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Emergy Evaluation of a Mountain Socio-Economic System and Traditional Agroproduction: A Case Study in Indian Trans-Himalaya

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ABSTRACT

The emergy evaluation of the Ladakh socio-economic system and traditional agriculture is presented. Ladakh is a region of West Himalaya (State of Jammu and Kashmir, northern India), geographically classified as "high cold desert" (altitude ranging from 2300 m to 7672 m a.s.l.), located among the Karakoram Range, the Himalayan Range and the Tibetan Plateau. The region is poor in natural resources and, for centuries, the population has led a self-reliant existence, mainly based upon subsistence agriculture and caravan trade. The local traditional agriculture, still the backbone of regional economy, is governed by seasonal cycles and supported by the careful management of environmental scarce resources (e.g. meltwater from glaciers) and man-made soil properties. This system is diagrammed and the UEVs of some of the main products (barley, wheat, peas, mustard and fodder) are calculated. At the regional level, population growth, the development of tourism, and the progressive openness to external resources characterize the current development trend, especially in the city of Leh. The steps towards modernization (e.g. infrastructural development or agriculture mechanization) are encouraged for economic purposes; however, they may also bring about unsustainable behavior in the use of resources and land, and a loss of traditional knowledge and environmental wisdom. The analysis of emergy flows and indices highlights some peculiarities of the area and the crucial role of environmental resources involved in local processes and activities.

INTRODUCTION

Ladakh is a region of northern India, situated in the West Himalaya, geographically classified as "high cold desert" (Negi 1995) (altitude ranging from 2300 m to 7672 m a.s.l.). It is located between the Karakoram Range (north), the Himalayan Range (south and west) and the Tibetan Plateau (east), bordered by Pakistan, China, and the Lahaul & Spiti districts of Himachal Pradesh (India). Politically, it is a division of the Jammu and Kashmir State of India, divided into two districts: Leh (area: 45110 km^2; 147104 inhabitants), and Kargil (area:14036 km^2; 143388 inhabitants). Both districts are governed by their respective Ladakh Autonomous Hill Development Councils (LAHDC).

The population is rather scattered in almost all the accessible areas, with the exception of the cities of Leh and Kargil. Settlements are typically located around the banks and terraces of major rivers and streams. For centuries this population, living in an area that is poor in natural resources, has led a relatively self-reliant existence, based upon subsistence agriculture and livestock husbandry (the so-called traditional land-based economy), but also upon trading goods with Tibet, central Asia, and the Indian plain (Rizvi 1996). In particular, agriculture is the backbone of every village economy, engaging up to the 70% of the working force (LAHDC-L 2009b). Traditional agricultural activity is governed by seasonal cycles, and farming work is done with the help of nature and supported by a careful management of scarce resources. Environmental resources, recycling, crop rotation, meltwater, organic manure, human and animal labour are the components of the farming system. Sabharwal & Singh (2005) noted that this "well-integrated, coordinated and balanced form of agriculture [...] has evolved in response to agro-climatic conditions unique in India". Indigenous knowledge is a crucial aspect. Verma (1998) stated that it is "the inter-generational wisdom of local inhabitants to perform their livelihood operations in a most eco-friendly manner under remote, isolated and inaccessible conditions characterized by harsh climate and limited survival options".

In the last decades, the modernization and development programs from the central government have resulted in an increasing reliance on the Indian plain economy (imported goods, subsidized food, fertilizers and fuels). Sustainable development programs are thus needed to connect the new socio-economic perspectives with the limits imposed by natural resources, without compromising the cultural identity and the memory of the local multi-century man-nature co-evolution.

This paper proposes a time series evaluation of the district of Leh, together with the assessment of the local traditional agroproduction, both based on emergy. The main characteristics of the region and of the local farming system are highlighted, as well as the importance of resources and the value of the work of nature in supporting activities. The application of emergy enables to identify, quantify and assess the flows of resources feeding these systems and provides information for a sustainable use of resources and land. It also gives the opportunity of enlarging local knowledge and monitoring population behaviour, especially in this case in which the human activity strongly interacts with ecosystems dynamics and resource cycles.

THE SYSTEMS UNDER STUDY

The Territorial and Socio-Economic System

Nowadays Ladakh society is in transition. New lifestyle, practices and social mores permeate the local community against a backdrop of centuries of old indigenous tradition and culture (Morup 2010). In 2005, the changes in socio-economic and cultural aspects led the LAHDC of Leh to formulate the report "Ladakh 2025 Vision Document (VD)", a road map to local sustainable development with the aim of designing a framework to integrate modern dynamics within the ecological and cultural heritage and social identity of the region. The Document states that the Leh district can be seen as "*an ideal society geared towards economic self-reliance, full employment and enhanced quality of life for its people, with equity, social justice, rights, peace and freedom, and focus on vulnerable and marginalised sections*" (LAHDC-L 2005). The VD identifies the traditional land based economy and the new service and off-farm economy as driving forces of the local development. In Figure 1 the energy diagram of the territorial system is presented. The large rectangle defines the boundaries of the Leh District system with an area of 51,358 hectares (LAHDC-L 2009a).

