives some additional clues about these processes, showing how between 1930 and 1960 absolute consumption declined in areas without access to new energies (areas that were losing population during this period), but rose in urban areas with access to modern energies, which shows the potential magnitude of this process. As for the origin of the firewood consumed, during this period, firewood taken from crops continued to increased, but in spite of this, it is highly likely that pressure on forest areas nonetheless intensified, in spite of state control and the reforestation activities taking place (Iriarte-Goñi, 2013). In fact, some evidence points to the fact that woodland masses were appropriated during this period at a higher rate than they were replenished in certain periods[11].

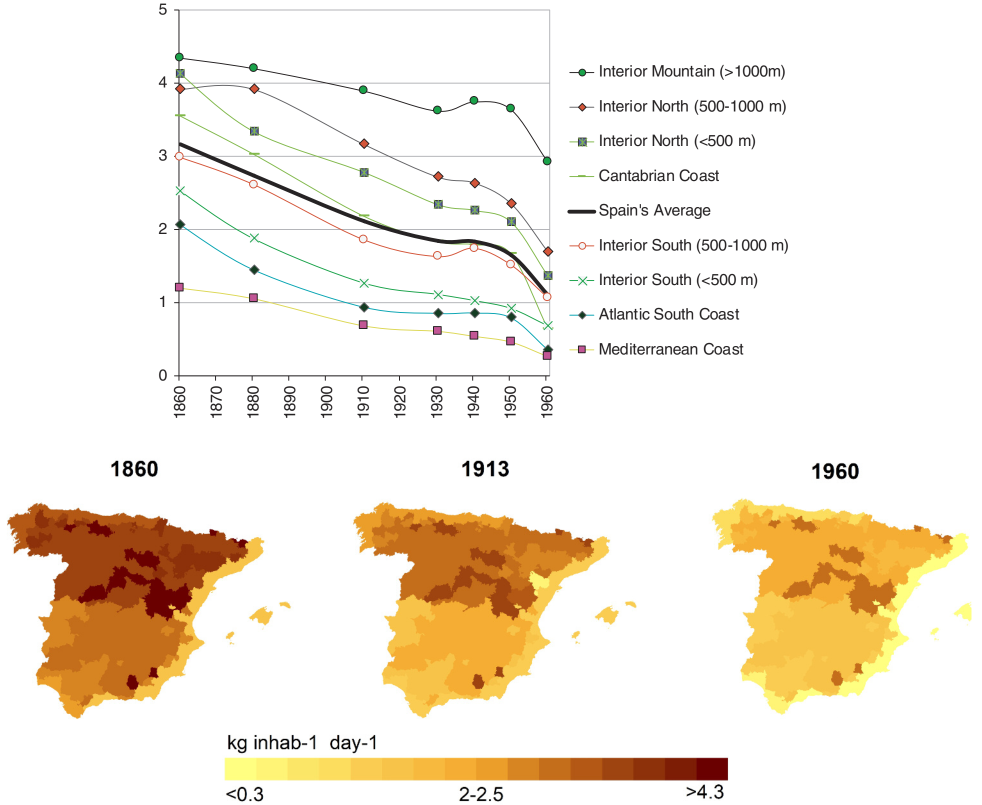
Figure 5 complements the picture of firewood consumption decline between 1860 and 1960, offering data in per capita terms broken down into the different bioregions. The process was faster and more intense in coastal areas, which were better connected, had a more concentrated urban population, and were the centres of much of the country's industrial development. The Mediterranean coast was clearly the least dependent on firewood from

11. In Infante-Amate and Iriarte-Goñi (2017) we show that appropriation was higher than production in the years of the First World War and also at certain points in Spain's post-war period, and consequently firewood stock fell slightly.

the start of the process, showing its advantage in the energy transition. The Cantabrian coast, on the other hand, initiated the process later, but experienced a more marked decline (from 3.56 down to 0.65 kg inhab^{-1} year^{-1} in extreme years). In the interior area of the north, consumption remained at high levels (above 3 kg inhab^{-1} year^{-1}) but the decline was steadier. Finally, in the country's mountainous areas (above 1000 metres) and in interior areas in the south, the curves are flatter, showing a slower rate of substitution, as well as a return to firewood that reached higher proportions that were even reflected in per capita terms. Economic reports from the late 60s show the energy gap between north and south, which may have been linked to this process[12].

FIGURE 5

Firewood consumption per inhabitant and per day in the eight bioregions defined in this study



Source: Infante-Amate and Iriarte-Goñi (2017).

12. Whereas in Madrid, 20% of homes had central heating, in the southern area, with major cities such as Seville and Malaga, this figure was only 1.2% (Banesto, 1969).

