Ecological Modelling 315 (2015) 28–36

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Scales of renewability exemplified by a case study of three Danish pig production systems

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ARTICLE INFO

Article history:
Available online 20 May 2015

Keywords:
Emergy assessment
Renewable inputs
Renewability fraction
Local resource use
Livestock systems
Pig production

ABSTRACT

Environmental indicators are increasingly defined and applied to estimate the human impact on nature and to evaluate human resource use. When considering the environmental impact of food production systems, there is a need to include the impact on different spatial scales. At present, emergy assessments do not, in general, consider global versus local origin of purchased goods. To provide a more detailed picture of how production systems perform with respect to different spatial scales, we expand the renewability concept with a set of indicators that categorise purchased goods according to their geographical origin being within system boundaries (on-site), from local sources, or from non-local sources. An emergy assessment of the resource use for production of pigs (measured as live weight of pigs sold) from three Danish pig production systems (organic small (OS), organic large (OL) and conventional (C)) exemplifies the use of this set of indicators. The results show that at the on-site scale the pig production systems had about the same fraction of renewable inputs of less than 0.5%. However, when the renewability fraction of inputs was accounted for at the global scale, the two organic systems were more renewable (about 20%) compared to the conventional system (13%). Further, local input represented the largest part of the input to OS (66%), while OL had the largest non-local input (74%). This demonstrates that the set of indicators is able to evaluate different strategies for purchasing goods and thus emphasises the importance of accounting for inputs from society differently depending on spatial scale.

1. Introduction

Feeding a growing global, human population on a diet increasingly based on meat will require huge amounts of productive land, water and energy, which are already scarce resources (FAO, 2009; Godfray et al., 2010; Shah, 2008). Recent studies suggest that food production needs to increase by 70% within the next 50 years, so this will be a severe challenge (Godfray et al., 2010). Resource requirements associated with increasing consumption of meat constitutes an increasing concern for global sustainability and environmental damage (FAO, 2006). Environmental performance and resource use of pig meat production has been evaluated using Life Cycle Assessment (LCA) (Basset-Mens et al., 2007; Cederberg and Flysjö, 2004; Nguyen et al., 2012; Stern et al., 2005). Emergy assessment (EmA) is another useful tool to compare environmental impact of different farming systems by accounting for all flows of energy and materials in a common unit of solar equivalent joules (seJ) (Brown and Ulgiati, 2002). It accounts for the total available energy (exergy) directly and indirectly required to make a product or service. This includes the three main natural energy flows that drive the biosphere (solar radiation, deep earth heat and tidal energy) and stock resources required for manufacturing products and providing labour and services. In contrast to other sustainability assessments it is an upstream approach, which includes all forms of energy including the contribution of nature to a product or service (Odum, 1996). Only few emergy assessments have evaluated sustainability of livestock systems, e.g. for poultry (Castellini et al., 2006; Zhang et al., 2013), for cattle (Alfaro-Arguello et al., 2010) and for pigs (Cavalett et al., 2006; Rugani et al., 2010).

A central feature of EmA is the ability to account for inputs of annual renewable flows to a process or product. The global use of non-renewable resources, accounted in seJ, has increased significantly during the past century (Brown and Ulgiati, 2011) which calls for a need to evaluate the use of renewable resources in more detail. In EmA the renewable input is determined by the direct energy flows from sun, rain, wind, geothermal heat and tidal energy meaning annual renewable flows received by Earth in a flow limited amount which cannot be increased (Odum, 1996). These are usually termed local renewable flows to the area of production within the system boundary. This practice does not account for the

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http://dx.doi.org/10.1016/j.ecolmodel.2015.04.018
0304-3800/

renewability of resources embodied in inputs at the place of origin and thus underestimates the renewability of, e.g. agricultural production. An expanded concept of renewable flows of input at different spatial scales has not been analysed in detail. However, renewability of inputs at the global scale has been applied in a number of previous emergy assessments (Agostinho and Ortega, 2012; Cavalett et al., 2006; Felix and Tilley, 2009; Kamp and Østergård, 2013; Ortega et al., 2005; Paoli et al., 2008; Ulgiati et al., 2005).

