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Widening the analysis of Energy Return on Investment (EROI) in agro-ecosystems: Socio-ecological transitions to industrialized farm systems (the Vallès County, Catalonia, c.1860 and 1999)

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ABSTRACT

Energy balances of farm systems have overlooked the role of energy flows that remain within agro-ecosystems. Yet, such internal flows fulfil important socio-ecological functions, including maintenance of farmers themselves and agro-ecosystem structures. Farming can either give rise to complex landscapes that favour associated biodiversity, or the opposite. This variability can be understood by assessing several types of Energy Returns on Investment (EROI). Applying these measures to a farm system in Catalonia, Spain in 1860 and in 1999, reveals the expected decrease in the ratio of final energy output to total and external inputs. The transition from solar-based to a fossil fuel based agro-ecosystem was further accompanied by an increase in the ratio of final energy output to biomass reused, as well as an absolute increase of Unharvested Phytomass grown in derelict forestland. The study reveals an apparent link between reuse of biomass and the decrease of landscape heterogeneity along with its associated biodiversity.

1. Introduction

Agro-ecosystems are nature transformed by humans (González de Molina and Toledo, 2011; Haberl et al., 2004). When farmers invest labour, animal draught power, mechanical work, seeds, fertilisers and other energy carriers, they create a new cultural landscape from the existing ecosystem (Odum, 2007). Their creation and maintenance requires continuous investment of energy and information by human society, in addition to naturally occurring solar radiation and photosynthesis (Altieri, 1989; Gliessman, 1998). Although present agriculture relies on fossil fuels, food production will always depend on ecosystem services closely linked to biodiversity, such as fresh water, pollination, biological pest control, N fixation, etc., which cannot be substituted by technical capital (Giampietro, 1997).

Economic analyses of agriculture not only dismiss the role of fossil fuels in agriculture, due to their low relative price, but also overlook the non-marketed energy flows of internal biomass reuses and the role that unharvested biomass plays for non-domesticated species (Martinez-Alier, 1997). An assessment of Energy Return on Investment (EROI) (Hall, 2011) measures the energy efficiency of an energy-gathering system. Expressed as a ratio, EROI compares a system's energy output to its energy input. As long as modern agriculture depends on fossil fuels for its largest energy input, the world food supply remains vulnerable to an eventual reduction in oil supplies (Campbell and Laherrère, 1998; Deffeyes, 2001). Understanding the energy efficiency of agricultural systems is important, whether oil's ultimate decline results from depleted supplies or from voluntary reduction in the face of climate change (Arizpe et al., 2011; Giampietro et al., 2013; Hall, 2011; Murphy and Hall, 2011; Scheidel and Sorman, 2012).

Abbreviations: EROI, Energy Return on Investment; GCV, Gross Calorific Value; NPP, Net Primary Productivity.

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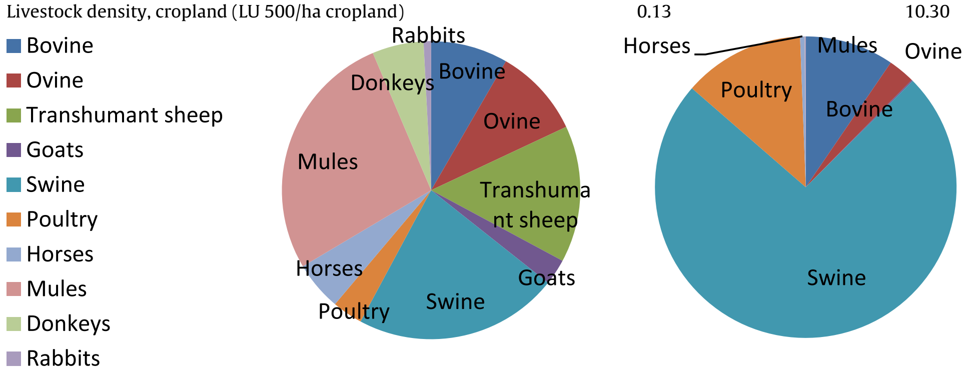
Table 1
Characteristics of Vallès County farm systems, c.1860 and 1999. (For interpretation of the references to colour in this table, the reader is referred to the web version of this article.)