The main system component is the traditional land-based economy, fed by natural resources. A crucial role is played by the stream of meltwater from glaciers, collected and distributed through man-made infrastructures. Glaciers are located within the administrative boundaries of the system, but they are represented as a finite storage in a dashed box to indicate that local population cannot influence their dimensions by withdrawing water; on the contrary, human activity can be affected by water shortage in case of glacier reduction due to climate change. The population and urban centres, represented by the large consumer on the right, also consume water and other materials extracted from local storages as well as an increasing flow of goods from outside the boundaries of the system. A limited energy production from fossil fuels (coming from external economies) meets the need of the population, especially in the city of Leh. The traditional farming activity stimulates feedback flows of energy and matter; however, modern dynamics are reducing the importance of the recycling practices because some inputs are very easy to find: subsidized food and machineries, chemical fertilizers, and more. Off-farm activities are also developing, in particular tourism (about 150,000 visitors/yr stimulate the sector) (Pelliciardi 2010) and job opportunities in tertiary and service sectors, government and military forces. These factors also influence economic growth, urbanization, and money circulation, stimulate the importance of (international) markets and trade, and generate problems like pollution and increasing pressure on infrastructural systems in the fields of water distribution, public heath, waste disposal, power generation, etc. The system is analysed for the period 1999-2007 and the spatial boundary of evaluation regards 511 km^2 according data reported in LAHDC-L 2009a.

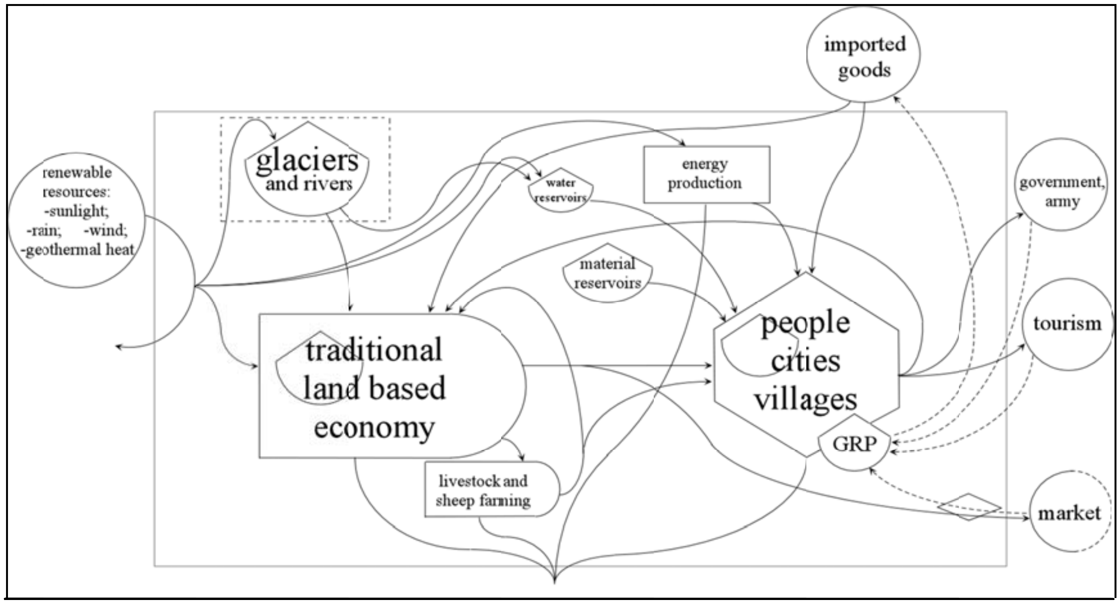

Figure 1. *Energy diagram of Leh district.*

The Traditional Farming System

The traditional farming system is a crucial component of the Ladakh socio-economic organization. The F.A.O. (2008) classifies Ladakhi agriculture among the possible “Globally Important Agricultural Heritage Systems”, defined as “remarkable land use systems and landscapes which are rich in globally significant biological diversity evolving from the co-adaptation of a community with its environment and its needs and aspirations for sustainable development”. It can be seen as an ordered series of cyclical sequential operations: manuring, ploughing, sowing, levelling, channelling, irrigating, weeding, harvesting, threshing. Farmers manure the fields at the beginning of springtime using a mixture of human and animal excreta. Traditionally, land preparation is performed with animals. Field weeding is usually done by the women, once a month. Water for irrigation comes from glaciers, outside the farming system. Sowing rates, irrigation times and water quantity depend on different factors: kind of crop, soil, field topography and location, average evapotranspiration. Harvesting goes from late August till the end of September. Expected harvest varies from year to year, and even from field to field, according to altitude, geomorphology, orientation, sowing rates, quantity of manure, water availability, and farmer knowledge and experience, among other factors. Crop is treated to separate grain from straw, using animals and also air movement and wind. Finally, crops are stocked in the house store.

