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Emergy evaluation on the production, processing and export of coffee in Nicaragua

M. Cuadra[a,b,*], T. Rydberg[b]

[a] Universidad Nacional Agraria-UNA, Apdo, 453 Managua, Nicaragua
[b] Swedish University of Agricultural Sciences – SLU, Department of Ecology and Crop Production Science, Box 7043, SE-750 07 Uppsala, Sweden

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ABSTRACT

An emergy evaluation was conducted on the systems of coffee (*Coffea arabica* L.) production, processing and export in Nicaragua in order to evaluate the environmental contributions to the tradeable products and thus enrich the discussion about fair trade. The emergy indices calculated were: transformities, % renewable, environmental loading ratio and emergy exchange ratio. The different emergy indices showed that coffee processing and industrialization are intensive activities, requiring large environmental support. The calculated transformities for coffee cherries, green coffee, roasted coffee and instant coffee were 3.35E+05, 1.77E+06, 3.64E+06 and 1.29E+07 sej/J, respectively. The emergy exchange ratio demonstrated that almost all purchasers benefit when buying green coffee from Nicaragua. The sales of roasted or instant coffee is of benefit for Nicaragua. This means that Nicaragua exports much more emergy in the green coffee sold than it imports in the money received for the coffee, thereby depleting its local natural resources. A fair price to pay for green coffee would range from 0.7 to 3 times the actual price paid now. Emergy analysis is a powerful tool in assessing the direct and indirect environmental requirements for a good or service and it is thereby able to evaluate trade in a much more comprehensive way than is usually done using standard economic measures. Inequity in international trade can be detected with this evaluation methodology. Therefore, we propose the use of emergy exchange ratio (EER), emdollars and emprice values as useful measures when trying to develop more sustainable and fair trade conditions.

1. Introduction

In this study, coffee production, processing and export in Nicaragua were evaluated using emergy analysis in order to: (1) assess the environmental support to coffee cherries, green coffee, roasted coffee and instant coffee and (2) evaluate the exchange of emergy that the country obtains from the sales of green, roasted and instant coffee on the international market. Emergy was used as a measure since it expresses the products sold and the money received on a common physical basis. We believe that information obtained from this type of integrated economical and ecological assessment study will prove useful for the sustainable management of environmental resources and, in this particular case, for decisions concerning coffee production and export of refined coffee products.

Emergy analysis can evaluate any system's energy flow on a common energy basis, according to Odum (1996). By using this open systems analysis method, it is possible to evaluate

* *Corresponding author*. Tel.: +505 2 33 22 71/505 2 33 18 45; fax: +505 2 33 18 45/505 2 33 12 67.
E-mail addresses: Margarita.Cuadra@una.edu.ni (M. Cuadra), Torbjorn.Rydberg@evp.slu.se (T. Rydberg).
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the inputs from the human economy and those from the environment. Money expresses the willingness to pay and therefore does not cover all aspects of the work done by nature. It operates where people are involved with processing and commerce. Money is therefore not a descriptor of real wealth when real wealth means to cover account for the work done by nature, but it is used to hasten and steer processes that affect human business activities and exchanges of goods (Rydberg, 2003).

Different countries have different emergy/USD ratios as shown by Odum and Arding (1991), Odum (1996), Rydberg and Jansén (2002), Brown (2003) and others. It is difficult to evaluate the international exchange between nations without considering the different emergy:money ratios for the currencies of different nations (Brown et al., 2003). Brown (2003) suggests that balanced trade is achieved when emergy of imports and exports of trading partners is equal. For example, USA's EMR is about 1.06E+12 sej/USD, while that of Nicaragua is 15.8E+12 sej/USD. As a result, the USA enjoys a trade advantage of about 16–1 when it trades with Nicaragua. Emergy evaluation often shows that such exchanges are not equal (Odum and Odum, 2001).

A consequence of the imprecise relationship between money and the environment is that even if trade is balanced between nations in monetary terms, there is an inequity in trade between nations with a high emergy:dollar ratio and those countries with a low emergy:dollar ratio. The trade inequity measured as the ratio of emergy received:emergy exported is huge and has been reported in studies by Odum (1996) and Brown (2003). When trade is carried out between nations, the suppliers of raw commodities give to the buyer more than they receive in exchange (Odum, 1996). When trade is measured in emergy, there is usually a large net emergy flow to the more economically developed buyer for two reasons. First, environmental products that are easy to extract have a high portion of 'free' emergy. Second, the emergy:money ratio is larger in less economically developed nations that supply the product than in those countries that purchase the product. More refined and manufactured products have a higher price due to the fact that more services and labour are required to make the product. The proportion of paid emergy increases by further processing and the proportion of unpaid free emergy decreases. This means that trade might be more balanced if raw products were processed to some extent before being sold for export.

Coffee is the most important export crop for the economy of Nicaragua, representing in economic terms 8.8% of gross national product and 64% of total agricultural exports (MAG, 1998; Robleto, 2000; Aguilar, 2001; BCN, 2002). In spite of its importance, coffee production has faced many limitations, such as the high dependence on imports to maintain coffee yields (fertilizers, pesticides, fuels) and to process coffee cherries and green coffee (machinery, technology, imported coffee, electricity, fuels and other goods). The poor profitability of the production and the low international prices for coffee have caused many bankruptcies in the sector (MAG, 1998; Robleto, 2000). The Ministry of Agriculture of Nicaragua has made a study of the chain of coffee production and processing (MAG, 1998) with the aim of assessing the economic feasibility of developing an agro-industrial chain of coffee production. However, the relationship to the environmental processes needed to support the activity is not dealt with in that study. Besides, there are indirect costs of lost ecosystem services due to coffee plantations. For example, pollination by wild bees increased coffee yields and coffee quality near forest patches (Ricketts et al., 2004; De Marco and Monteiro, 2004). Other negative consequences of forest clearing for agriculture are increased soil erosion, lower soil fertility and reduced biodiversity (Matson et al., 1995; Green et al., 2005). One of the main strengths of emergy analysis is the possibility to internalize these external costs.

Specific objectives of this study were: (a) to assess whether the export of refined instead of green coffee would result in an increased benefit for Nicaragua; (b) to compare the emergy to money ratio of coffee products through the production chain; (c) to determine the USD price that would lead to equitable resource exchange.

2. Materials and methods

2.1. *Emergy analysis*

Emergy analysis evaluates resources and services in both ecological and economic systems on a common energy basis. It quantifies the direct and indirect environmental work for generating a resource or a service (Odum, 1996). The parameter is solar emergy and it is defined as the solar available energy (or exergy) previously required directly and indirectly to make a product or service. The energy flow network supporting each driving force of importance for the system studied is expressed in solar emergy units. Solar transformity is defined as the solar emergy required to make 1 J of a service or a product. Its units are solar emjoule per Joule (sej/J). A product's solar transformity is its solar emergy divided by its available energy.

