Multiple-perspective performance analysis of dairy production systems in Slovenia

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Abstract

The paper illustrates synergies between the socio-economic and emergy evaluation of agricultural activity by studying the dairy sector in Slovenia. Evaluation was performed on nine farm types, representing the diversity of the country's dairy sector. Results indicate that socio-economic evaluation favours larger conventional systems. Emergy analysis however, favours organic farms, which better exploit local resources and put less stress to the local environment. Socio-economic and emergy indicators show that small conventional farms are the poorest performers overall. Analysis of emergy flows reveals a high dependency of all farm types from the wider socio-economic system, suggesting a limited scope to improve their sustainability.

Keywords: dairy sector, sustainability, multiple-perspective evaluation, emergy

1. Introduction

Despite growing recognition that natural resources sustain the economy, they are largely neglected in the decision-making process at individual, corporate or government levels (Millennium Ecosystem Assessment, 2005). This finding holds true for all economic sectors but is especially significant when dealing with land-based sectors, such as agriculture. Rising demand for food, increasing resource scarcity, high market volatility and growing environmental pressures, challenge the agricultural sector not only to increase productivity, but to do so in a more sustainable manner (Godfray et al., 2010, OECD/FAO, 2012). To address these challenges, agricultural producers should take into account a number of factors with often conflicting objectives.

Decision-makers in agriculture should form decisions with respect to a diverse range of information, evaluation methods and decision support techniques. Many authors (e.g. Funtowicz and Ravetz, 1994, Gasparatos and Scolobig, 2012, Patterson, 1998) support the idea of methodological pluralism. Evaluating alternative decision options solely from a single perspective (either economic, or environmental), does not provide sufficient information for integrated and sustainable planning of agricultural production. Economic evaluation methods may be sufficient for assessing the functioning of economic and social aspects of human-dominated activities, however they have been argued to fail proper evaluations of ecosystem services and hence underestimate the contribution of natural resources to production processes (Brown and Ulgiati, 2011, Christie et al., 2006, Wilson and Howarth, 2002). Likewise, evaluation approaches that focus solely on natural flows and processes are equally inadequate for making assessment of economic performance. In order to integrate different aspects (e.g., economic, social and environmental) into decision-making in agriculture, several criteria and evaluation approaches need to be considered simultaneously (Conway, 1987, Kropff et al., 2001, Pannell and Schilizzi, 1999).

In this paper we attempt to integrate an economic and environmental evaluation of a selected agricultural activity. As agriculture is situated at the intersection of human-based activities and nature, both aspects should be regarded when considering its performance. This work investigates a multiple-perspective performance of agricultural activity, which is illustrated through the case of the milk production sector in Slovenia. Milk production makes a substantial contribution to the national agricultural output and can be regarded as the main agricultural consumer of natural resources in the country. Socio-economic analysis is applied at first to determine the economic performance (anthropocentric perspective) of nine different and sometimes contrasting milk production systems. Secondly, emergy analysis (Brown and Ulgiati, 2004, 2010, Odum, 1988, 1996) is used to capture an environmental viewpoint (eco-centric perspective) of the systems' functioning. This environmental accounting method has been applied extensively to agricultural systems (Alfaro-Arguello et al., 2010, Castellini et al., 2006, Lefroy and Rydberg, 2003, Rótolo et al., 2007), but rarely applied specifically to milk production (Bastianoni and Marchettini, 2000, Vigne et al., 2013).

2. Materials and methods

2.1 System characterisation

Slovenian agriculture is characterised mostly by a large proportion of small family farms (98%). Almost 75% of Utilised Agricultural Area (UAA) is characterised as Less Favourable Areas (LFA). Meadows and pastures represent 58% of agricultural land (SURS, 2012a). For this reason milk production is the predominating and most important agricultural activity in the country. According to the annual report of the Agricultural Institute of Slovenia (KIS, 2011a), milk production contributes 14% to the total value of agriculture, which makes Slovenia a net exporter of milk. In the last decade the sector witnessed intensive structural change that lead to concentration and specialisation, resulting in a substantial decrease in the number of dairy farms, a doubling of the average herd size, an increase in the milk yield and improved milk quality. Simultaneously with a 60% decrease in the number of dairy farms, the number of large dairy farms increased fourfold. Such changes are likely to continue, even more so due to the abolition of milk quotas in the EU in 2015 (European Commission, 2009). Nonetheless, Slovenian dairy farms are still relatively small (average 11 ha) with small herds (average 10 cows per farm) and low production intensity (average 5.500 kg per cow) (KIS, 2011a).

For the purpose of this study, the Slovenian milk production sector was categorised into nine farm types. The key objective of farm type formulation was not only to identify the most common types of dairy farms in Slovenia, but to represent the diversity of agricultural practice that derives from country specific characteristics. Accordingly, formulation of the farm types was derived from the following fundamental assumptions.