The farm under study, located in Hemis Shukpachan (3650 m a.s.l.), a village within the district of Leh, includes six small fields cultivated by the family of the farmer (5 persons): barley (750 m² + 950 m²), wheat (1750 m²), peas (575 m²), mustard (1000 m²), fodder (2825 m²).

As shown in Figure 2, the system is supported by natural inputs that are consumed or withdrawn without being exhausted. Renewable resources are locally available according to contextual conditions: for instance, this area is characterized by intense solar radiation and scarce precipitation. Meltwater from glaciers plays a crucial role for irrigation; it is exploited through an artificial channel system, and rather fair water rationing. Glaciers are remote and out of the farmers’ control: their dependence on global climatic conditions determines the vulnerability of the farming system. Each product generates straw and grain that support animals and the population (consumers). The small storages represent infrastructures (buildings, channels and terraces): these are very old and built with

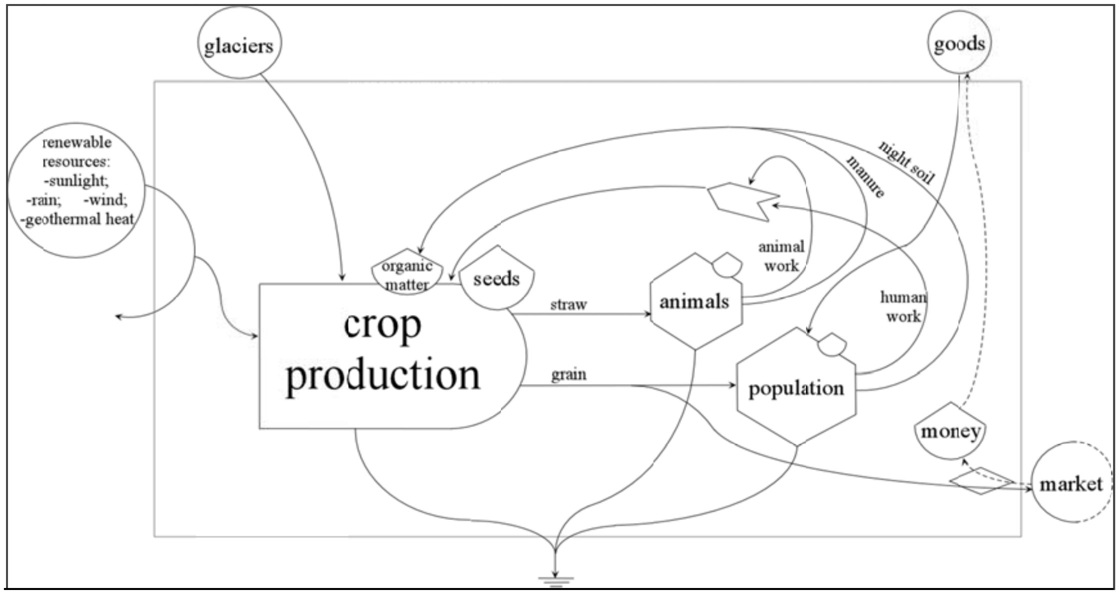

Figure 2. *Energy diagram of the traditional agricultural practices in Leh district.*

local materials so that their annual influence in the calculation is negligible. The system is also characterized by feedbacks. Products are recycled both directly as seeds and indirectly as animal and human labour and organic manure. Part of the final product is stored for food security; the product exceeding the need is sold and money (dashed arrows) is also used to buy rice, fruit, tea, sugar and salt, that, in the representation of traditional farming activity, are negligible flows. Data and background information (general questions to the Agriculture Department in Leh; specific questions directly to the farmer, and direct field measurements) have been collected during two missions to Ladakh in 2009 and 2010. Reference year for the analysis of farming system is 2010. UEVs available in literature have been used.