Finally, from the 1960s onwards, the decline in firewood consumption occurred at an increasingly accelerated rate. Initially, the rapid decline can be explained principally by the reduction in the population in areas without access to new energy networks, which occurred for two complementary reasons. On the one hand, the rural population declined as urban employment demand increased, whilst at the same time farming work became increasingly mechanised. On the other, the possibilities of the rural population accessing new energies increased. Although the rail network during this period was hardly extended at all, the road network did expand, linked to the early development of road transportation, which in turn allowed for the arrival of new energies in places that had until that point remained outside of the transition (Gómez Mendoza & San Román, 2005). The butane distribution network created from the late 50s onwards, together with the distribution of cookers and heaters powered by butane gas, played a vital role at this time. The transition sped up over the subsequent years, as new technologies for using modern energies in the domestic sphere appeared and became more widespread, including centralised heating systems as well as the total electrification of the country. The low oil prices maintained artificially in Spain practically until 1978 (Sudrià, 1997) facilitated this replacement. From the early 80s onwards, however, the rise in energy prices and the search for alternatives in biomass have halted the decline, maintaining a certain level of consumption.

This process affected different types of firewood differently (Figure 4). Firewood from forest sources was most affected by the decline (specifically, between 1950 and 1980, the annual average decline was 1.3%, the fastest in history), owing to the greater cost of obtaining and transporting this firewood. However, in the case of firewood from crops, the decline was much more moderate. This is explained by the very nature of the appropriation of its firewood flows, which had to be carried out regularly in the form of pruning, not for use as a source of energy but as a required management process for the correct production of fruit. As a result, every year millions of tonnes of firewood become available, which must be processed and can be used as an energy source, more so before the appearance of recent technologies that allow it to be shredded on the farm, for example (see Infante-Amate, 2014). To this we must add the growing use of firewood derived from the waste products of the timber industry, whose production has increased substantially since the 1970s, and part of which can also be destined to the production of energy.

In any case, firewood originating from crops and from forest by-products are increasingly being used with much more efficient technologies (see Goldemberg & Coelho, 2004). The modern uses of bioenergies are not only limited to firewood biomass but also to the biomass of other non-firewood crops and by-products (straw, industrial crops…). According to current statistics, the biomass energy consumed for energy purposes has grown hugely over the past two decades, and its current levels have even surpassed the level of consumption documented here for the mid 19th Century, and, probably, any historic consumption. In other words, the abandonment of firewood has not necessarily implied an abandonment of biomass for energy purposes owing to the increase in the use of certain crops to generate fuels or electricity.

5. CONCLUSIONS

This paper reconstructs a data series for firewood consumption for the whole of Spain over the very long term, adding new regional evidence and differentiating between different types of firewood according to its origin from forests or crops. Although it would be wise to continue exercising caution, especially with regard to estimations pertaining to the 19th Century, we believe that this estimation improves on previous ones and provides information of interest to open the black box of the energy transition process, in which firewood is usually cast in an irrelevant and anachronistic role, which contrasts with the fact that in many parts of the world, including in certain industrial countries, its consumption is still vital to energy supply.

Our estimation considerably increases the levels of firewood consumption, particularly for the mid 19th Century. However, it offers figures that are consistent with those calculated for other areas in Europe, and which are also coherent with the economic situation of a country that, although growing in economic and population terms, at least from 1840 onwards, was barely using fossil fuels in 1860. The regional breakdown of figures offered here also shows that levels of consumption were very disparate, depending on the geographic and economic features of different parts of the country.

The evolution of long-term consumption went through four major stages, which adds complexity to the flat account attributed to firewood in narratives of the energy transition. Up to the First World War, a gradual but continual decline was observed, which can be attributed to the entry of coal into the market. However, the transition process was very partial, mainly because over half the country was excluded from the commercialisation circuits of new energies. Furthermore, even in urban areas that did have access to modern energies, firewood never disappeared completely. Between 1914 and the mid 1950s, the consumption of firewood stopped falling and evenexperienced the occasional upturn at certain times, owing to the energy shocks generated by the Great War and then later by the Civil War, and the autarchic post-war period. This situation led to a return to firewood that halted the energy transition process. In fact, consumption did not collapse until practically the 60s, when the rural exodus and greater accessibility to new technologies the length and breadth of the territory permitted it. From the 80s onwards, a new upsurge was observed in consumption, explained by the modern use of biomass as a source of energy, which becomes even more important if we include non-firewood bioenergies, seemingly pointing to a new stage of consumption.

The origin of the firewood used (forest or crops) played an important role in the evolution of consumption. In fact, firewood from grapevines, olive groves and fruit trees reached high percentages, and its consumption surpassed that of firewood from forests from the 60s onwards. The increase in crop firewood did not prevent deforestation (in fact, some forest areas may have been uprooted precisely to plant these crops), but the increase in the land area and the firewood productivity of these crops may have contributed to lowering pressure on forests that, if this alternative source of firewood had not existed, could have suffered greater deterioration. The particular importance of firewood crops in Southern and Mediterranean Spain indicates a unique Mediterranean pathway to transition to new energies.

Finally, although this estimation improves our knowledge about the role played by firewood in the energy transition process, there are still many questions left open, such as: the differences in consumption according to different sectors and social groups; the specific effects of the slowness of the firewood replacement process on forests of different regions; and the renewed role of energies from biomass in recent decades.

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