Farm types range from small, subsistence oriented farms (type 1) to semi-subsistance farms (type 2), organic farms with a varying degree of production intensity and market presence (types 3 and 4), ant to various types of conventional production systems, differing in herd size, proportion of arable land, breeds, and the amount of compound feed (types 5 to 9). All farm types under consideration, depending on their characteristics are subject to various public payments, either in the form of income support (direct payments per hectare), or in the form of remuneration for production externalities (compensation payments for less favourable farming conditions, various agri-environmental schemes).

Average farm size (measured by the number of animals and the amount of agricultural land) and intensity of production (measured in annual milk production per cow) within the types served as a starting point to formulate the systems' technological, economic and environmental parameters. Accordingly, annual agricultural output and input flows were quantified and a data inventory was created for each farm type. Main characteristics of the farm types are summarised in Table 1.

Table 1: Main characteristics of the farm types

	FT1	FT2	FT3	FT4	FT5	FT6	FT7	FT8	FT9
farm type	subsistance	half-subsistance	extensive organic	intensive organic	conventional	smaller intensive	highly intensive	larger intensive	agricultural enterprise
Breed [a]	S, BS	S, BS	S, BS	S, BS	S, BS	HF, S, BS	HF	HF	HF
Dairy cows	2	8	4	26	20	46	51	105	654
Milk yield (kg/cow)	3,600	4,500	3,000	4,500	5,500	7,400	9,300	7,500	7,000
UAA (ha)	4	9	9	44	17	37	37	90	762
crop field	11%	19%	8%	13%	37%	56%	59%	53%	58%
terrain	steep/hilly	steep, hilly, flat	steep/ hilly	hilly/flat	hilly/flat	hilly/flat	flat	flat	flat
public payments PP [b]	direct & LFA payments	direct & LFA payments	AE, direct & LFA payments	AE, direct & LFA payments	direct & LFA payments	AE, direct & LFA payments	direct payments	AE & direct payments	direct payments

[a] Slovenian cattle breeding is based on Simmental (S) and Brown Swiss (BS) breeds (combined breeds), and Holstein-Friesian breed (HF) (milk breed).

[b] LFA: compensation payments for less favourable farming conditions; AE: are agro-environmental payment, i.e. payments for organic farming (F3, F4) or payments supporting sustainable animal breeding, fields under greening and integrated crop production (F6, F8); direct payments: payments coupled to the production (milk quota payments) and utilised agricultural area.

2.2 Socio-economic analysis

The aim of socio-economic analysis was to evaluate and compare the economic performance and societal position of the investigated farm types.

The human controlled inputs into agricultural production considered in the study included agricultural mechanisation, fossil fuels, electricity, water for animals, seed, fertilisers, pesticides, purchased feedstuff, labour and other purchased services such as veterinary and financial services. Cost analysis was carried out to calculate annual production costs, including annual depreciation values of fixed assets and costs of their maintenance. The expected money inflows were calculated considering the market value of annual production and entitled public payments in the year 2010.

The indicators selected for socio-economic analysis of the investigated dairy production systems are listed in Table 2. Emphasis was placed on three aspects of socio-economic performance; a farm’s profitability, productivity and social sustainability. Profitability assessment addressed the farm’s financial performance, while productivity indicators assessed the economic efficiency of employed production factors. Social sustainability evaluation was applied to address possible problems relating to insufficient income leading to financial dependency of farmers on other economic systems.

Table 2: Socioeconomic indicators

Performance	Indicator	Definition	
Profitability	economic efficiency	TR/TC	The ratio between total annual revenues, including public payments (TR), and total annual costs of production, including maintenance of buildings and machinery (TC).
	cost efficiency	TC/Q	A quotient of total costs and total production (Q) defines an average cost per unit of production.
	income	(TR-TC)/Q	The difference between total revenues and total costs. An income before tax measured per unit of production.
Productivity	land productivity	Q/ area	Milk production per hectare of land.
	labour productivity	Q/ labour	Milk production per hour of labour.
	machinery utilisation efficiency		The time (in years) for which machinery is used on a farm comparing to its theoretical life expectancy. It measures to what degree machinery owned is being utilised.
Social sustainability	public payments dependency	S/ TR	The share of subsidies in total revenues is an indicator of farm's dependency on support from public payments.
	hourly wage	∏ [a]/ own labour [b]	Income per hour of home labour is an indicator of income sufficiency for an acceptable standard of living (public payments included).
	income sufficiency		The ratio between home labour fully paid with an income earned from sales and services and total amount of home labour invested on a farm. Indicates income sufficiency without support from public payments.

[a] Apart from the agricultural enterprise (FT9), the farms investigated are family farms operated by household members and therefore in many ways different from an enterprise. For this reason, rather than referring to the term »profit« that is a result of business activity, we refer to farmer's »income«. To avoid confusion, the same term is used for all the farms and denotes the money earned after total costs have been subtracted.

[b] Economic value of own labour reflects its opportunity cost and is assumed to be 8.5€/hr (KIS, 2011b).

2.3 Emergy analysis

Emergy analysis (Odum, 1988, 1996,) is an environmental accounting approach that adopts a biophysical understanding of value. It adheres to the notion that the work of the geo-biosphere is a driving force of all global processes and supports the idea that the natural capital invested in the production of goods and services determines their real value. Contrary to the conventional economic analysis, this value does not reflect the usefulness of a product, but rather the cumulative environmental support for its existence.