RESULTS AND DISCUSSION

Table 1 and Figure 3 show the trend in the use of resources, expressed in emergy. In absolute terms, natural resources play a fundamental role in feeding the territorial system. The most important one is the melted water from glaciers, as it represents the main source of water for domestic use and irrigation. Its quantity is two orders of magnitude larger than that of water withdrawn from local sources, also due to high UEV. Also extracted minerals and loss of top soil are important categories of resources: the former depends on urbanization dynamics, the latter derives from the progressive modernization of agricultural practices that privilege mechanization and the use of chemical fertilizers instead of the careful management of soil functions and organic matter recycling (Pelliciardi, 2012). Among imported resources, the most important are energy, food, building materials, and various inputs for agriculture. A special category is the generic miscellaneous of goods that includes, for instance, electronic and electric goods, plastic, rubber and paper commodities, tobaccos and liquors (J. & K., 2008). It reflects the tendency of people to purchase a large set of different goods coming from the globalized world. All input aggregates tend to increase in time. In particular, extracted water and local and purchased building materials depend on urbanization and population growth; imported food and energy consumption are stimulated also by the tourism industry and the increase of population density in the city of Leh; the import of fertilizers and other chemicals depends on the conversion of agroproduction from traditional into modern; the import of miscellaneous goods is due to the increase in money availability and consumption propensity which are, in turn, influenced by new job opportunities, especially in the urban centre, and commercial connections with outside the boundaries of the system, and central government development plans.

Table 1. Emergy inputs to the territorial system (in semj/yr), time series 1990/00 – 2006/07. Baseline 15.83 x 10^{24} semj/yr (see Appendix A for calculations and UEVs).

		1999/00	*2000/01*	*2001/02*	*2002/03*	*2003/04*	*2004/05*	*2005/06*	*2006/07*
	1 Rain	6.07E+18	6.07E+18	6.07E+18	6.07E+18	6.07E+18	6.88E+18	6.90E+18	6.90E+18
R	2 Earth heat	4.53E+19	4.53E+19	4.53E+19	4.53E+19	4.53E+19	5.13E+19	5.15E+19	5.15E+19
	3 Meltwater	2.34E+20	2.69E+20	2.69E+20	2.68E+20	2.67E+20	2.67E+20	2.71E+20	2.71E+20
	4 Water	3.14E+18	3.64E+18	4.23E+18	4.71E+18	5.47E+18	6.36E+18	7.30E+18	8.38E+18
N	5 Sand and ballast	4.95E+19	5.18E+19	5.34E+19	5.67E+19	6.96E+19	8.12E+19	8.39E+19	9.65E+19
	6 Loss of topsoil	2.23E+19	2.55E+19	2.56E+19	2.55E+19	2.54E+19	2.54E+19	2.58E+19	2.58E+19
F1	7 Fuel & Coal	1.83E+19	1.99E+19	2.09E+19	2.05E+19	2.01E+19	2.38E+19	2.51E+19	3.20E+19
	8 Cereals	1.37E+19	1.19E+19	1.57E+19	1.56E+19	1.69E+19	1.59E+19	1.45E+19	1.72E+19
	9 Vegetables	1.29E+19	2.46E+19	2.47E+19	2.76E+19	2.96E+19	2.79E+19	3.14E+19	2.90E+19
	10 Fruits	2.37E+18	2.24E+18	2.41E+18	2.42E+18	3.05E+18	2.97E+18	3.43E+18	3.48E+18
	11 Sugar	1.88E+19	1.95E+19	2.10E+19	2.57E+19	3.38E+19	2.02E+19	1.99E+19	2.22E+19
	12 Manufact. food	5.19E+18	4.91E+18	5.63E+18	5.18E+18	5.60E+18	7.00E+18	3.17E+18	9.13E+18
	13 Animals	1.51E+19	1.76E+19	1.57E+19	1.75E+19	1.72E+19	1.58E+19	1.71E+19	1.86E+19
	14 Fodder	2.26E+17	5.61E+17	6.08E+17	6.62E+17	6.42E+17	6.52E+17	5.30E+17	7.97E+17
F2	15 Clothes	1.39E+19	1.39E+19	1.38E+19	1.61E+19	7.94E+18	9.43E+18	8.36E+18	1.18E+19
	16 Cement	1.79E+19	1.88E+19	1.93E+19	2.04E+19	2.50E+19	2.91E+19	2.99E+19	3.43E+19
	17 Iron bars	1.45E+19	1.57E+19	1.88E+19	1.62E+19	2.09E+19	1.68E+19	5.50E+18	2.21E+19
	18 Build. materials	2.05E+18	4.79E+18	2.80E+18	3.60E+18	4.06E+18	2.93E+18	4.54E+18	4.40E+18
	19 Mechanics	2.20E+18	1.81E+18	1.90E+18	2.19E+18	3.18E+18	1.69E+18	1.42E+18	5.35E+18
	20 Fertilizers	1.20E+19	1.31E+19	1.58E+19	1.39E+19	1.53E+19	1.54E+19	1.42E+19	1.81E+19
	21 Others chemicals	1.30E+19	1.79E+19	1.52E+19	2.01E+19	2.25E+19	2.17E+19	1.39E+19	2.09E+19
	22 Miscellan. goods	7.55E+19	6.67E+19	9.46E+19	9.49E+19	1.79E+20	1.29E+20	1.78E+20	1.62E+20
U	*Total Emergy flow*	5.98E+20	6.55E+20	6.93E+20	7.09E+20	8.23E+20	7.78E+20	8.18E+20	8.24E+20

Note: To avoid double counting for total emergy flows, only the largest emergy input, among sun, rain and wind, has been considered for Table 2 calculation.

