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ENERGY ASSESSMENT OF A MIXED DAIRY CROP-LIVESTOCK SYSTEM: CASE STUDY OF THE EXPERIMENTAL DAIRY UNIT OF INIA – LA ESTANZUELA, URUGUAY

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Abstract: The dairy sector is facing difficulties in its environmental sustainability. A method is presented to assess sustainability based on the analysis of energy flows, with a particular focus on circularity. The results show that intensive dairy production systems, even those based on grazing, present an unbalanced situation in flow circularity and mobilizing more resources than they provide. This type of analysis is a first step in the research of sustainable solutions for the dairy sector, and where the measurement of carbon and nitrogen flows would be complementary.

Key words: Circularity; Agroecosystem; Sustainability; Efficiency

Introduction

The dairy production sector is facing important challenges. It must continue to supply food for a growing population and reduce its environmental impact (FOLEY *et al.*, 2011). In addition, global warming calls for new strategies to reduce its negative effects on the dairy sector. (GAULY; AMMER, 2020).

To apprehend the sustainability of the dairy farm system, energy assessment is a useful method to be applied. Energy use is strongly related to human activity and also a key factor for explaining ecosystem process (HERCHER-PASTEUR *et al.*, 2020). Recent development of the method have presented a circular perspective on energy assessment (GUZMÁN *et al.*, 2015).

The objective of this work is to assess sustainability of the dairy production system through energy analysis giving a special attention to the circularity of flows. The method is applied to an integrated crop-livestock dairy production system.

Materials and Methods

The case study concerns the experimental dairy unit station of the National Institute of Agriculture Research (INIA), Uruguay. The farm covers 247 ha, with 150 ha of temporary pasture, 34 ha of natural pasture and 34 ha of crops, with 413 livestock units.

The method is built through a systemic approach with four sub-systems: i) Cultivated biomass, ii) Domestic animals, iii) Facilities and tools, iv) Associated ecosystem (AE) (HERCHER-PASTEUR *et al.*, 2021). Biomass production is based on Gross Calorific Value (GCV) and external inputs on Cumulative Energy demand (CED) through a life cycle perspective and expressed in Gigajoule (GJ). Four indicators are mobilized:

$$(1) \qquad EROI = \frac{O_M}{I_M} \qquad\qquad (2) \qquad EROI_{Ag} = \frac{O_M + O_{AE}}{I_M + I_{AE}}$$

with O_M the sum of the outputs from the farm to the market and I_M the sum of the inputs from the market to the farm. *EROI* (Energy Return On Invest) represents the efficiency of the system. *Agroecosystem EROI* integrates the flows from and to the AE (i.e. its local agroecosystem), where O_{AE} is the sum of the outputs from the farm to the associate ecosystem and I_{AE} the sum of the inputs from the associated ecosystem to the farm.

$$(3) \qquad Circ_{in} = \frac{I_{AE}}{I_M + I_{AE}} \qquad\qquad (4) \qquad Circ_{out} = \frac{O_{AE}}{O_M + O_{AE}}$$

Inflow circularity (eq. 3) describes the portion of energy provided by the AE (i.e. soil mineralization) relative to the total energy consumed by the agroecosystem. It can be associated to an indicator of self-sufficiency which would reveal to what extent the farm system depends on flows coming from the AE. Outflow circularity (eq. 4) describes the portion of biomass left to the AE relative to the biomass exported and reinvested.

Results and discussion

Figure 1 represents the energy flow diagram of the case study. The largest flow is the biomass used for animal feeding (311189 GJ), followed by vegetal biomass residue (26590 GJ), manure (23628 GJ), and Services provided by the associated ecosystem (11679 GJ). The Main external input is the purchased feed (20650 GJ), when the flows going to the vegetal production is mainly due to nitrogen fertilization (1974 GJ of the 2615 GJ). Also, the consumption of energy carrier is principally due to electric consumption (1182 GJ of the 1728 GJ). Finally, milk and meat products exported out of the system represents 6928 GJ.