The peculiarity of emergy analysis is an accounting approach that unifies the past and present work of nature as well as society's contribution to its processing. By introducing a common unit of measurement, it enables quantification of the contributions from various sources and in various forms. Emergy (commonly solar, measured in solar emergy Joules, seJ) is a universal measure which defines the amount of available (solar) energy required to deliver a given product or service or to support a given flow (Odum, 1996). The conversion of any energy, material or monetary flow into solar emergy is done by multiplying the flow (J, g, €) with its own unit emergy value (UEV), which attempts to define the amount of solar emergy required to generate one functional unit of the flow (seJ/J, seJ/g, seJ/€). Commonly the term transformity is used when referring to solar emergy per Joule (seJ/J). All UEVs in the study refer to the global emergy baseline 15.2 E24 seJ/yr (Brown and Ulgiati, 2010).

In line with this methodology, an energy circuit diagram (Odum, 1983, Odum, 1996) of a dairy farm was devised to visualise the system's boundary, driving forces, key elements and interactions that occur between them (Figure 1).

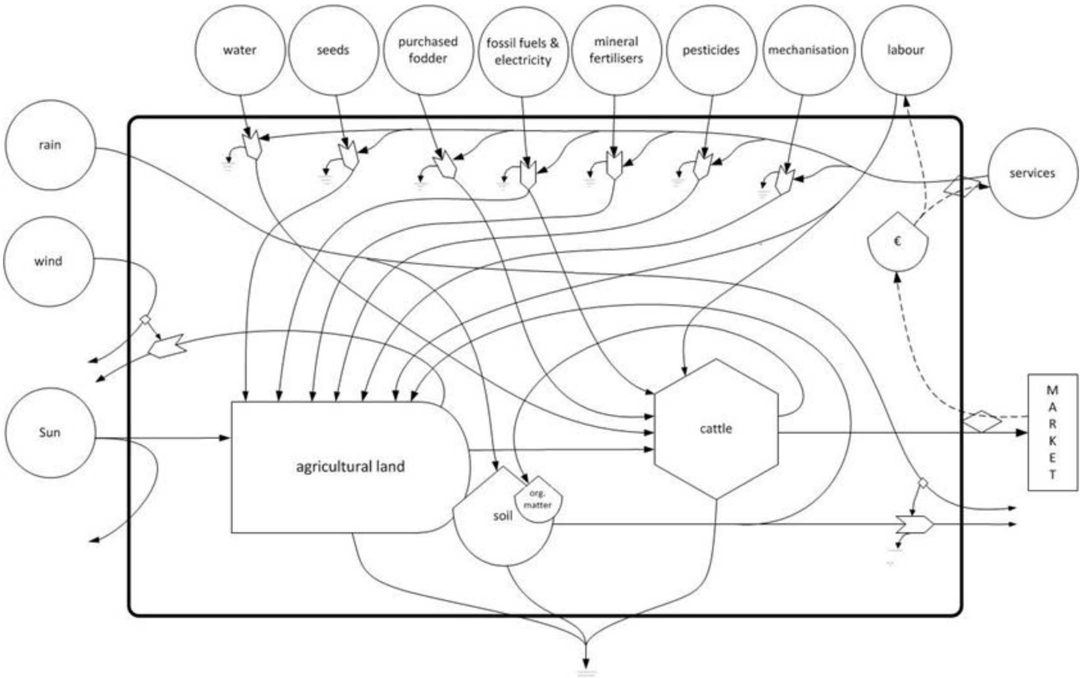

Figure 1: A generalised production diagram of a dairy farm in Slovenia.

All relevant energy inputs were listed in emergy evaluation tables. In this paper, the emergy table corresponding to the farm type F5 is presented in Table 6. The tables for other eight farm types have a similar structure and are available on request from the authors. All inputs into milk production were accounted for in terms of their emergy and summed to determine the total emergy (U) invested in the process. By defining each flow as renewable (R) local non-renewable (N) or fed-back from the economy (F) we calculated a set of emergy indicators that provide a qualitative assessment of various aspects of the system's biophysical performance. Unit emergy value of the final product (UEV =U/output; emergy per unit of production) and empower density (ED=U/ha; emergy per unit of utilised area) are intensity measures and indicate the product's renewability and emergy-use efficiency of the production. The emergy exchange ratio (EER=U/emergy of output's monetary value; emergy of a product sold to emergy of money received for the sale) evaluates the return on the invested emergy and indicates the relative trade advantage in emergy exchanged between two partners. Emergy yield ratio (EYR= U/F), environmental loading ratio (ELR= (F+N)/R) and renewable fraction of emergy use (%R= R/U) assess the system's performance in relation to its local environment. Finally, the system's sustainability is defined by the emergy sustainability index (ESI= EYR/ELR) as an aggregated indicator suggesting that more sustainable systems are those with a higher ability to exploit local resources (EYR) whilst simultaneously creating less pressure on the local environment (ELR). A more in depth description of the methodology and indices can be found in Brown and Ulgiati, 1997, 2004, Odum, 1996.