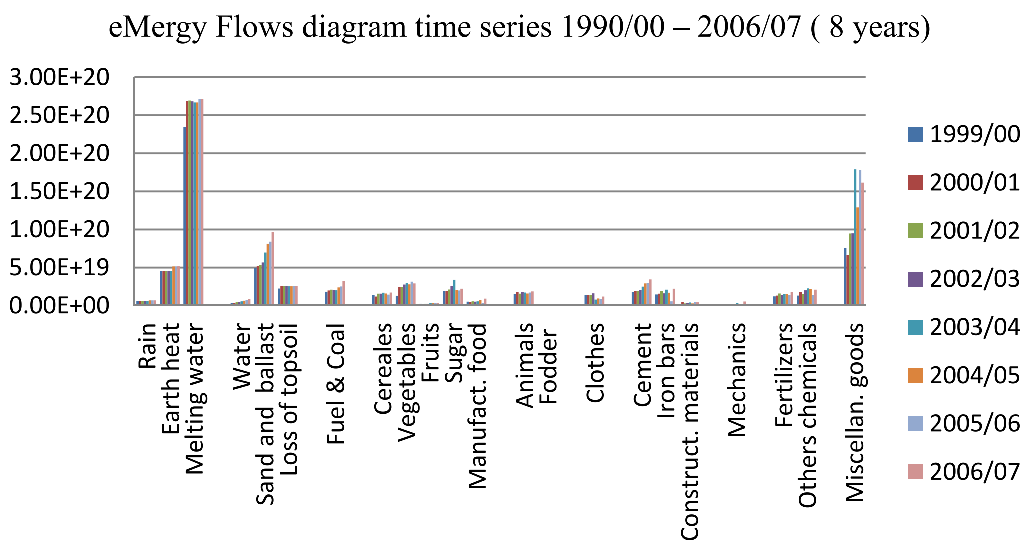

Figure 3. *Emergy inputs to the system – time series 1990/00 – 2006/07.*

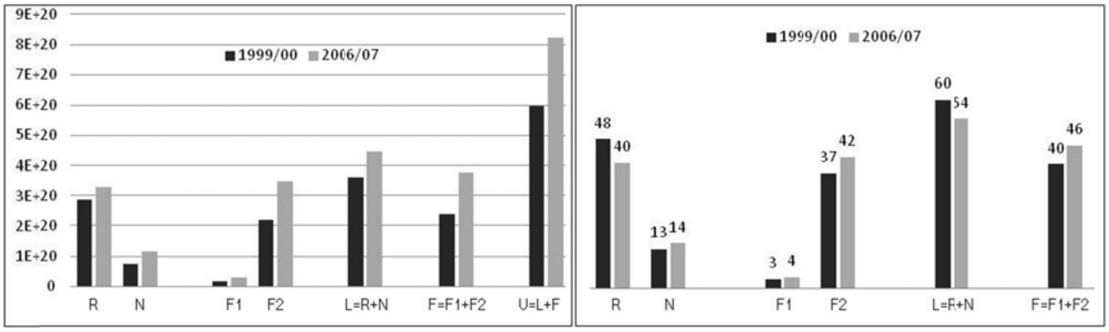

Figure 4. *Comparison of emergy flow categories (1999/00 vs 2006/07).*

Table 2. Emergy indices for Leh district and all India (1999/2000 - 2006/07)

	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	All India 2000
EpP = U / Pop.	5.41E+15	5.75E+15	5.91E+15	5.91E+15	6.71E+15	6.20E+15	6.37E+15	6.28E+15	5.24E+15
ED = U / Area	1.32E+12	1.45E+12	1.53E+12	1.57E+12	1.82E+12	1.72E+12	1.81E+12	1.83E+12	1.79E+12
Renew. %	48	49	46	45	39	42	40	40	28
ELR = (N+F)/R	1.09	1.05	1.16	1.22	1.59	1.39	1.48	1.50	2.53
EIR = F/(N+R)	0.66	0.63	0.72	0.74	0.97	0.78	0.83	0.85	0.17
EYR = U/F	2.52	2.58	2.40	2.34	2.03	2.29	2.20	2.18	1.39

Figure 4 shows that all flow categories are increased, in absolute terms, in the interval under investigation. A decrease in renewability and a parallel increase in the use of local non renewable resources and imported goods must be acknowledged. Moreover, the inputs from outside the system are increasing in percentage while the weight of local resources is decreasing. This is reflected also in the emergy indices presented in Table 2.