	1860	1999
Inhabitants (number)	7941	39,189
Population density (cap/km2)	64	327
Full-time farm workers, annual average (number)	2057	250[a]
Installed power (kilowatts)	289[b]	12,065
All livestock, LU 500 (number)	870	22,465
Livestock density, total area (LU 500/ha all land)	0.07	2.41
Livestock density, cropland (LU 500/ha cropland)	0.13	10.30



Source: Tello et al. (2015) and Marco et al. (forthcoming).
[a] 62% of agricultural workers in 1999 were family members without formal salary.
[b] From draft animals. Transhumant sheep stayed only half a year within the system.

Some studies have addressed the energy accounts of agricultural systems (Balogh et al., 2012; Bayliss-Smith, 1982; Campos and Naredo, 1980; Conforti and Giampietro, 1997; Giampietro et al., 2013, 1994, 1992; Leach, 1976; Odum, 1984; Pimentel and Pimentel, 1979; Pracha and Volk, 2011). While they all account for labour, fossil fuels and embodied energy in fertilizers, pesticides and machines, only those addressing pre-industrial agriculture take into account energy flows generated and also consumed within the agro-ecosystem. Examples include self-produced feed and straw for livestock and other energy carriers related to local fertility management practices. These internal energy flows are not normally accounted in monetary terms, nor do they appear in official farm statistics, making them difficult to quantify. However, internal energy loops were very important in past organic farm systems that used little or no fossil fuels (González de Molina and Guzmán, 2006; Naredo, 2004; Tello et al., 2012). Remembering that agriculture's main purpose is to produce food, fibre and fuel, an assessment of agriculture's energy efficiency in a scenario without fossil fuels requires acknowledging the multifunctionality of past agrarian systems. How much of the biomass produced was reused within the system? What other products did farmers extract from non-cultivated areas of the farm system?

This paper compares a past organic[1] farm system that did not use fossil fuels with one today that utterly depends upon them. Doing so requires taking into account internal flows usually neglected in EROI assessments of modern farm systems. Performing a wider comparison of the energy profiles of organic and industrial farms systems necessitated the development of a set of several different EROIs, instead of a single one. We based these EROIs in an empirical case study that presents these EROIs for the farm systems in four villages of the Vallès County in Catalonia, Spain, in 1860 and 1999 (Tello et al., 2016).

Vallès County had a higher EROI in 1860 than in 1999, as expected, and the wider analysis revealed two contrasting strategies, one relying on biomass reused (in 1860) and the other on external inputs (in 1999). These external inputs were mainly livestock feed imports to sustain the present specialisation in feedlot meat production, which is tightly linked with a global agri-food system that depends on the availability of cheap fossil fuels.

Section 2 introduces the case study location, describes agro-ecosystem energy inputs and outputs, and explains the EROI formulas. Section 3 presents the EROI results for this case study. Section 4 discusses those results while Section 5 outlines some general conclusions and opportunities for future research.

2. Case study description, concepts and methods

2.1. Sources and description of the case study

The Vallès County study area is a small plain situated in a tectonic basin between Catalonia's littoral and pre-littoral mountain ranges in northeastern Spain. Its diverse geological substrata and precipitation above the Mediterranean average (600–800 mm) created a considerable variety of soils with a broader range of agricultural possibilities than in drier parts of the country (Olarieta et al., 2008). The area has always been well-connected to Barcelona, just 35 km to the south, and its commercial and demographic dynamics, even in the nineteenth century when the trip took between 5 and 12 h on horseback (Cussó et al., 2006a).

The data for this study comes from four villages in Vallès County: Sentmenat, Polinyà, Caldes de Montbui and Castellar del Vallès (Fig. 1). For previous research about the area, see Cussó et al. (2006a, 2006b), Marco et al. (forthcoming) and Tello et al., 2015.

From 1860 to 1999 forest and scrubland increased to 55% and cropland decreased by 67% (Fig. 2). The main crop cultivated in 1860 was vineyards, which, after the Phylloxera plague, had almost disappeared by the beginning of the twentieth century (Tello and Badia-Miró, 2011). Built up and agriculturally unproductive area had increased by an order of magnitude in 1999 due to urbanization. Grassland occupied little area in 1860, as was typical in Mediterranean regions, but decreased to even less in 1999 with the reduction of grazing livestock such as sheep (Table 1).

[1] In this paper, we use the term örganicïn the sense introduced in the classical work of Wrigley (1988) to distinguish land-based energy economies from fossil fuel-based energy economies.