The theoretical and conceptual basis for the emergy methodology is grounded in thermodynamics and general systems ecology (Brown et al., 2000). Emergy analysis is based on observations that both ecological systems and human socioeconomic systems are energetic systems, which exhibit characteristic designs that reinforce energy use. The dynamics of these systems can be measured and compared on an equal basis using energy metrics (Odum, 1988; Odum et al., 2000b). Brown et al. (2000) term the methodology emergy synthesis since it is an approach that strives for understanding the wholeness of the system and its relation to surrounding systems rather than the dissection and fragmentation that is involved in analysis. A more comprehensive description of the concept, principles and applications of the methodology can be found in Odum (1996) and Brown and Herendeen (1996).

2.1.1. *Money and real wealth*

Money by itself is not real wealth. Money circulates among people who use it to buy real wealth. Money measures what people are willing to pay for products and services while emergy measures real wealth (Odum and Odum, 2001). Real wealth or wealth potential is food, minerals, fuels, information, art, biodiversity, etc. and can be scientifically measured using emergy (Odum, 1996). By wealth potential we mean the

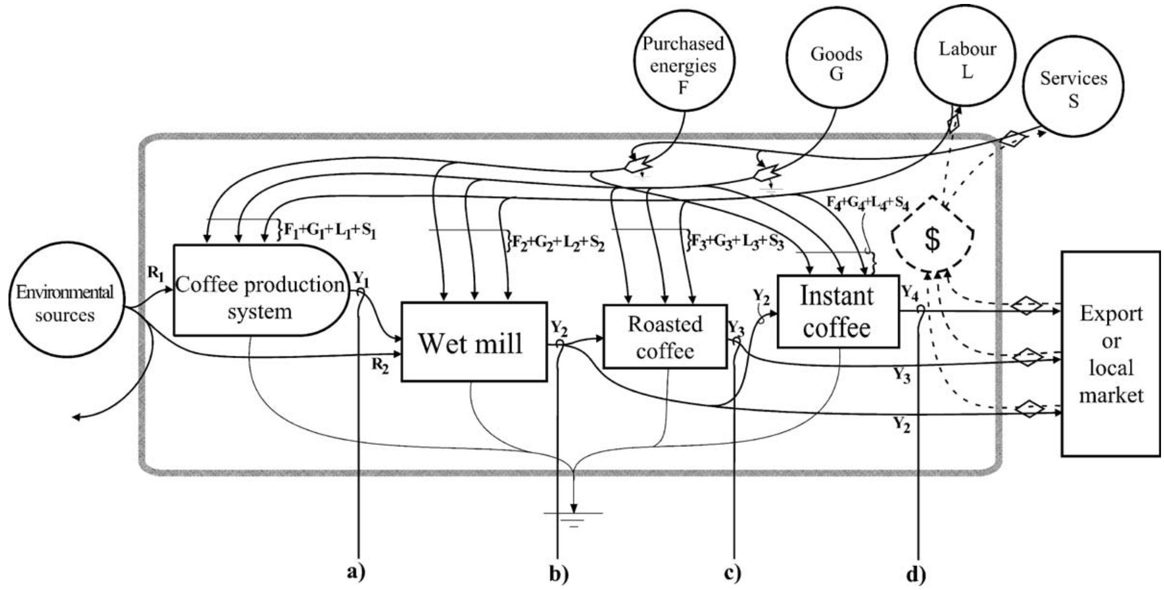

Fig. 1 – System diagram of coffee production, processing and exportation in Nicaragua. Letters a–d indicate where the emergy evaluation is performed: (a) coffee production in the field, coffee cherries harvested, (b) wet mill processing, (c) roasted coffee production, (d) instant coffee production. Letters in figure correspond to those in Table 1.

natural resource base, local and imported, that is supporting a country.

Emergy as a donor based value system and maximum power principle and in the relation to that something about money and the willingness to pay as a receiver based value system. That means that the measures give totally different information about the system and that emergy is focusing on giving information on the dependence upon the surroundings.

2.1.2. Details of the coffee system

Fig. 1 presents an overview of the systems using energy system symbols. The diagram shows the chosen system boundaries and the energy sources driving the processes. The different energy sources were aggregated into: environmental energies (R) shown on the left-hand side of the diagram, purchased energies (F) such as fuel and electricity, goods (G), labour (L), services (S) which include direct labour used in the different processing steps and labour needed for processing purchased goods, and yield (Y). Each processing step was evaluated and indicated with letters a–d. All letters in the diagram correspond to the letters used in Table 1.

2.1.3. Emergy indices and definitions

Emergy indices were calculated for each step of the production chain of coffee. Further discussions and definitions of terms and indices can be found in Odum (1996), Ulgiati et al. (1995), Brown and Ulgiati (1997) and Brown et al. (2003).

2.1.3.1. Percent renewable (%Ren), (R/Y). This is the ratio of renewable emergy to total emergy use. It is the percentage of the total emergy driving a process that stems from local renewable sources. It reflects some aspects of the system's sustainability or ability to be driven by local renewable resources. In the end, only processes with high %Ren are ecologically sustainable. Since 77% of the total emergy budget for Nicaragua according to Cuadra and Rydberg (2000) stems from renewable sources we also calculated the %Ren for coffee production and the processing steps with an addition of the renewable emergy that supports labour and services. By doing this, we are not only considering the local renewable emergy but also the renewable portion of the purchased emergy via labour and services. In this presentation we call this Adjusted %Ren.

All activities, products and processes and all nations have different emergy signatures, meaning that they are formed and they use different resources for their maintenance and development. Some of the emergy flows that drive those processes can be categorized as renewable and other are depleted in a rate that is faster than they can be renewed and therefore they are called non-renewable.

2.1.3.2. Environmental loading ratio, $ELR = (NR + F + G + L + S)/R$. Renewable resources and products and by-products from environmental processes are necessary for our prosperity and our life on the globe. If all those flows are directed to human processing and market products we will risk to have an environmental catastrophe due to environmental degradation and losses of life-support functions. For a time period we can run our economy on non-renewable resources, but those sources are limited in size and can only last for specific time. In a longer time perspective the entire economy of the globe is dependent on the renewable emergy sources and a healthy vital environment that can provide us with adequate life-support functions.