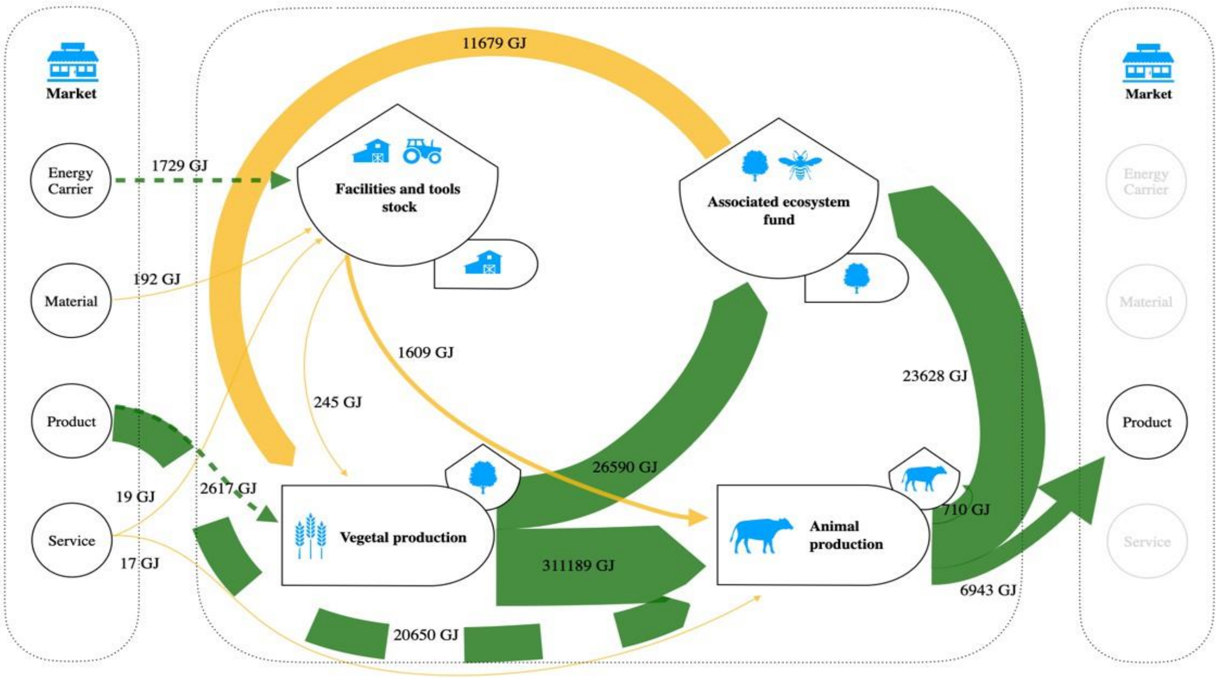

Figure 1: Energy flow diagram of the dairy farm case study. The larger of the arrows are proportional to the quantity of energy. The yellow arrow represents services energy flow and it is related to energy dissipation. The green arrow represents material and energy flows and it is related to physical flows.

Table 1 indicates the value of the different indicators mobilized. They are compared to three scenarios based on the paper of Hercher-Pasteur et al., 2021. The case study presents the lower EROI (0.28), meaning that it mobilizes more energy than it exports. The proportion of biomass reinvested into the system on the biomass exported is high (88%). Indeed, the presence of animal enhances biomass return into the associated ecosystem in comparison to intensive vegetal production. However, the high dependency on external flows could be a sign of unbalance situation ($Circ_{in}$32%). Indeed, biomass reinvested in the system is artificially boosted by animal feed external inputs, which can lead to nutrient losses.

Table 1: Indicators of the case study with simulated scenarios from Hercher-Pasteur et al., 2021

	Mixed-farming case study	Scenario 1: intensive breeding		Scenario 2: intensive vegetal production		Scenario 3: Diversified mixed-farming	
EROI	0.28	0.47	123 %	4.30	1113 %	2.22	575 %
Agroecosystem EROI	1.57	1.98	113 %	4.77	272 %	2.87	163 %
Output circularity	88 %	83 %		52 %		83 %	
Input circularity	32 %	29 %		47 %		78 %	

The case study follows the same trend as the intensive breeding production system with a better $Circ_{in}$ due to its pasture-based system. The diversified mixed-farming scenarios is based on a four year temporal pasture with three years of commercial crops. This last option allows combining animal circularity promotion and the efficient energy conversion of crops. Also reducing purchased feed would improve EROI and Input circularity.

However, it is important to note that the case study presents positive indicators of productivity (6400 L/hd) and of efficiency (stoking rate of 2 cows/ha), representing the most profitable production systems within the alternatives compared locally.

Conclusions

Agroecosystem energy analysis assess efficiency and circularity at the system scale considering both the farm activity and its associated ecosystem. The method is useful to describe flows of energy and material that compose the production system. Yet, it would be necessary to consider other flows such as nitrogen and carbon to have a full representation of the sustainability of the system. Diversification of the activity to reach better resource use efficiency apply new forms of organization and collaboration between the animal production sector and the vegetal production sector to maintain economic viability.

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