The %R decreases from 48 to 40% and this is in line with the increase in ELR. It indicates that the tendency towards the use of non-renewable (both local and imported) can be a threat to the system in the future, also due to its intrinsic marginality and resource scarcity. The dependence on external inputs is also highlighted by the EIR, slightly increasing, even though local resources still play the most important role. The slow decrease in EYR represents, however, a decreasing contribution of [R+N] to the emergy used in the area. The emergy per capita increased by 16% in the period under study, especially in the first 5 years, indicating that the development is generating a slow increase of resource consumption. Also the ED is slightly increasing, but since the ratio is related to the portion of land that is really accessible (the high mountainside is not considered in the reporting area), the actual concentration of human settlements is very low and large portions of land remain free from direct human influence.

Overall, the district of Leh is not particularly stressed, but the socio-economic dynamics of the last decades are generating changes especially in population and market organization, as well as in flow dimension, job opportunity, infrastructures (urban, rural), tourism system, agroproduction. Ladakh society is in transition from a traditional land based economy to a modern structure involving different set of resources and also influencing culture and social behavior.

A focus on the land-based economy can derive from the investigation of the traditional farming system. Table 3 presents the emergy inputs to 5 crop production systems. All the fields are characterized by the same annual contextual conditions (solar radiation, wind speed and direction, rainfall, geothermal heat, together with humidity, soil and land relief) but by different area, quantity of water for irrigation, and quantity of organic manure utilized. The main emergy input is meltwater, also characterized by high UEV. Human and animal work and seed can be considered as feedback flows. Loss of topsoil is not included because the farmers have always been able to maintain soil functions year after year, thanks to crop rotation and excreta recycling. Finally, no input from outside the system is necessary to support the production. Yield is often good, so that the UEVs of the products (Table 4) are comparable with those of similar products from conventional (intensive) agriculture.

Also topsoil can be considered a co-product of the entire system, whose UEV is given by dividing the entire emergy flow (everything that is necessary in order to have a residue to be recycled in the ground) by the energy embodied in manure conferred in the fields minus the energy loss due to top soil erosion and cultivation. Formally:

$$UEV_{soil}\ [semj/J] = total\ emergy\ [semj/yr]\ /\ (energy\ conferred\ with\ manure - energy\ loss\ by\ erosion\ and\ cultivation)\ [J/yr].$$

The result of this calculation (1.62×10^7 semj/J – see Appendix C for details) is a site-specific UEV of man-made agricultural fertile soil: it is the product of centuries of fair resource management aimed at concentrating and storing (indirect) solar energy into the ground and can be used in those cases in which chemical fertilizers are progressively used in fields that were previously cultivated with a traditional soil fertility management, as in the surroundings of the Leh town.

Overall, this kind of system has been able, for a very long time, to produce, select and recycle all the matter and energy necessary for the activity to be maintained indefinitely. It has always been well integrated within the ecosystem dynamics, using resources without compromising their availability and closing cycles. Problems related to resource scarcity and unfertile soil have been tackled through careful management and social control. At the same time, however, the fact that only few inputs are used to generate agroproducts for people's subsistence implies that the vulnerability, as a lack of resource redundancy, of this system must also be taken into consideration; moreover, the dependence on remote water sources, climatic events, together with other factors such as population growth in certain areas and the transition of society towards modernization, may influence the delicate relationship between man and its environment.

Table 3. Emergy inputs to the traditional farming system. Baseline: 15.83×10^{24} semj/yr (see Appendix B for calculations and UEVs).

	Input		Unit	Barley	Wheat	Peas	Mustard	Fodder
	Field area		m^2	1700	1750	575	1000	2825
1	Sunlight		J/yr	1.10E+13	1.13E+13	3.72E+12	6.47E+12	1.83E+13
		emergy flow	semj/yr	1.10E+13	1.13E+13	3.72E+12	6.47E+12	1.83E+13
2	Rain		g/yr	1.77E+08	1.82E+08	5.98E+07	1.04E+08	2.94E+08
		emergy flow	semj/yr	2.56E+13	2.64E+13	8.67E+12	1.51E+13	4.26E+13
3	Wind		J/yr	5.49E+08	5.65E+08	1.86E+08	3.23E+08	9.12E+08
		emergy flow	semj/yr	1.34E+12	1.38E+12	4.55E+11	7.91E+11	2.23E+12
4	Earth heat		J/yr	2.95E+09	3.04E+09	9.97E+08	1.73E+09	4.90E+09
		emergy flow	semj/yr	1.70E+14	1.75E+14	5.76E+13	1.00E+14	2.83E+14
5	Meltwater		g/yr	4.28E+08	5.39E+08	1.29E+08	2.24E+08	3.16E+08
		emergy flow	semj/yr	2.74E+15	3.45E+15	8.24E+14	1.43E+15	2.02E+15
Total emergy flow = 2 + 4 + 5			semj/yr	2.94E+15	3.65E+15	8.91E+14	1.55E+15	2.35E+15

Table 4. Agroproducts of the farming system (in g and J) and corresponding Unit Emergy Values.