The environmental loading ratio is the ratio of all local non-renewable and import flows needed to operate the process to the flow from the local renewable resource. The emergy-loading ratio indicates the pressure that a production process places on the local environment. If this ratio is looked upon

Table 1 – Emergy analysis of the systems of coffee production and processing in Nicaragua

Note		Item	Annual flow[a]	Transformity[b]	Solar emergy[c]
(a) Conventional coffee production					
R_1	1	Solar insolation (J)	1.64E+13	1	16
	2	Wind, kinetic energy (J)	1.22E+11	2.51E+03	307
	3	Rain, chemical energy (J)	2.47E+10	3.06E+04	756
	4	Rain, geopotential energy (J)	3.83E+08	1.76E+04	7
F_1	5	Fuels and lubricants (J)	5.49E+08	1.11E+05	61
G_1	6	Nitrogen (g)	1.62E+04	6.62E+09	108
	7	Phosphate (g)	4.06E+04	9.35E+09	380
	8	Potassium (g)	1.35E+04	9.32E+08	13
	9	Urea (g)	1.93E+05	6.62E+09	1281
	10	Pesticides and fungicides (J)	4.25E+07	9.42E+04	4
	11	Water (J)	2,88E+07	8.06E+04	2
	12	Seeds (J)	2.48E+06	5.85E+04	<1
	13	Machinery and equipment (g)	2.61E+03	6.89E+09	18
	14	Buildings, wood (J)	1.66E+07	8.19E+03	<1
	15	Buildings concrete (g)	7.31E+04	2.42E+09	177
	16	Buildings, glass (g)	6.01E+01	2.69E+09	<1
	17	Buildings, iron and steel (g)	1.54E+01	4.45E+09	<1
L_1	18	Labour (USD)	8.28E+01	2.25E+13	1860
S_1	19	Fuels and lubricants (USD)	9.43E+00	2.25E+13	212
	20	Chemicals (notes 6–10) (USD)	8.64E+00	2.25E+13	194
	21	Water (USD)	2.18E+00	2.25E+13	49
	22	Seeds (USD)	2.01E+00	2.25E+13	45
	23	Machinery and equipment (USD)	2.22E+01	2.25E+13	498
	24	Buildings (USD)	8.24E+00	2.25E+13	185
	25	Harvest transportation (USD)	2.33E+01	2.25E+13	524
	26	Technical assistance (USD)	6.27E−01	2.25E+13	14
	27	Maintenance & repairing (USD)	6.70E+00	2.25E+13	151
Y_1	28	Coffee cherries (J)	1.95E+10	3.35E+05	6531
(b) Wet mill processing					
R_2	29	Water (J)	1.74E+06	8.06E+04	<1
F_2	30	Electricity (J)	1.03E+08	2.92E+05	30
G_2	31	Machinery and equipment (g)	1.33E+03	1.13E+10	15
	32	Buildings, concrete (g)	1.63E+04	2.42E+09	40
	33	Buildings, steel sheets (g)	1.49E+03	2.99E+09	4
L_2	34	Labour (USD)	1.49E+01	2.65E+13	396
S_2	35	Electricity (USD)	2.80E+00	2.65E+13	74
	36	Machinery and equipment (USD)	8.03E-01	2.65E+13	21
	37	Buildings (USD)	3.32E+00	2.65E+13	88
Y_2	38	Green coffee (J)	4.06E+09	1.77E+06	7 200
(c) Roasted coffee					
F_3	39	Gasoline and diesel (J)	1.64E+09	1.11E+05	181
	40	Electricity (J)	9.46E+08	2.92E+05	276
G_3	41	Water (J)	1.41E+07	8.06E+04	1
	42	Machinery and equipment (g)	5.84E+01	1.13E+10	1
	43	Buildings, concrete (g)	2.25E+03	2.42E+09	5
	44	Buildings, steel sheets (g)	4.47E+02	2.99E+09	1
L_3	45	Labour (USD)	1.70E+02	2.65E+13	4519
S_3	46	Electricity (USD)	2.31E+01	2.65E+13	613
	47	Water (USD)	2.38E+00	2.65E+13	63
	48	Machinery and equipment (USD)	7.60E−01	2.65E+13	20
	49	Buildings (USD)	1.34E+00	2.65E+13	36
Y_3	50	Roasted coffee (J)	3.55E+09	3.64E+06	12918
(d) Instant coffee					
F_4	51	Purchased fuels (J)	6.34E+08	1.11E+05	70
	52	Electricity (J)	3.67E+08	2.92E+05	107
G_4	53	Water (J)	5.48E+06	8.06E+04	<1

Table 1 (*Continued*)

Note		Item	Annual flow[a]	Transformity[b]	Solar emergy[c]
	54	Machinery and equipment (g)	6.62E+01	1.13E+10	1
	55	Buildings, concrete (g)	8.72E+02	2.42E+09	2
	56	Buildings, steel sheets (g)	1.73E+02	2.99E+09	1
L_4	57	Labour (USD)	2.55E+01	2.65E+13	676
S_4	58	Electricity (USD)	1.09E+01	2.65E+13	290
	59	Water (USD)	1.13E+00	2.65E+13	30
	60	Machinery and equipment (USD)	6.27E−01	2.65E+13	17
	61	Buildings (USD)	3.47E−01	2.65E+13	9
Y_4	62	Instant coffee (J)	1.09E+09	1.29E+07	14121

Calculations are shown in Appendix 1.

[a] Annual flow in J, g, or USD/t.

[b] sej/unit.

[c] E+12 sej/t/year.

as an expression of non-renewable emergy to renewable local emergy, labour (L) and services (S) have to be considered as partly renewable (77%) and partly non-renewable (23%). This adjusted ELR is also presented in this study. NR in the formula indicates non-renewable local emergy sources. We have not found any information of dependence of this category in the studied systems.

2.1.3.3. *Emergy/money ratio (EMR)*. The total wealth of a nation is usually measured using GDP. This economic index measures only the monetary flows of a national economy. However, this index does not tell how much resource base or real wealth there is in a country. The total emergy use for a nation is something different that includes the global processes needed to generate the resources used by a nation or more correctly the potential that is possible to use.

The emergy to money ratio is the ratio of all emergy supporting the economy of a country to the gross domestic product (GDP) of the same country. This ratio is an average measure of the purchasing power for a nation when compared with ratios from other nations. With this measure, monetary flows can be expressed in emergy by multiplying them by the EMR.

2.1.3.4. *Emprice (Emp)*. The emprice (Emp) of a good is the emergy one receives for the money spent on it. Its units are sej/USD. This measure relates to each good or service individually. It has the same units as EMR, which estimates the average buying power of the currency.

Emergy flows of environmental resources can also be expressed in emergy-converted currency (such as emdollars), by dividing the emergy flow of the resources by the EMR. Emergy dollars are, for example, abbreviated as $Em, which makes it easier to distinguish them from dollars. This expression relates the human economy to its biophysical basis and is an estimation of the natural resources needed to generate the human services that each unit of money buys.

2.1.3.5. *Emergy exchange ratio (EER)*. This is the ratio of emergy exchange in a trade or purchase (Fig. 2). Trade could be carried out with two commodities or with sales of commodities. When a good is sold and money is received in exchange, both flows are converted to emergy units. The ratio is always expressed relative to one or other trading partner and it is a measure of the relative trade advantage of one partner over the other. The emergy exchange ratio between two different countries is calculated as the ratio between their EMRs. In trade between two nations, the country with the lowest EMR gains an average in emergy over those nations with higher EMR. The money buys more emergy abroad than it does at home.