2.4 Data

The main data sources for the farm type characterisation were Agricultural census 2010 and milk yield control database from Agricultural Institute of Slovenia. Human-controlled inputs into agricultural production were quantified based on "Calculation Catalogue for Good

Husbandry Planning" (KGZS, 2011), "Model Calculations 2010" (KIS, 2011b), "Catalogue of Agricultural and Forestry Mechanisation Costs" (KGZS, 2008) and personal communication with experts from the fields of farm management and animal science. Prices of inputs and data for the calculation of public payments were taken from the aforementioned sources and the Statistical Office of the Republic of Slovenia (SURS, 2012b) for the year 2010 (VAT excluded). Meteorological data was collected from the Environmental Agency of the Republic of Slovenia (ARSO, 2012) and relate to average values from 1997 to 2011. Soil erosion for each farm type was estimated according to Komac and Zorn (2008).

3. Results and discussion

3.1 Socio-economic performance

Based on agricultural prices in 2010, total annual production costs, revenues and income were calculated. Monetary flows were expressed per hectare of land and are summarised in Table 3. Own labour (OL) included, the cost structure analysis showed that the labour costs accounted for up to 55% of the total costs. This percentage decreased with farm size and production intensity, however it still represented larger annual cost (> 20%) for all farm types. The major costs in largest and most intensive farm types, however, were costs of agricultural machinery and buildings (F7) and costs of services (for F8-F9).

Table 3: Monetary flows driving milk production

All flows are expressed in € per hectare (€/ha).

Farm type	Monetary flows				
	Total costs without own labour (TC)	Total costs with own labour (TC*)	Revenues from sales and services	Total revenues, incl.PP (TR)	Income (TR-TC)
	€/ha	€/ha	€/ha	€/ha	€/ha
F1: subsistance	912.0	2,035.1	1,162.2	1,504.0	592.0
F2: half-subsistance	1,493.0	2,858.3	1,982.8	2,352.2	859.2
F3: extensive ecological	630.0	1,268.0	969.2	1,520.5	890.4
F4: intensive ecological	961.8	1,538.2	1,347.4	1,868.5	906.7
F5: conventional	2,079.7	3,596.9	2,497.9	2,949.6	869.9
F6: smaller intensive	2,938.0	4,085.0	3,428.9	4,225.9	1,287.9
F7: highly intensive	3,853.3	4,992.1	4,605.0	5,284.6	1,431.3
F8: larger intensive	2,763.4	3,330.9	3,160.4	3,833.8	1,070.4
F9: agricultural enterprise	2,062.1	2,156.7	2,122.0	2,535.0	472.9

Indicators demonstrating socio-economic performance of the farm types are listed in Table 4. The most land and labour productive farm types were F7 and F9 respectivelly, where productivity was almost up to ten times higher than in F3 and F1. Utilisation of the economies of scale, including efficient use of machinery, explained low production costs in F7, F8 and F9, especially when own labour was taken into consideration. Machinery use efficiency indicates the extent to what machinery is utilised. A value equal to 1 is a reference value (minimum) suggesting its full utilisation. As larger farms F6-F9 and F4 appeared to be more efficient in machinery use, F1 and F3 revealing the contrary.

Table 4: Socio-economic indicators

	F1	F2	F3	F4	F5	F6	F7	F8	F9
	subsistance	half-subsistance	extensive organic	intensive organic	conventional	smaller intensive	highly intensive	larger intensive	agricultural enterprise
Economic efficiency	1.65	1.58	2.41	1.94	1.42	1.44	1.37	1.39	1.23
Cost efficiency (€/kg) excl. OL	0.49	0.37	0.48	0.36	0.32	0.32	0.30	0.32	0.34
Cost efficiency (€/kg) incl. OL	1.09	0.72	0.97	0.57	0.55	0.44	0.39	0.38	0.36
Income (€/kg)	0.32	0.22	0.68	0.34	0.13	0.14	0.11	0.12	0.08
Land productivity (t/ha)	1.87	3.99	1.30	2.69	6.59	9.21	12.78	8.77	6.01
Labour productivity (kg/hr)	14.2	24.9	17.3	39.6	36.9	68.2	95.4	98.5	127.1
Machinery use efficiency	3.31	2.33	3.06	1.89	2.41	1.98	1.75	1.53	1.19
Subsidy dependence	0.23	0.16	0.36	0.28	0.15	0.19	0.13	0.18	0.16
Hourly wage (income/hr)	4.48	5.35	11.86	13.37	4.87	9.54	10.68	16.03	60.02
Income sufficiency	0.22	0.36	0.53	0.67	0.28	0.43	0.66	0.77	0.91
Sum of std values (z-scores; $\mu = 0$; $\sigma = 1$)	-7.64	-2.70	-3.11	0.13	-2.19	0.52	4.44	3.82	6.73

Furthermore, contrary to low land and labour productivity, organic farms (F3 and F4) showed the highest economic efficiency (2.4 and 1,9 € revenue/€ cost, respectively), and the highest income per unit of production (0.68 €/kg, 0.34 €/kg respectively), assumedly due to a higher market price of organic milk, the low production costs of grazing-based production, low milk production and additional public payments to organic milk production. The latter explained the farms' high economic efficiency only partly. Public payments excluded, the economic efficiency of organic farms F3 and F4 largely decreased (36% and 28% respectively), however still remained the highest among all farm types.