Output	Unit	Barley	Wheat	Peas	Mustard	Fodder
Grain	g/yr	3.41E+05	3.41E+05	4.80E+04	8.00E+04	-
	J/yr	5.58E+09	5.50E+09	7.85E+08	1.57E+09	-
Straw	g/yr	4.82E+05	4.81E+05	7.26E+04	1.20E+05	2.26E+06
	J/yr	7.79E+09	7.55E+09	1.14E+09	1.89E+09	4.10E+10
UEVs						
Grain	semj/g	8.61E+09	1.07E+10	1.86E+10	1.94E+10	-
	semj/J	5.27E+05	6.64E+05	1.13E+06	9.87E+05	-
Straw	semj/g	6.09E+09	7.60E+09	1.23E+10	1.29E+10	1.04E+09
	semj/J	3.77E+05	4.83E+05	7.80E+05	8.21E+05	5.73E+04

CONCLUSION

The system under study seems to be an example of compliance with the rules of sustainability, i.e. durability, respect of biophysical limits, preservation of relations among people and between the community and the environment (see Pulselli *et al.* 2008). At the same time, the extreme climatic conditions and resource scarcity have always been crucial in determining the limiting factors of local development: these limits must be carefully considered in order to assure sustainable perspectives. For long time, "renewability" has been the keyword of the Ladakhi attitude and local nonrenewable natural capital has not been systematically depleted. However, modern dynamics are slightly influencing the impact of the population on the environment; consequently, attention should be paid to the use of resources, both local and imported, and land, and some tools must be adopted to investigate these aspects.

Emergy gives the opportunity to improve the knowledge on the dynamics of this system. This is a prerequisite for checking its state under the influence of modernization and globalization. In stating how to implement the Ladakh Vision Document, local authorities and stakeholders expressed the need of coordination and convergence among the components of the system and a systematic investigation in order to gain the information necessary to implement right programs and plans. In our opinion, emergy gives the basis for collecting and representing this information in an organic way; furthermore, it seems an efficacious and suitable tool in particular for this system in which the link between human activities and the environment is very strong.

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APPENDIX

Appendix A. Calculation and UEVs for Table 1

(1) Rain = (District area) m^2 x (annual average rainfall) m/yr x (water density) 1E+06 g/m^3 = g/yr. Annual average rainfall = 0.104 m/yr (Archer & Fowler 2004). (2) Earth heath = (District area) m^2 x (heat flow) W/m^2 x (365 x 24 x 60 x 60) (one year period in second) = J/yr. Average heat flow = 0.055 W/m^2 (Hochstein & Regenauer-Lieb 1998). (3) Meltwater = (Irrigated area) m^2 x (evapotraspiration supply by irrigation) m/day x (cropping season avg. days per year) day/yr x (water density) 1E+06 g/m^3 = g/yr. Average evapotraspiration = 0.0043 m/day (Osmaston 1994); cropping season avg. days per year: 93 (LAHDC-L 2009a). (4) Water = (Resident + Floating population) pc x (annual estimated per capita consumption) m^3/pc yr x (water density) 1E+06 g/m^3 = g/yr. (5) Sand & Ballast = (number of imported cement bags per year) n° x (bag weight) 50 kg/bag x 5 (assumed the following quantity to make regular concrete: 1 part in weight of cement + 2 parts dry sand + 3 parts dry stone (+ 1/2 part water)). (6) Loss of top soil = (Irrigated Area) m^2 x (average speed erosion) g/m^2 yr x (percentage of organic matter in soil) %/100 x (average energy content in organic matter) J/g = J/yr. Average erosion rates = 1.00 E+06 g/ha yr = 1.00 E+02 g/ m^2 yr (Dawa 2008), organic matter 0,68 % (Sagwal 1991), energy contents 20930 J/g (Odum 1996). From item 7 to 22, the quantity of manufactured goods, fuel, food, and other commodities imported into Leh District, expressed in g/yr (and in some cases transformed into J/yr), has been calculated by scaling down aggregated data for Jammu & Kashmir State, referred proportionally to the number of inhabitants or workers employed in each specific manufacturing sector.