In order to assess the inequity in terms of price paid for coffee, we calculated what would be a fair price to be received by the producer or processor of coffee. This fair price (USD/t) of the different coffee products was calculated as the product of the emergy exchange ratio (EER) and the price received (USD/t) for the coffee.

2.2. *The system of coffee production and processing*

The coffee production system evaluated was a conventional production system where the coffee bushes are grown together in a mixed stand with shade trees. After picking, the coffee cherries undergo several processes: washing, pulping, fermentation (or mucilage removal), washing, drying, hulling, cleaning and selection. The final product is washed green coffee. Wet milling is the main method of processing the coffee cherries in Nicaragua. About 80% of the green coffee produced in the country is exported to other countries (MAG, 1998). The remainder is used in the local industry for further processing in the form of roasting and solubilization. Roasting develops the fragrance and taste of coffee and the beans have to be roasted as late as possible before sale to prevent the loss of aroma (Renard, 1993). The preparation of instant coffee requires high investment in economic capital. The soluble coffee solids and volatile compounds are extracted and then dried into powder or granules. The soluble coffee solids

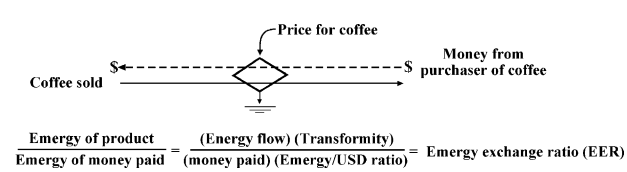

Fig. 2 – Diagram showing the solar emergy exchange of an economic transaction in the sales of coffee and the way it is calculated.

are extracted using water as the solvent. The extracts are dried using a spray drier (ITDG, 2003). Coffee is usually packed in polypropylene bags to preserve flavour and stored at low temperature, low humidity and free from pests in a shaded dry area. Most of the ground coffee is sold in the local market, while significant amounts of instant coffee are exported (CETREX, 2004).

2.2.1. Data used

Coffee production data were obtained from a coffee farm (San Marquito) in Masatepe (11°54′N, 86°08′W) during the period January–February 2001. These farm data were first published by Lundström and Olsson (2002) and raw data from their study were used in this evaluation. According to the Masatepe Coffee Farmers' Association, this farm is considered representative of conventional coffee production in the area.

Data on the processing of the coffee cherries and green coffee were obtained from two private coffee companies in Nicaragua (Ramírez, A., personal communication, 2003). All buildings, materials and machinery used in the system were converted to annual flows based on their expected life length. The life length for machinery was estimated at 40 years and for buildings 40–50 years. In order to avoid double counting of emergy in service and labour we reduced the emergy to dollar ratio by subtracting the contribution of emergy from the coffee-sector to the economy.[1] Emergy in services for the processing steps (15.8E+12 sej/USD) was calculated from a ratio of the average emergy flow per unit money flow for Nicaragua, (Cuadra and Rydberg, 2000). As the baseline for our emergy calculation, we used the emergy budget of the geobiosphere calculated by Odum et al. (2000a).

Data on energy content of coffee cherries were calculated from the content of fat, protein and carbohydrates in the pulp and seed (Pandoy et al., 2000) using the formula from Senser and Scherz (1991). The energy content of green coffee, roasted coffee and instant coffee was measured as the calorific value of combustion using the method described in ISO, 1928 (1995).

Data on the volume and price of exports of green and instant coffee were obtained from CETREX (2003, 2004). Data on the volume and price of exports of roasted coffee were obtained from the FAOSTAT database (FAOSTAT, 2003. http://faostat.fao.org/default.jsp. Accessed on 05/12/03).

Numbered footnotes to the tables describe the data sources, while calculation procedure is shown in Appendix 1.

3. Results

For the coffee production system (Table 1), the purchased services (S_1) contributed almost 29% of the total emergy. The services needed for making the machinery and equipment and in the transportation of harvest were the largest single items. Direct labour on farm (L_1) accounted for 28% of total emergy, and all goods (G_1, items 6–17) accounted for 30% of the emergy support required. Fuel (F_1) represented 1% of total emergy, while local renewable emergy (R_1) accounted for 12% of the total emergy for producing coffee cherries on farm. Adding the indirect renewable emergy in labour and services, the % renewable emergy part is 20.7%. The transformity calculated for the coffee cherries was 3.35E+05 sej/J.

The wet mill processing transforms the cherries into tradeable green coffee, adding more emergy. The largest emergy flow, 59% of emergy support to this process, was labour (L_2). Emergy for services paid for electricity, machinery and buildings added 28% to the process. Direct renewable emergy to the wet mill process, component R_2, was less than 1%. The adjusted %Ren accounted for 19.5%. The transformity increased and for green coffee was calculated to 1.77E+06 sej/J.

The process that transforms the green coffee into roasted coffee requires a large emergy support, most of all through labour ($L_3 = 79\%$). Emergy for services in electricity and fuels and for electricity (F_3) were the second largest flows to this process (11 and 8%, respectively). No direct renewable emergy flows were identified in this process. The total amount of emergy at this process step was two times larger than at the farm gate. The transformity for the roasted coffee was calculated to 3.64E+06 sej/J. The process of making instant coffee requires the green coffee beans to be roasted first. Thereafter, extra emergy is needed for the extraction and drying processes. The largest emergy inputs were similar to the roasting process. Labour (L_4), fuel and electricity (F_4) and services for electricity (item 58) were the dominant emergy flows to this process, too. The transformity for the instant coffee was calculated to 1.29E+07 sej/J.

3.1. Emergy indices of sustainability

A summary of the indices calculated for the different steps in coffee production and processing is presented in Table 2. The percent renewable (%Ren) and the adjusted %Ren decreased with the processing of coffee, with coffee production in the field showing the highest values (11.6 and 20.7%, respectively) and instant coffee the lowest values (5.4 and 12.7%, respectively). In contrast, the environmental loading ratio (ELR) and the adjusted ELR increased for each processing step, with coffee cherries showing the lowest values (7.6 and 3.8, respectively), and instant coffee the highest values (34.7 and 6.9, respectively).

3.2. Emergy benefit for Nicaragua with the sales of coffee

Table 3 shows the price in USD/t received for coffee and the emergy exchange ratio (EER) for trading to different countries and the calculated fair price.

In the local market, the highest price is paid for the green coffee (317 USD/t) and the lowest price for the coffee cherries (146 USD/t). In the international market, the highest average price is received by the instant coffee (7826 USD/t) and the lowest by the green coffee (1499 USD/t). When comparing individual countries, the prices received varied between countries and by quality. Sweden paid the lowest price for green coffee (1371 USD/t) while Denmark paid the highest price for the same quality (2845 USD/t). For instant coffee, Germany paid

[1] The contribution of coffee production to the agricultural sector is around 13% (BCN, 2002).