Considering an hourly wage of 8.5€/hr as a threshold for an acceptable standard of living in Slovenia, farm types F1 (4.5€/hr), F2 (5,3€/hr) and F5 (4,9€/hr) did not satisfy this condition, which indicates their dependency on alternative sources of income. Moreover, without public payments the same would hold true for all other farm types, which can be inferred from low income sufficiency figures (all below 1). The results put forth a very poor income position of (traditional) small scale farmers in Slovenia (KIS, 2011a, 2012). In addition to this, agricultural input prices are constantly increasing (SURS, 2012b), which suggests that livelihoods of farmers continue to be threatened. Increased pressure on farmers to find an alternative source of an income, or to reorganise production or to exit the sector explains the recent structural changes in the sector (section 2.1).

Indicators were organised in such a way that a higher value reflected a more desirable performance, and normalisation on the standard score (z-score) was performed to allow direct comparison and integration The sum of standard scores of all indicators (last row in Table 4) determined overall socio-economic performance of each individual farm type in comparison to others. The results suggested better socio-economic performance for larger and more intensive farm types. Farm types F9, followed by F7 and F8 were most successful whereas smaller farms, F1 followed by F3 and F2 showed the poorest performance Due to the higher labour intensity of production (Table 3), the divergence of these farm types from the more economically successful larger farms became more apparent when own labour was included in the production costs.

3.2 *Emergy evaluation*

The main categories of emergy flows for all farms are summarised in Table 7. This table lists the emergy of invested natural resources (U*) for each type of dairy production and categorises them as local renewable (R), local non-renewable (N) and imported (fed-back) emergy flows (F). Emergy of labour and services (LS) accounts for the emergy of processing these flows within society. These are also included in the total emergy symbolised by U. For comparison all flows are expressed in annual solar emergy (seJ) per hectare.

Table 5: Emergy flows driving milk production

Farm type	Driving forces									
	Local renewable (R)		Local non-renewable (N)		Imported (F)		Emergy (R+N+F=U*)	Labour and services (LS)		Total emergy (R+N+F+LS=U)
	10^{14} sej/ha	%of U*	10^{14} sej/ha	% of U*	10^{14} sej/ha	% of U*	10^{14}sej/ha	10^{14}sej/ha	%of U	10^{14} sej/ha
F1: subsistance	11.49	56.3	4.65	22.81	4.25	20.8	20.38	131.96	86.6	152.34
F2: half-subsistance	11.49	32.0	5.50	15.32	18.93	52.7	35.92	189.72	84.1	225.64
F3: extensive organic	11.49	61.6	4.33	23.20	2.85	15.3	18.66	82.43	81.5	101.09
F4: intensive organic	11.49	50.9	4.86	21.53	6.23	27.6	22.58	98.84	81.4	121.42
F5: conventional	11.49	22.5	7.43	14.53	32.21	63.0	51.12	238.79	82.4	289.91
F6: smaller intensive	11.49	12.7	8.23	9.14	70.38	78.1	90.09	267.51	74.8	357.60
F7: highly intensive	11.49	9.1	8.50	6.74	106.12	84.2	126.11	328.99	72.3	455.10
F8: larger intensive	11.49	13.2	7.97	9.15	67.59	77.7	87.05	223.99	72.0	311.04
F9: agri.enterprise	11.49	18.4	8.48	13.56	42.55	68.1	62.51	146.99	70.2	209.50

To avoid double counting, only the emergy of rainfall was accounted for as a renewable inflow. The absolute renewable emergy per hectare was set to be equal between farms. However, there were larger discrepancies shown in the share of renewable emergy in total emergy use. If labour and services are not included in the accounting the share of renewable emergy in total emergy would range from low 9 % in F7 to almost 62% in F3. In F6, F7, and F8, renewable sources for production accounted for less than 14%. When taking into account the total emergy, including emergy of labour and services (U), the relative renewable support was considerably lower, ranging from 11 % in F3 to less than 3 % in F7 and F6. A low share of renewable emergy was counteracted by a large amount of non-renewable, especially purchased emergy. Labour and services excluded, in farm types with low renewable input (F6 – F8), purchased emergy F amounted to more than 77% of total emergy use. The main purchased flows were feedstuff (0% to 68%), diesel (9% to 23%) and mineral fertilisers (0% to 14%). However, these flows became insignificant when compared to the total emergy of labour and services, which accounted for more than 70% of the total emergy in all dairy systems. Emergy of labour and services was inversely correlated with farm size and intensity of production. Further dissection showed that farm types F1- F3 depended heavily on emergy of labour (46%- 56%) and less on emergy of services (31%- 38%), whereas the opposite was found for farm types F4 - F9 (15%- 40% and 43%- 56% respectively).