Values and references for UEVs: 1.45E+05 semj/g n° 1, 1.68E+09 semj/g n° 5, 6.69E+04 semj/J n° 7 only for Coal, and 1.68E+09 semj/g n° 18 only for Quarry (Odum *et al.*, 2000); 5.78E+04 semj/J n° 2 (Odum, 1996); 6.40E+06 semj/g n° 3 (Odum, 2000); 3.42E+06 semj/g n° 4, 3.04E+09 semj/g n° 16 (Pulselli *et al.*, 2009); 1.62E+07 semj/J n° 6 (this study); 2.92E+09 semj/g Petrol, 2.83E+09 semj/g Diesel, 3.11E+09 semj/g GPL, 2.64E+09 semj/g Lubricant, 2.88E+09 semj/g Kerosene Oil, all n° 7 for Fuel (Bastianoni *et al.*, 2009); 1.36E+09 semj/g n° 8, 6.79E+08 semj/g n° 18 only for Wood, 3.97E+08 semj/g n° 14 (Castellini *et al.*, 2006); 1.09E+10 semj/g n° 9 and 4.05E+10 semj/g n° 20 (Brandt-Williams 2002); 1.44E+09 semj/g n° 10 (Niccolucci *et al.*, 2010); 1.40E+10 semj/g n° 11 (Simoncini *et al.*, 2009); 3.24E+09 semj/g n° 12 (Ulgiati *et al.*, 1993); 2.23E+10 semj/g n° 13 (Ulgiati *et al.*, 1994); 1.29E+11 semj/g n° 15, 1.01E+10 semj/g n° 17 and n° 19, 1.53E+10 semj/g n° 21 (Campbell *et al.*, 2005); 1.41E+09 semj/g n° 18 only for Glass (Odum & Odum, 1987); 1.30E+10 semj/g n° 22 (Odum & Odum, 1983).

Appendix B. Calculation and UEVs for Table 3

(1) Sunlight = (field area) m^2 x (average annual insolation) J/m^2 yr x (1-albedo) = J/yr. Annual average insolation = 7.80E+09 J/m^2 yr (Jacobson 2000); albedo 0.17 (bare soil Markvart & CastaŁżer 2003). (2) Rain = (field area) m^2 x (annual average rainfall) m/yr x (water density) 1E+06 g/m^3 = g/yr. Annual average rainfall = 0.104 m/yr (Archer & Fowler 2004). (3) Wind = (field area) m^2 / (altitude) m x (density of air) 1.23 kg/m^3 x (average wind speed square) $(m/s)^2$ x (diffusion coefficient) m^2/s x (one year period in second) (365 x 24 x 60 x 60) s/yr = J/yr. Altitude = 3650 m asl; average wind speed = 1.4 m/s (Bansal & Yadav 2000); diffusion coefficient = 15.1 m^2/s (Campbell 1998). (4) Earth heath = (field area) m^2 x (heat flow) W/m^2 x (365 x 24 x 60 x 60) (one year period in second) = J/yr. Average heat flow = 0.055 W/m^2 (Hochstein & Regenauer-Lieb 1998). (5) Meltwater = (cultivated area) m^2 x (height of water irrigation) m/day x (cropping season avg. days per year) day/yr x (water density) 1E+06 g/m^3 = g/yr. Height of water diverted into field calculated through the volume measured during one day irrigation = 0.028 m/day (personal measure); number of days for irrigation during one year cropping season: 9, 11, 8, 8, 4 day/yr respectively for barley, wheat, peas, mustard, and fodder (farmer communication).

Values and references for UEVs: 1 semj/J, for input n° 1 and 5.78E+04 semj/J for input n° 4 (Odum 1996); 1.45E+05 semj/g for input n° 2 and 2.45E+03 semj/J for input n° 3 (Odum *et al.* 2000); 6.40E+06 semj/g for input n° 5 (Odum 2000).

Appendix C. Calculation and UEVs of man-made soil

Quantity of manure (barley and wheat only) = 2725 kg/yr; energy content in manure = 72 kcal/kg (Gezer *et al.* 2003); total energy contribution to soil by manure = (quant. of manure) kg x (energy content in manure) kcal/kg x 4186 J/kcal = 8.21E+08 J/yr. Energy lost from top soil erosion in cultivated area = 6.8E+03 g/ha/yr (org. mat. loss) x 5 kcal/g (Odum 1996) x 4186 J/kcal = 1.42E+08 J/ha/yr. Loss of organic matter = m^2 (field area) x 100 g/m^2 yr (mass of topsoil loss) x 0.0068 (organic matter content) = 6.8E+03 g/yr. Erosion rate = 1.0 tonnes/ha yr (Dawa 2008) equals to 100 g/m^2 yr; average of organic matter content in soil 0.68 % (Sagwal 1991).