Table 2 – Summary of the emergy indices of % renewable (%Ren), adjusted %Ren, environmental loading ratio (ELR), and adjusted ELR for the different coffee alternatives

Coffee alternative	% Ren[a]	Adjusted %Ren[b]	ELR[c]	Adjusted ELR[d]
Cherries[e]	11.6	20.7	7.6	3.8
Green coffee[e]	10.5	19.5	8.5	4.1
Roasted coffee[f]	5.9	13.6	16.1	6.3
Instant coffee[f]	5.4	12.7	34.7	6.9

[a] % Renewable (R/Y).
[b] Adjusted %Ren = R/[R + F + G + (non-renewable portion of L + S)].
[c] Environmental loading ratio (F + G + L + S)/R.
[d] Adjusted ELR = [F + G + (non-renewable portion of L + S)]/R.
[e] Local market.
[f] International market.

Table 3 – Price received, emergy exchange ratio and fair price calculated for the production, processing and export of coffee

Coffee alternative	Price (USD/t)[a]	EER[b]	Fair price (USD/t)[c]
Local market			
Coffee cherries	146	1.99	209
Green coffee	317	1.01	321
International market			
Green coffee[d]	1499	1.90	2845
Australia	2165	0.73	1581
Denmark	2845	0.90	2566
Italy	1529	1.92	2935
Sweden	1371	2.17	2976
Switzerland	1987	3.08	6123
USA	1453	2.78	4043
Roasted coffee[e]	4580	0.90	4105
Instant coffee[f]	7826	0.48	3752
Costa Rica	7459	0.23	1740
Germany	4000	2.88	11514
Guatemala	8409	0.43	3592
USA	8512	0.93	7929

[a] Price in USD/t from CETREX (2003) and FAOSTAT (2003).
[b] EER: emergy exchange ratio for the price received = emergy in product/(price in USD × emergy/USD ratio for country).
[c] Fair price in USD/t = emergy exchange ratio for the real price received × real price in USD/t.
[d] Average price received, EMR used is average of countries that buy green coffee in sample (1.51E+12 sej/USD).
[e] Average price received, EMR used is average of countries that buy green and instant coffee in sample (1.87E+12 sej/USD).
[f] Average price received, EMR used is average for countries that buy instant coffee in sample (2.24E+12 sej/USD).

the lowest price (4000 USD/t), while the USA paid the highest price (8512 USD/t).

There is a clear tendency for a decrease in the emergy advantage for the buyer as coffee undergoes more processing. In the local market, coffee cherries had the highest advantage for the purchaser (1.99), and green coffee the lowest (1.01). On the international market, the highest average advantage was obtained by the purchasers of green coffee (1.90), and the lowest by the purchasers of instant coffee (0.48). Of different countries studied, Switzerland was the nation with the highest gain when purchasing green coffee (3.08), while Australia and Denmark actually showed a disadvantage (0.73 and 0.90, respectively). Germany was the country with the highest gain when purchasing instant coffee (2.88), while on the other hand Costa Rica, Guatemala and the USA actually showed a disadvantage (0.23, 0.43 and 0.93, respectively).

4. Discussion

4.1. *Emergy indices for coffee production, processing and export*

As expected, the transformation of coffee beans into roasted and instant coffee is an intensive activity, requiring large inputs. This intensity of the process was demonstrated by the transformities and high ELR obtained for these steps. These values were caused by the great amount of inputs from the economy and very little renewable inputs from within the system, ranging from 5.9% for roasted coffee to 5.4% for instant coffee. This indicates that the coffee processing systems have a low degree of long-term sustainability, since a large portion of their inputs derives from non-renewable sources.

But, when we consider that labour and services have a high portion of renewable emergy (adjusted %Ren), the results ranged between 2.4 and 2.8 times higher than with %Ren. For the ELR, the adjusted values were between 1/5 and 1/2 those of the normal way to calculate ELR. This is because the normal way to calculate %Ren and ELR makes the assumption that labour and services are non-renewable, while in the case of Nicaragua it has been calculated by Cuadra and Rydberg (2000) that 77% of total emergy use is from renewables, and this includes labour and services.

However, the calculation of these indices depends on how they should be interpreted and understood. For example, if the ELR is looked upon as an indicator of the amount of pressure or load that the production process places on the local environment regardless its background, then no adjustment is needed. It is also of importance to make clear that a high ELR does not necessarily indicate a stress or load that leads to environmental degradation. A high ELR indicates the system's distance from the state of environmental equilibrium, and a high dependency from outside or a high degree of support from outside. The system can be dependent on outside sources that do not cause environmental damage. The system becomes non-sustainable due to the inputs if they are not likely to last.

The EER showed that there were benefits for the purchasers of coffee cherries and green coffee (Table 3). However, a more processed product decreased the emergy benefit for the purchaser, situation that resulted in benefits for Nicaragua. Economists and businessmen who claim that the sale of more processed and value-added products will result in increased benefits and gains for the economy of a country (La Prensa, 2003) are right, and evaluated in emergy those processing steps show to be advantageous for the economy.

The emergy indices of EMR (emergy to money ratio) and exports to imports ratio are indicators of the balance in trade at the national level. According to Cuadra and Rydberg (2000) the EMR for Nicaragua was 15.8E+12 sej/USD and the exports to imports ratio was 2:1. These results show an imbalance in trade not favourable for Nicaragua. In average, the nation is exporting twice as much emergy than importing. If the value of the exports to imports ratio is larger than the EER for coffee, then the exports of coffee improves the imbalance. On the other hand, if the EER for coffee is larger than the exports to imports ratio, then, the export of coffee deteriorates the imbalance and should not be continued.

In Tale 3, we present the EER's for the exports of green, roasted and instant coffee. The EER's for green, roasted and instant coffee are lower than the ratio of exports to imports for Nicaragua (ratio exports: imports = 2.14–1, in Cuadra and Rydberg, 2000). This means that in average the exports of green, roasted and instant coffee have shown to be of advantage for Nicaragua and should be continued, because the export of coffee improves the imbalanced situation for Nicaragua. Stopping the production and export of coffee would only deteriorate the imbalance of emergy.

But if we look at individual countries, the EER for green coffee sold to Sweden, Switzerland and the USA and for instant coffee sold to Germany are higher than the export:import ratio (Table 3). This means that trade with those countries should be more carefully evaluated, because those countries seem to have the largest advantage in emergy term when trading with Nicaragua. Then, what are the options for Nicaraguan coffee? There are some possible options that can be discussed here. One first option would be to increase the price of exported coffee. This would probably be the easiest and more direct way to increase the EER in favour of Nicaragua. However, this does not seem possible, as Nicaragua alone does not determine the price for coffee. A second option would be to decrease the use of labour, which is the main emergy input, and increase the use of fertilizers and machinery to increase productivity. This will result in a more favourable exchange ratio. However, this option will most likely result in increased unemployment and social problems. Another option would be to trade only with countries with similar emergy to money ratio. This is something Nicaragua could possibly do, to strengthen collaboration with other countries that also have less developed economies, in order to develop together.