Emergy of labour and services is an important item in emergy analysis and needs to be discussed further. Labour and services account for the emergy of direct labour and indirect labour for goods provision (services). Their high percentage suggests that milk production is mainly based on indirect contributions from society, which is typical for modern agriculture. Any provider of (indirect) labour (an economic agent) is supported by a societal network of activities (health services, national defence, education, transport, hobbies, consumption of energy, food etc.), which are paid for by money that has been earned in a process. Therefore, emergy that supports milk production is actually the emergy that supports the quality of life of farm households, covered by their monetary revenues. The high share of emergy of labour and services suggests that very little emergy is directly invested in the local milk production process – the largest proportion is invested in farmer's social welfare.

To further investigate the biophysical performance of the nine dairy systems, emergy indices and ratios were calculated (Table 8).

Table 6: Emergy indicators of nine dairy systems (with LS)

	F1	F2	F3	F4	F5	F6	F7	F8	F9
farm type	subsistance	half-subsistance	extensive organic	intensive organic	conventional	smaller intensive	highly intensive	larger intensive	agricultural enterprise
Transformity (sej/J)	3.0E+06	2.1E+06	2.9E+06	1.7E+06	1.6E+06	1.5E+06	1.3E+06	1.3E+06	1.3E+06
ED: Empower density (sej/ha)	1.5E+16	2.3E+16	1.0E+16	1.2E+16	2.9E+16	3.6E+16	4.6E+16	3.1E+16	2.1E+16
EYR: Emergy Yield Ratio	1.12	1.08	1.19	1.16	1.07	1.06	1.05	1.07	1.11
ELR: Environmental Loading Ratio	12.26	18.65	7.80	9.57	24.24	30.14	38.62	26.08	17.24
ESI: Emergy Sustainability Index	0.09	0.06	0.15	0.12	0.04	0.04	0.03	0.04	0.06
% R: Renewable fracture	8%	5%	11%	9%	4%	3%	3%	4%	5%
EER: Emergy Exchange Ratio incl.PP	1.89	1.64	1.50	1.30	1.67	1.50	1.42	1.65	1.42
EER: Emergy Exchange Ratio excl.PP	1.46	1.38	0.96	0.93	1.41	1.22	1.24	1.32	1.19
Sum of std values ($\mu = 0$; $\sigma = 1$)	-1.53	-2.16	5.89	5.79	-2.62	-1.95	-2.60	-1.85	1.02

Including emergy of labour and services, transformity of milk was the lowest in F9, followed by F8 and F7 and the highest in F1 and F3. High values of this indicator suggest poor production efficiency and hence low renewability of the final product (milk and calfs). Additionally, F3, F4 and F1 were characterised by the lowest empower density, suggesting a low amount of emergy is required per hectare of land. By contrast, production in organic farm types, especially in F3, was characterised by a high share of renewable emergy use, %R. Likewise, F3 and F4 showed the highest values of EYR (indicating the ability to exploit free local resources), lowest values of ELR (indicating less pressure from production on the local environment), and hence, higher ESI values, suggesting greater sustainability of the systems. The opposite was shown for larger and more intensive farm types (F6-F9). Among these F9 performed marginally better with respect to interaction with the local environment and the system's sustainability. An EER equal to 1, indicates equity in trade, when the emergy of a product sold equals to the emergy value of money received. Public payments excluded, trade was closest to an equal exchange in F3 and F4. However a producer's trade advantage that is present in F4 and F3 existed only when public payments were received. An exchange was strongly in favour of the purchaser in F1, where emergy received was up to almost twice the amount traded.

Due to a high share of emergy of labour and services in all dairy systems (Table 6) indicators without labour and services were also calculated to provide a clearer insight into the systems' performance based only on direct natural flows (disregarding any socio-economic processes). The comparison of emergy indicators with and without emergy of labour and services emphasised a negative effect of socio-economic interaction on biophysical performance and sustainability of the systems. This effect was less pronounced for F5-F9 yet more significant for smaller and less intensive farm types, especially F1 and F3.

To capture various aspects of system functioning, the whole set of emergy indicators were considered simultaneously. The standardisation procedure described in section 3.1 was applied to integrate the indicators (LS included). Sums of their standard scores for each farm are stated in the last row of Table 8. Assuming that all emergy indicators were equally important, organic farm types, especially extensive organic F3, showed the best system performance, mostly due to effective interaction with the local environment. Agricultural enterprise F9 was ranked third. The results showed that besides the highly intensive F7, some smaller farm types, considerably F5 and to a lesser extent F2, had the poorest biophysical performance.

3.3 Multiple-perspective evaluation

A combined economic and emergy evaluation was applied to evaluate different types of dairy production. The results in section 3.1 and 3.2 indicate somehow inverse relationship in farms'performance between these two approaches. Standard socio-economic indicators favour larger, intensive and more productive systems that are cost efficient and income sufficient (F7-F9). Emergy analysis however, favours less productive, labour intensive organic farms that have lower environmental impact and greater ability to exploit free local resources (F3, F4).

