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Energy transition in Agri-food systems. Structural change, drivers and policy implications (Spain, 1960–2010)

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ABSTRACT

This paper analyses the use of energy in the Spanish Agri-Food System (ASF) between 1960 and 2010. It distinguishes between several different forms of energy (renewable, non-renewable, final and primary), six sectors and up to a hundred activities. The use of energy in the AFS increased 10.2 fold during the period analysed, from 181 TJ to 1855 TJ, between 1960 and 2015. In the first stage, up to 1985, agriculture accounted for the majority of new consumption. However, from that date onwards, consumption in other sectors such as transport, packaging and homes grew at a faster rate. A decomposition analysis reveals that the increase in activity in the sector, in other words managed biomass, explains 46% of the increase in the use of energy, whereas the rest is explained by losses in efficiency, chiefly losses in efficiency within a sector that requires a greater amount of resources per biomass produced. The final energy consumption of the AFS over the total consumption of the economy represents 19.6%, suggesting a significant potential of agri-food policies as means of reducing the use of energy.

1. Introduction

Among the great transformations taking place during the recently coined Anthropocene age is the way in which we produce and consume food (Tilman and Clark, 2014; Steffen et al., 2015). Food is the activity through which we meet our endosomatic energy needs (Lotka, 1956). Nevertheless, food production and consumption also require energy investments. Improving the ratio between energy invested and produced in food systems has been, and still is, a fundamental challenge to guarantee food and energy security (Pimentel and Pimentel, 1979; Pelletier et al., 2011).

From an energy standpoint, we can distinguish between two major transformations in agri-food systems (AFS) in the rise of the Anthropocene: Firstly, the industrialisation of agricultural production has led to unprecedented levels of agricultural production, as well in land and labour productivity (Federico, 2005). However, a large part of this success has relied on a growing dependence on energy intensive external inputs (both as direct consumption and as indirect consumption of non-caloric inputs, e.g. chemical fertilisers) (Gingrich et al., 2017). Today, the high dependence of world agricultural production on external inputs is one of the main threats to its future sustainability (IAASTD, 2008; IPES-Food, 2016): on the one hand, due to the growing scarcity of some key resources such as oil or phosphorus (Cordell et al., 2009; Murray and King, 2012); on the other hand, due to other associated impacts such as the emission of greenhouse gases, eutrophication, losses of biodiversity, social conflicts, etc. (e.g. Dutilh and Kramer, 2000; Wenar, 2015).

Motivated by these concerns, several authors began studying the energy balances of agricultural systems in the 1970s (e.g. Leach, 1976; Pimentel and Pimentel, 1979). This research revealed that the new methods of agricultural production were less energy efficient and that they increasingly depended on fossil fuel-based inputs, in the form of fuel, electricity and agrichemicals. Although the energy production of the agroecosystem had grown during a century of agricultural industrialisation throughout most of the world, it had done so at a slower rate than energy consumed (e.g. Cleveland et al., 2005; Gingrich et al., 2017; Guzmán et al., 2017). Nevertheless, over the last few years this trend might be changing in some countries, and even worldwide (Harchaoui and Chatzimpiros, 2018; Pellegrini and Fernandez, 2018).

The second great transformation has to do with the new economic activities that have been developed between agricultural production and the final consumption of food. 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 farm (Davis and Goldberg, 1957). The gap has continued to grow over recent decades between the concept of "agricultural product", which is understood to

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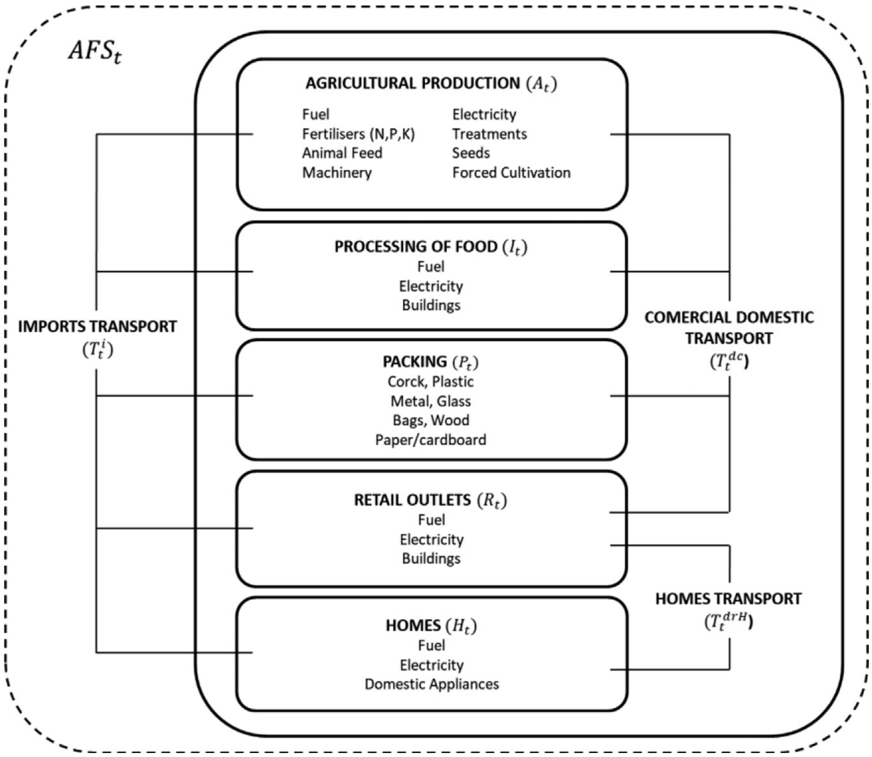