We think that the best would be a combination of the different options, for example, to increase the price of coffee with the production of a high quality ecological coffee. High quality coffee uses more labour, less pesticides and fertilizers. This means less unemployment and lower impacts on the environment. And at the same time, Nicaragua could develop a policy to favour trade with less developed economies, in a way that both seller and purchaser benefit. In the case of exports of green, roasted and instant coffee, the best option seems to maintain or increase such exports, especially the sales to the other Central American countries, and to countries with similar emergy to money ratio to itself. However, we must take into consideration that Nicaragua needs also to buy goods like oil and medicines that are crucial for its development and the well being of its people.

In a desired balanced emergy trade scenario to be reached by the money received, we found that the fair price for coffee ranged from 291 USD/t for coffee cherries in Nicaragua to 11 514 USD/t for instant coffee sold to Germany. This means that the fair price to be paid ranged from 0.23 to 3.08 times the actual price paid.

Trading coffee makes it better than the average EER for Nicaragua. The question then is how to improve the EER further for Nicaragua. A refinement of any 'raw' product might improve the EER. The EER can also be changed in favour of Nicaragua by imports of goods with a high emprice. Earlier studies have indicated that raw products such as oil, other minerals and rural products from forestry, agriculture and fishery generally tend to have high emergy exchange ratios (Doherty and Brown, 1991; Odum and Arding, 1991). The emergy per dollar or emprice provides a means of calculating terms of trade on a commodity by commodity basis (Brown, 2003) and it represents how much emergy is received for every dollar spent.

Oil and paper are two such products that could make an emergy benefit when purchased by Nicaragua. We found that the emprice for crude oil was 26E+12 sej/USD and for paper products 9.7E+12 sej/USD.[2] Those are goods that are consid-

[2] Data for energy in oil from Odum (1996) and for paper products from Doherty et al. (2002). Transformity for oil (66 000 sej/l) from Odum (1996) and for paper products (112 854 sej/J) from Doherty

ered to have high emprice but still they do not generate a net emergy inflow to Nicaragua when purchased. With an EMR of 26.5E+12 sej/USD for Nicaragua, the EER is one for oil, which means that the outflow of emergy is as big as the inflow of emergy. The EER for paper is 0.37, indicating a substantial emergy loss when purchased.

Without being too radical, we could guess that the price of oil will rise in the future. If in average, trade with other nations is a matter of losing emergy, what strategy should Nicaragua try to develop? We think that one possibility is to continue growing and selling refined coffee. The emergy gain from the exports of refined coffee would then amplify the Nicaraguan people and the internal development, increasing the wealth in Nicaragua. However, this solution strongly depends on the demand for a particular product, and it is not clear it would necessarily lead to a better standard of living. This depends on what the land is used for and what is the local demand for different products. According to the economic concept, trade can increase the overall productivity if each nation supplies to the market what it has that is special. We can agree upon this, if this means that one nation does not drain the other nation's emergy base. In addition, the emergy benefit from trade should exceed the emergy required for the trade arrangements and the transportation needed. It would be a great loss not to use the information of an emergy evaluation when trying to develop a more sustainable use and equitable distribution of resources locally as well as globally.

5. Conclusions

In general, trading refined coffee makes a positive change in favour of Nicaragua. Trading partners also make a difference. In particular, we can say that it is important to trade with countries with emergy to money ratio similar to that of Nicaragua. The items to trade also make a difference and we have used the case of coffee as an example.

Finally, we think that emergy analysis could be a powerful tool to assess the trade, as was shown in this study, and we propose the use of emergy exchange ratio as a more standard measure of traded goods and services. This type of information will be necessary if we want to approach fairness in trade. It also has implications on the sustainable development process, since it provides important knowledge on the environmental requirements for the production processes.

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et al. (2002, p. 88) and updated to new global baseline; price for one barrel of oil on 31 December 2000 (La Prensa, 2000) and price for paper for June 2001, from FOEX (2004), price for STD Newsprint 30 lb paper.

Appendix A

A.1. *Coffee production*

1. Solar energy: land area = 8.08E+04 m^2. Insolation = 5.43 kWh/m^2/day (University of Massachusetts, 2004). Length of cropping cycle = 365 days. Albedo crop = 0.225 (Romo and Arteaga, 1989). Energy (J) = (area) × (average insolation/day in kWh, m^2) × (days) × (1–albedo) (3.6E+06 J/kWh) = Energy (J) = 4.47E+14 J/year = 1.64E+13 J/t/year. Transformity = 1 by definition (Odum, 1996).
2. Wind energy: surface wind speed = 2.6 m/s (INETER, 1999). Area = 8.08E+04 m^2. Wind energy formula from Tilley (1999) = wind energy absorbed within each height interval, J/m^3 = E, E = [(speed at top interval, m/s)^2 − (speed at bottom interval, m/s)^2] × (1.23 kg/m^3/2). Air exchange (volume) = (wind speed at top level − wind speed at bottom level) × surface area × s/year. Average annual energy absorbed within each height interval in J/year = (E, J/m^3) × (speed difference at interval, m/s) × (surface area, m^2) × (3.154E+07 s/year). Length of cropping cycle = 365 days. Energy = 3.33E+12 J/year = 1.22E+11 J/t/year. Transformity from Odum (1996).
3. Rain, chemical potential energy: land area = 8.08E+04 m^2. ETP (Potential evapotranspiration) = 1.88 m/year (Salinas and Rodríguez, 1998). K_c (crop coefficient) = 0.9 (for coffee Doorenbos and Kassam, 1979). Length of cropping cycle = 365 days. Crop ET = ETP × K_c = 1.69 m/year. Energy = (area) × (crop ET) × (Gibbs free energy in rainwater, 4.94E+03 J/kg) (1000) = 6.75E+11 J/year = 2.47E+10 J/t/year. Transformity from Odum (1996). In order to avoid double counting of renewables, we only took the flow of chemical energy in rain, which is the largest single renewable emergy flow. This flow represents the global contribution of renewable emergy for the coffee production.
4. Rain, geopotential energy: area = 8.08E+04 m^2. Average elevation = 4.55E+02 m (Aguilar, 2001). Runoff = 2.90E−02 m/year (Rivas, 1993). Energy (J) = (area) (runoff) (average elevation) (gravity) = (8.08E+04 m^2) (2.90E−02 m) (1000 kg/m^3) (4.55E+02 m) (9.8 m/s^2) (Brown and McClanahan, 1996) = 1.04E+10 J/year = 3.83E+08 J/t/year. Transformity from Odum (1996).
5. Fuels & lubricants: total consumption = 46.68 l/ha/year (Conrado, A., personal communication, 2001). Energy per litre = 3.95E+07 J/l. Energy (J) = (46.68 l) × (3.95E+07 J/l) = 1.85E+09 J/ha/year = 5.49E+08 J/t/year. Transformity from Odum and Odum (1983), pp. 394, without services.
6. Nitrogen fertilizer: consumption = 5.49E+01 kg/ha/year (Conrado, A., personal communication, 2001) = 5.49E+04 g/ha/year = 1.62E+04 g/t/year. Transformity from Odum and Odum (1983), 453 p., without services.