The results presented in the previous subsections already indicate certain cluster patterns between the farms. The formation of three main clusters was confirmed by hierarchical cluster analysis using Ward’s linkage method. The clusters and their members were positioned in relation to their socio-economic and emergy performance (Figure 2,left).

Disaggregated performance of the main clusters (Figure 2, right) shows that large and intensive farms are highly productive and financially independent. Intensive production at a large scale results in high production efficiency, from both an economic and biophysical perspective. Although having several economic advantages, intensive production relies heavily on non-renewable purchased resources causing increased pressure on the local environment and low system sustainability. By contrast, organic farm systems are noticeably more sustainable, due to their effective interactions with the local environment and hence lower reliance on purchased inputs. However a disadvantage of organic production lies in its low labour and land productivity, resulting in emergy-use inefficiency of the system and high reliance on public payments. Finally, smaller conventional farms show below average results across all aspects considered. The particularly concerning factor is low profitability that leads to a strong dependency on alternative income sources and again raises questions about the farmer’s standard of living. As pointed out in section 3.1, due to their low economic performance small conventional farms are most likely to be negatively affected by economically driven structural changes. It is reasonable to assume that in the light of these changes small conventional farms will have to reorganise their production or exit the sector. Due to farms commonly being located in hilly and mountainous areas, widespread transition to large intensive production is not possible. Likewise, such natural conditions are less suitable for alternative types of agricultural production, such as plant production. A promising solution may lie in their reorganisation towards organic production, which is more economically viable and environmentally sustainable. Further, these farms are more likely to become multifunctional farms that provide other economic and ecosystem services. The results infer that a strong policy incentive to invest into increasingly attractive auxiliary activities such as rural tourism and on farm educational services improves the competitiveness and vitality of small family farms (Ohe, 2011).

An integration of multiple perspective criteria at the individual farm level (Figure 2, left) showed that the intensive organic farm type (F4), closely followed by the agricultural enterprise (F9), had the best overall ranking, due to its high emergy and above average economic performance. The superior performance of the agricultural enterprise (F9) is a result of the economies of scale that enable efficient use of resources and also emergy-use efficiency. By contrast the extensive organic farm (F3) despite low productivity and emergy-use inefficiency was ranked third due to its exceptional emergy performance. The latter is a result of a large fraction of renewable emergy invested in the production. This reveals that a larger reliance on renewable flows offsets less efficient use of resources and provides a higher ranking. Such production does not fit the present economic structure (high yield, high productivity), however it is more viable in the conditions of declining non-renewable resources. Highly intensive farm type (F7) was ranked fourth, followed by larger and intensive farm (F8) and small intensive farm (F6). Subsistence (F1), half-subsistence farm (F2) and conventional (F5) were ranked the lowest. It should be noted that ranking is performed under the assumption that all criteria are equally important. We are aware that simplification in this way has its limitations as it does not consider the different interests of multiple (economic) stakeholders. Assigning weights to different criteria is the domain of a participatory assessment (see e.g. Hajkowitz, 2008, Munda, 2004), an application of which exceeds the scope of this particular work. However we agree that its integration with multiple-criteria evaluation is significant in the decision-making process at various levels.

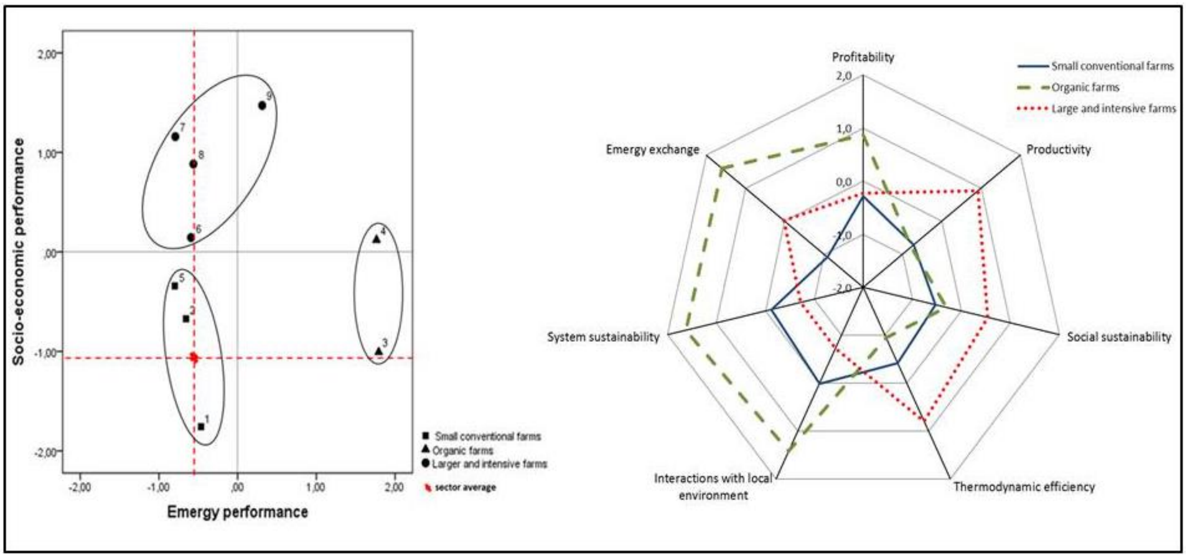

Figure 2: A scattergram (left) displaying three farm type clusters. A radar graph (right) visualising multiple-perspective performance of three main farm type clusters