Increased global trade has decoupled livestock from the supporting natural resource base leading to uncompensated environmental effects of livestock production, such as degraded water quality biodiversity loss or nutrient depletion (Marsden, 2012; Naylor et al., 2005; Sundkvist et al., 2005). Livestock production may need increasingly to rely on renewable and local resources in order to become more sustainable and less dependent on the volatile global market. Analysing systems within a strict and narrow system boundary ignores how systems are attached to a larger economy be it local, regional or global, where input and output are exchanged in a network. To evaluate production systems properly, we need to know not just the amount of resources used, but also where they come from geographically, i.e. within the system boundary (on-site), from the neighbourhood (local) or from the global scale. The use of different scales applied in this study includes an assessment of certain characteristics of the economy in which a production is embedded and allows for evaluation of how dependent production systems are on the global market. This reveals the degree of self-sufficiency of an agricultural system and helps to clarify to consumers what is behind the product they buy. Import, especially of feed, increases the fossil fuel use through transportation and leads to disturbances of the global nutrient cycles and balances such that some environments are suffering from nutrient abundance while others are depleted (Grote et al., 2005; Naylor et al., 2005; Pengue, 2005).

The aim of this paper is to develop and apply a scale dependent division of input flows in order to be able to understand and evaluate different strategies for using renewable and non-renewable resources as well as local and global resources. We introduce a set of new indicators related to different geographical scales: Within the system boundary (on-site), from local sources, or from non-local sources. An emergy assessment of the resource use for production of pigs (measured as live weight of pigs sold) from three Danish pig production systems (organic small (OS), organic large (OL) and conventional (C)) exemplifies the use of this set of indicators.

2. Materials and methods

2.1. The case study: three pig production systems

The analysis was based on three Danish pig farms using different management strategies (Table 1). Data for the two organic farms, OS (organic small) and OL (organic large), were collected in the year 2011. Data for the conventional farm, C (conventional), were from the year 2012 due to on-farm restructuring in 2011. Data were collected through single interviews with the farmers at all three farms in Jutland and on Funen in November 2012 and additional data were collected by email in the spring 2013.

The farm OS kept 300 breeding sows and sold all pigs for slaughter at about 110 kilos (denoted finishers); most feed was grown on the farm. OL kept about 1300 breeding sows and sold some pigs for fattening at 30 kilos (denoted weaners) and some for slaughter at 115 kilos; all feed was bought. OL additionally sold older breeding animals (a mix of sows, gilts and boars). For the organic farms, feed input was organic and the pigs foraged freely on outdoor areas or in a stable with a straw covered floor. C kept 1000 breeding sows and mainly sold piglets and weaners for fattening elsewhere and also a few finishers and older pigs. All pigs were kept indoors and fed with conventionally grown feed, which was either grown on the farm or bought. Common for all three farms was that they kept pigs at several locations. The breeds in the three production systems were combinations of traditional Danish Landrace, Danish Yorkshire and Danish Duroc.

The chosen system boundaries included all area directly related to the pig production system, i.e. stables and in case of the organic systems also outdoor areas for foraging. Feed, however, was considered an external input in all three systems (Fig. 1). Output was calculated in mass (grams of live weight). The output of manure was not considered.

2.2. Emergy assessment

Emergy may be referred to as 'energy memory', as it is the available energy (exergy) previously used up, directly or indirectly, in the transformation of one kind of energy to another (Odum, 1996). All input flows to a system are multiplied by their transformation factor or Unit Emergy Value (UEV) to evaluate the emergy invested and all flows are summed to evaluate the total emergy use (U).

The emergy use of a studied system is traditionally divided into three different categories: local renewable resources (R), local non-renewable resources (N) and feedback from the economy (F), which is again split into purchased materials (M) and direct and indirect labour (L&S) (Fig. 1). Direct labour is the so-called foreground labour directly controlled by the operator of a process while indirect labour (service) is the labour required for producing the inputs and thus not directly controlled by the operator (Ulgiati and Brown, 2014).

2.2.1. Definition of on-site, local and non-local renewability

In EmA, all inputs from outside the system boundary (F) are usually considered non-renewable. However, important information is lost when this generalisation is used and the renewable flows are not accurately accounted for in a world where production is a part of complex network interactions in production chains. The inputs

Table 1
Schematic overview of the main differences of the three production systems.

	OS (2011)	OL (2011)	C (2012)
Management	Organic	Organic	Conventional
Breeding sows	300 (outdoor/stable)	1300 (outdoor/stable)	1000 (stable)
Feed	Organic	Organic	Conventional
Protein feed	Soybean meal, sunflower and rapeseed	Soybean meal, sunflower and rapeseed	Soybean meal and pig fat[a]
Heating	None	None	Oil and straw
Feed	Mainly on farm	Bought	On farm and bought
Number of locations	2	7	4
Output	Finishers	Weaners, finishers, sows, gilts and boars	Piglets, weaners, finishers, sows, gilts and boars
Pigs sold (tons live weight)	687	2391	751
Production area	27 ha	99 ha	15 ha

OS = Organic Small production system; OL = Organic Large production system; C = Conventional production system.
[a] Input of pig fat has been included as soybean meal.