7. Phosphate fertilizer: consumption = 1.37E+02 kg/ha/year (Conrado, A., personal communication, 2001) = 1.37E+05 g/ha/year = 4.06 E+04 g/t/year. Transformity from Brandt-Williams (2001), Table 22, without services.
8. Potassium fertilizer: consumption = 4.57E+01 kg/ha/year (Conrado, A., personal communication, 2001) = 4.57E+04 g/ha/year = 1.35E+04 g/t/year. Transformity from Odum and Odum (1983), 447 p., without services.
9. Urea: consumption = 6.53E+02 kg/ha/year (Conrado, A., personal communication, 2001) = 6.53E+05 g/ha/year = 1.93E+05 g/t/year. Transformity from Odum and Odum (1983), 453 p., without services.
10. Pesticides & fungicides: consumption of liquids = 8.54E−01 l/ha/year (Conrado, A., personal communication, 2001). Energy per liter = 3.95E+07 K/l (Odum, 1996). Energy (J) = (8.54E−01 l) × (3.95E+07 J/l) = 3.37E+07 J/ha/year. Consumption of solids = 1.96E+00 kg/ha/year. Energy (J) = (1.96E+00 kg) × (5.6E+07 J/kg) = 1.10E+08 J/ha/year. Total energy = 1.43E+08 J/ha/year = 4.25E+07 J/t/year. Transformity for refined oil products from Odum (1996), without services.
11. Water: consumption = 19.72 m^3/ha/year (Conrado, A., personal communication, 2001). Energy (J) = (19.72 m^3/year) × (1000 kg/m^3) × (4940 J/kg, Gibbs free energy of rainwater) = 9.74E+07 J/ha/year = 2.88E+07 J/t/year. Transformity for fresh water inflow from Odum (1996), 120 p., without services.
12. Seeds: consumption = 0.67 kg/ha/year (Conrado, A., personal communication, 2001). Energy (J) = (0.67 kg) × (3.0E+3 kcal/kg) × (4186 J/kcal) = 8.39E+06 J/ha/year = 2.48E+06 J/t/year. Transformity for seeds from Odum and Odum (1983), p. 414, without services.
13. Machinery & equipment: weight = 8.83E+00 kg/ha/year. Mass = 8.83E+03 g/ha/year = 2.61E+03 g/t/year. Transformity from Buranakarn (1998), p. 142, without services.
14. Buildings, wood = 7.43E−03 m^3/ha/year. Energy (J) = (0.007 m^3) (5.0 E+05 g/m^3) (3.6 kcal/g) (4186 J/kcal) (Brown and McClanahan, 1996) = 5.60E+07 J/ha/year = 1.66 E+07 J/t/year. Transformity from Doherty et al. (2002), p. 58, without services.
15. Buildings, concrete = 2.47E+02 kg/ha/year = 2.47E+05 g/ha/year = 7.31E+04 g/t/year. Transformity for ready-mixed concrete from Buranakarn (1998), p. 142, without services.
16. Buildings, glass = 2.03E−01 kg/ha/year = 2.03E+02 g/ha/year = 6.01E+01 g/t/year. Transformity for flat glass from Buranakarn (1998), p. 143, without services.
17. Buildings, steel sheets = 5.20E−02 kg/ha/year = 5.20E+01 g/ha/year = 1.54E+01 g/t/year. Transformity for pig iron blast furnace from Buranakarn (1998), p. 142, without services.
18. Labour: dollar value = 2.80E+02 USD/ha/year = 8.28E+01 USD/t/year (Conrado, A., personal communication, 2001). Transformity from Cuadra and Rydberg (2000).
19. Fuel & lubricants: dollar value = 3.19E+01 USD/ha/year = 9.43E+00 USD/t/year (Conrado, A., personal communication, 2001). Transformity from Cuadra and Rydberg (2000).
20. Chemicals (notes 6–10): dollar value = 2.92E+01 USD/ha/year = 2.64E+00 USD/t/year (Conrado, A., personal communication, 2001). Transformity from Cuadra and Rydberg (2000).
21. Water: dollar value = 7.36E+00 USD/ha/year = 2.18E+00 USD/t/year (Conrado, A., personal communication, 2001). Transformity from Cuadra and Rydberg (2000).
22. Seeds: dollar value = 6.81E+00 USD/ha/year = 2.01E+00 USD/t/year (Conrado, A., personal communication, 2001). Transformity from Cuadra and Rydberg (2000).
23. Machinery & equipment: dollar value = 7.50E+01 USD/ha/year = 2.22E+01 USD/t/year (Conrado, A., personal communication, 2001). Transformity from Cuadra and Rydberg (2000).
24. Buildings: dollar value = 2.78E+01 USD/ha/year = 8.24E+00 USD/t/year (Conrado, A., personal communication, 2001). Transformity from Cuadra and Rydberg (2000).
25. Harvest transportation: dollar value = 7.88E+01 USD/ha/year = 2.33E+01 USD/t/year. Transformity from Cuadra and Rydberg (2000).
26. Technical assistance: dollar value = 2.12E+00 USD/ha/year = 6.27E−01 USD/t/year. Transformity from Cuadra and Rydberg (2000).
27. Maintenance & repair: dollar value = 2.26E+01 USD/ha/year = 6.7E+00 USD/t/year (Conrado, A., personal communication, 2001). Transformity from Cuadra and Rydberg (2000).
28. Coffee cherries: production = 3.38 t/ha/year dry weight = 3.38E+03 kg dry weight coffee cherries/ha/year (Conrado, A., personal communication, 2001). Energy (J) = (3.38E+03 kg) × (1951.3 kJ/100 g), calculations based on data from Pandoy et al. (2000) and Senser and Scherz (1991) × (10) = 6.59E+10 J/ha/year = 1.95E+10 J/t/year. Transformity for coffee cherries calculated in this study (3.35E+05 sej/J).