Fig. 1. Scope of the study. Energy flows examined.

be the output derived from the production of the agricultural sector, 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).

In the 1970s, two papers were published in *Science* analysing energy consumption in the US AFS as a whole (Hirst, 1974; Steinhart and Steinhart, 1974). They exposed how in a short period of time not only did the agricultural production witness dramatic transformations but also the rest of the food system. Energy use in food-related industries, commerce, and household activities increased fourfold between 1940 and 1970. Recently, some articles have studied energy use in the current AFS in the USA (Heller and Keoleian, 2003; Canning et al., 2010) and Spain (Infante-Amate and González de Molina, 2013). They highlight that off-farm activities in modern AFS are responsible for between 70% and 80% of total AFS energy use, emphasising the need to pay attention to what happens away from the farm when studying energy demand in agri-food-related activities. This evidence helps to explain the rise in new theories such as Food Regimes (e.g. McMichael, 2013). From a biophysical perspective, a large body of research is emerging, calculating energy uses in stages of the agri-food chain beyond the farm gate. The case of transport is the most recurrent (e.g. Martinez et al., 2010). Under the idea of "food miles", estimations of transport-related energy use in food systems have multiplied, generating on-going debates about the relationship between the distance travelled per product and energy consumption (e.g., Schlich and Fleissner, 2005; Martinez et al., 2010). A great number of studies have also estimated energy use throughout the entire agri-food chain in specific products based on Life Cycle Assessment (LCA) methodologies (e.g. Roy et al., 2009; Clune et al., 2017).

All of this evidence has improved our understanding of the energy use/agri-food nexus. Yet, there is still a lack of evidence on how the rise of the modern AFS has taken place from an energy standpoint and the implications behind that growth curve. In other words, we barely know how the use of energy evolved in the AFS during the transition from traditional (mostly organic and local) to modern systems (mostly industrial and globalised). This article seeks to bridge that gap, by quantifying for the case of Spain the energy use in different levels of the agri-food chain in the long term. We analyse three different benchmark years (1960, 1985 and 2010), covering the period in which the major socio-ecological transformation has occurred in this country (Infante-Amate et al., 2015).

Our goal is threefold: (i) to provide an initial approach to the role of the AFS in the rise of the Anthropocene by estimating the energy weight of AFS activities in the economy as a whole, and how it has evolved over time; (ii) to better understand how the energy transition has taken place in the case of food systems, identifying major structural and technological changes, as well as main drivers; and (iii) to assess the potential of food policy as energy policy. Most programmes aimed at reducing the use of energy tend to focus their actions and recommendations on economic sectors as compiled in energy statistics (i.e. households, transport, industry…). Nevertheless, certain transversal activities such as those related to food, may lead to substantial reductions of energy use in different economic sectors at the same time. By estimating the weight of AFS energy use and identifying major hotspots of consumption, we can better understand the potential of food policy in the reduction of energy use.

2. Methodology, sources and scope of the study

The scope of the study refers to energy consumption of the Spanish AFS in the years 1960, 1985 and 2010, following the proposal developed by Infante-Amate and González de Molina (2013) for the case of Spain, which was based on Heller and Keoleian (2003). This research, therefore, does not measure the energy embodied in food intake in Spain, but instead analyses the energy consumption of agri-food activities taking place in the country.

We break the AFS down into six main economic sectors as shown in Fig. 1. Therefore, total energy use by *AFS* in year *t*, can be expressed as the sum of energy used by every sector:

$$AFS_t = A_t + I_t + P_t + R_t + H_t + T_t \quad (1)$$

Where *A* is energy use in the Agriculture sector, *I* in Processing, *P* in