The results raise questions about the constraints and possibilities that can affect the overall performance of milk production at a national level. Small conventional farms are the most widely represented farm types in Slovenia in terms of the number of holdings with a significant share of total milk production in the country. Hence, their poor performance is a concern for a stable and sustainable dairy sector. Based on the results, the current trends of structural change in the dairy sector moving towards more intensive and larger scale production systems may lead to an improved overall performance of the dairy sector. The multiple-perspective evaluation of large and intensive farms indicates that improvement would occur mostly, but not entirely due to the economic advantages of such a system (Figure 2). However, due to natural limitations, the scope for the improvements may be marginal. Even more, the results of emergy analysis confirm that intensive production is heavily dependent on inputs purchased from a fossil fuel driven economy (Table 6). This raises questions not only about the limited resources for further intensification but even of the capacity to maintain the existing technologies of agricultural production. Furthermore, the results indicate that the expansion of organic dairy production may substantially improve emergy performance of the dairy sector. Organic production is shown to be organised around free local renewable flows to a greater degree than other types of production. This implies that in an unstable economic environment with high price volatility, organic production (especially extensive production) lowers the sector's dependency on purchased (imported) resources and hence potentially increases the resilience of the sector. However, factors such as low land productivity and high reliance on public payments would present obstacles to a widespread increase in organic dairy production. Furthermore, large-scale conversion of the milk sector to organic production would result in a reduced production of milk, which is one of the few net exporting agricultural commodities in the country. Nevertheless, keeping a diversity of solutions available, although at higher costs, is vital for resilience and survival.

Finally, the analysis of emergy flows shows that dairy production (regardless of its type) depends heavily on the emergy of labour and services. The comparison of emergy indicators with and without services shows that the incorporation of socio-economic flows remarkably decreases renewability and sustainability of the systems. Labour and services represent an important linkage between emergy (environmental) assessments and economic analysis, however they are often not fully understood and properly accounted for. As discussed in section 3.2, emergy of labour and services reflects the emergy required to support direct and indirect human labour (i.e. the whole socio-economic network) and is directly related to its economic cost, determined by the wider economic system. A high share of these flows suggests that agriculture itself has little ability to affect its own sustainability. The problem of high labour cost cannot be solved by decreasing farmers' wages and the quality of life, but instead by increasing overall efficiencies within society. Lower resource use and reducing luxuries and resource waste would lead to lower emergy required to support the economy. A decrease in emergy per capita and emergy value of money (Emergy/GDP; seJ/€) would decrease emergy of labour and services in all sectors, but would not reduce societal welfare. The same amount of money would purchase fewer resources, but due to higher efficiencies this smaller amount of resources would be sufficient to support the same standard of living.

4. Conclusion

Economic and biophysical evaluation approaches originate from different concepts of value and as such answer different questions. A multiple-perspective assessment was performed on nine dairy farm types. Socio-economic indicators were calculated to provide anthropocentric evaluation of the farms' performance, whilst emergy based indicators were applied to determine their biophysical performance. Results shown in the paper suggest the following remarks.

Firstly, multiple-objective and particularly multiple-perspective evaluation of alternative options in agriculture generates new information to support decision making at various levels, and to communicate the consequences of its actions. The results show larger discrepancies in the performance of the farm types when defined by socio-economic or biophysical criteria. The emergy and standard economic evaluations of the dairy farms are not mutually exclusive; instead their joint application provides an informative insight into agricultural performance on different scales suggesting a strong complementarity of the approaches.

Secondly, our research shows that a compromise between the priorities of economic agents and the natural environment is needed. The results do not negate the possibility of a link between intensification of the agricultural sector and its overall improvement (from both an economic and biophysical perspective). However, they do suggest that development of the sector may be constrained by the country's natural conditions (land), and additionally by the uncertainty of future availability of other key production factors (fossil fuels). Likewise, several constrains exist for a widespread increase of more environmentally sustainable and less market dependent agricultural systems. The complexity of the problem further advocates the potentials of an integrated approach.

We believe that a well-informed decision-making process has the capacity to redirect economically driven short-term oriented structural changes to better comply with limitations of modern agriculture and to exploit potentials of a more sustainable agricultural practices. Nevertheless, perhaps the most important contribution of emergy analysis is that it clearly illustrates for all types of dairy production, an extremely high dependence on the wider socio-economic environment. Therefore, we conclude this paper by acknowledging that a broader multiple-criteria approach is crucial for developing an appropriate policy framework towards sustainable agriculture. However at the farm level the abilities to improve the sustainability and efficiency of the system are negligible. To achieve significant improvements towards long-term sustainability, social values need to be re-evaluated and the broader economic system reorganised.

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