A.2. *Wet mill processing*

29. Water: consumption = 1.73E+02 m^3 (Ramírez, A., personal communication, 2003). Energy (J) = (1.73E+02 m^3/year) × (1000 kg/m^3) × (4940 J/kg, Gibbs free energy of rainwater) = 8.53E+08 J/year = 1.74E+06 J/t/year. Transformity for fresh water inflow from Odum (1996), pp. 120.
30. Electricity: electricity use = 1.40E+04 kWh/year (Ramírez, A., personal communication, 2003). Energy (J) = (kWh/year) × (3.6E+06 J/kWh) (Odum, 1996) = 5.04E+10 J/year = 1.03E+08 J/t/year. Transformity from Odum (1996), pp. 305.
31. Machinery & equipment: weight = 6.49E+05 g/year = 1.33E+03 g/t/year. Transformity from Odum et al. (1987). Full calculations available from the authors.
32. Buildings, concrete = 7.99E+06 g/year = 1.63E+04 g/t/year. Transformity for ready-mixed concrete (conventional) from Buranakarn (1998).
33. Buildings, steel sheets = 7.27E+05 g/year = 1.49E+03 g/t/year. Transformity for iron & steel from Odum (1996), p. 186. Full calculations available from the authors.
34. Labour: dollar value = 7.30E+03 USD/year (Ramírez, A., personal communication, 2003) = 1.49E+01 USD/t/year. Transformity from Cuadra and Rydberg (2000).
35. Electricity: dollar value = 1.37E+03 USD/year (Ramírez, A., personal communication, 2003) = 2.80E+00 USD/t/year. Transformity from Cuadra and Rydberg (2000).
36. Machinery & equipment: dollar value = 3.93E+ 2 USD/year = 8.03E−01 USD/t/year. Full calculations available

from the authors. Transformity from Cuadra and Rydberg (2000).

37. Buildings: dollar value=1.62E+03 USD/year =3.32E+00 USD/t/year. Full calculations available from the authors. Transformity from Cuadra and Rydberg (2000).
38. Green coffee: production = 489 t/year dry weight = 4.89E+05 kg dry weight/year (Ramírez, A., personal communication, 2003). Energy (J) = (4.89E+05 kg/year) × (2.14E+07 J/kg green coffee dry weight) = 1.04E+13 J/year = 4.06E+09 J/t/year. Transformity for green coffee calculated in this study (1.77E+06 sej/J).

A.3. *Roasted coffee production*

39. Gasoline & diesel: total consumption = 1.44E+04 l/year. Energy per litre = 3.95E+07 J/l. Energy (J) = (1.44E+04 l/year) × (3.95 J/l) = 2.15E+12 J/year = 1.64E+09 J/t/year. Transformity from Odum (1996), p. 186
40. Electricity: electricity use = 3.45E+05 kWh/year. Energy (J) = (kWh/year) × (3.6E+06 J/kWh) (Odum, 1996) = 1.24E+12 J/year = 9.46E+08 J/t/year. Transformity from Odum (1996), pp. 305.
41. Water: consumption = 3.76E+03 m^3. Energy (J) = (3.76E+03 m^3/year) × (1000 kg/m^3) × (4940 J/kg, Gibbs free energy of rainwater) = 1.86E+10 J/year = 1.41E+07 J/t/year. Transformity for fresh water inflow from Odum (1996), pp. 120.
42. Machinery & equipment: weight = 7.66E+04 g/year = 5.84E+01 g/t/year. Transformity from Odum et al. (1987). Full calculations available from the authors.
43. Buildings, concrete = 2.95E+06 g/year = 2.25E+03 g/t/year. Transformity for ready mixed concrete (conventional) from Buranakarn (1998).
44. Buildings, steel sheets=5.87E+05 g/year = 4.47E+02 g/t/year. Transformity for iron & steel from Odum (1996), p. 186.
45. Labour: dollar value = 2.24E+05 USD/year = 1.70E+02 USD/t/year. Transformity from Cuadra and Rydberg (2000).
46. Electricity: dollar value = 3.03E+04 USD/year = 2.31E+01 USD/t/year. Transformity from Cuadra and Rydberg (2000).
47. Water: dollar value = 3.12E+03 USD/year = 2.38E+00 USD/t/year. Transformity from Cuadra and Rydberg (2000).
48. Machinery & equipment: dollar value = 9.98E+02 USD/year = 7.60E−01 USD/t/year. Full calculations available from the authors. Transformity from Cuadra and Rydberg (2000).
49. Buildings: dollar value = 1.76E+03 USD/year = 1.34E+00 USD/ha/year. Calculations available from the authors. Transformity from Cuadra and Rydberg (2000).
50. Roasted coffee: production = 1312.88 t dry weight/year = 1.31E+06 kg dry weight/year. Energy (J) = (1.31E+06 kg/year) × (2.22E+07 J/kg green coffee dry weight) = 2.92E+13 J/year = 3.55E+09 J/t/year. Transformity for roasted coffee calculated in this study (3.64E+06 sej/J).

A.4. *Instant coffee production*

51. Gasoline & diesel: total consumption = 2.56E+04 l/year. Energy per litre = 3.95E+07 J/l. Energy (J) = (2.56E+04 l/year) × (3.95 J/l) = 1.01E+12 J/year = 6.34E+08 J/t/year. Transformity from Odum (1996), p. 186
52. Electricity: electricity use = 1.62E+05 kWh/year. Energy (J) = (kWh/year) × (3.6E+06 J/kWh) (Odum, 1996) = 5.84E+11 J/year = 3.67E+08 J/t/year. Transformity from Odum (1996), pp. 305.
53. Water: consumption = 1.77E+03 m^3. Energy (J) = (1.77E+03 m^3/year) × (1000 kg/m^3) × (4940 J/kg, Gibbs free energy of rainwater) = 8.73E+09 J/year = 5.48E+06 J/t/year. Transformity for fresh water inflow from Odum (1996), pp. 120.
54. Machinery & equipment: weight = 1.05E+05 g/year = 6.62E+01 g/t/year. Transformity from Odum et al. (1987). Full calculations available from the authors.
55. Buildings, concrete = 1.39E+06 g/year = 8.72E+02 g/t/year. Transformity for ready-mixed concrete (conventional) from Buranakarn (1998).
56. Buildings, steel sheets = 2.76E+05 g/year = 1.73E+02 g/t/year. Transformity for iron & steel from Odum (1996), p. 186.
57. Labour: dollar value = 4.05E+04 USD/year = 2.55E+01 USD/t/year. Transformity from Cuadra and Rydberg (2000).
58. Electricity: dollar value = 1.74E+04 USD/year = 1.09E+01 USD/t/year. Transformity from Cuadra and Rydberg (2000).
59. Water: dollar value = 1.79E+03 USD/year = 1.13E+00 USD/t/year. Transformity from Cuadra and Rydberg (2000).
60. Machinery & equipment: dollar value = 9.98E+02 USD/year = 6.27E−01 USD/t/year. Full calculations available from the authors. Transformity from Cuadra and Rydberg (2000).
61. Buildings: dollar value = 5.53E+02 USD/year = 3.47E−01 USD/t/year. Full calculations available from the authors. Transformity from Cuadra and Rydberg (2000).
62. Instant coffee: production = 1592.3 t instant coffee dry weight/year = 1.59E+06 kg dry weight/year. Energy (J) = (1.59E+06 kg/year) × (1.78E+07 J/kg green coffee dry weight) = 2.83E+13 J/year = 1.09E+09 J/t/year. Transformity for instant coffee calculated in this study (1.29E+07 sej/J).

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