Journal of Environmental Accounting and Management 4(3) (2016) 251-266

Journal of Environmental Accounting and Management

https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Greening A Cuban Local Mango Supply Chain: Sustainability Options and Management Strategies

B.F. Giannetti[1,2,3,†], L. Prevez[1,2,3], F. Agostinho[1,2,3], C. M. V. B. Almeida[1,2,3]

[1] Laboratório de Produção e Meio Ambiente

[2] Programa de Pós-Graduação em Engenharia de Produção

[3] Universidade Paulista, R. Dr. Bacelar 1212, Cep 04026-002, São Paulo, Brazil

Submission Info

Communicated by Sergio Ulgiati
Received 14 May 2016
Accepted 17 August 2016
Available online 1 September 2016

Keywords

Emergy
Production costs
Local sustainable supply chain
Mango
Cleaner production

Abstract

Articulating all actors and activities of supply chain having an impact on sustainability is a complex task especially for a limited domestic market production sector. This complexity is the result of several factors, such as the quality of the product, the degree of competitiveness and the high costs of transactions, which arise from a small economic scale. This paper proposes a sustainability analysis using emergy accounting and the Cleaner Production approach applied to the case study of a mango pulp supply chain on a local level in Santiago de Cuba. The results obtained show that the current agricultural economy model is characterized by i) the use of chemical fertilizers, II) a large presence of labor and iii) a small use of natural resources. The cleaner production strategy applied to the local fruit supply chain increased the benefits for ecosystems and society. Emergy indices pointed towards higher efficiency, lower energy appropriation for production, lesser pressure on the environment, and a greater contribution to the local economy. The assessment method used proved to be helpful in evaluating the agricultural chains dynamics, especially, after the introduction of Cleaner Production practices.

1 Introduction

The fruit sector is one of the main generators of income, employment and rural agribusiness development in Cuba, which aspires for the 2018 to cultivate 7139 hectares of mango and reach 70 826 ton of fruits per year. Nevertheless, most existing production chains in the country emerged spontaneously and operate without establishing relationships between the chain actors that are not just commercial. This situation derives from the lack knowledge about the added value that may result from the supply chain vision (Acosta, 2006; Van der Heyden and Camacho, 2007). One of the most effective actions for greening existing informal supply chains is the application of Cleaner Production (CP). These actions directed to the operational performance have been considered of great help not only for increasing the environmental performance of the supply chains, but

† Corresponding author.
Email address: biafgian@unip.br (B.F. Giannetti).

ISSN2325-6192, eISSN2325-6206, CN 10-1358/X /$- see front materials
DOI:10.5890/JEAM.2016.09.002

also for their economical enforcement (Almeida et al., 2015). However, most studies combining supply chain management and CP deals with large chains that arise by the action of a large focal firm (Silvestre, 2015). For Sarkis et al. (2011), one of the main challenges for the adoption of sustainable practices in local supply chains is the initial cost, which increase investment facing a not encouraging rate of return. Up to now, several approaches have been developed to evaluate food chains regarding their design (Chen, 2015), logistics (Martikainen et al., 2014), quality control (Chen et al., 2014), and energy consumption (Wallgren and Höjer, 2009). Considering the increasing significance of environmental policies around the world (Tukker et al.,2008), the greening of supply chains has been widely analyzed under the operational viewpoint (Swanson et al., 2005; Walker and Brammer, 2009), cost/benefit efficacy (Hall and Purchase, 2006), barriers (Walker and Brammer, 2009), viability (Nissinen et al., 2009; Parikka-Alhola, 2008), and public incentives (Testa et al., 2012).There are no studies dealing with the local resource base and the potential improvement that can be obtained from CP practices on existing agricultural supply chains. In addition, due to the diversity of products, indirect actors and the complexity observed in logistics processes the development of indicators and metrics to measure the sustainability performance of agribusiness chains is still pending (Bourlaskis et al., 2014, Brandenburg et al., 2014). Some authors consider that this intricacy of conditions hinder the establishment of standards for evaluating sustainability in supply chains (Searcy et al, 2009; Tweed, 2010).

The aim of this work is to propose a sustainability analysis using emergy accounting and CP approach applied to the case study of a Cuban mango pulp supply chain. Santiago de Cuba, has a potential production of 5 521 t of mango per year but 30% is lost and persist the high costs, the low yields, the low financial results with unfavorable impacts in connection with the economic incentives, productivity and the life quality of the population in the supply chains at local level (Cabrera, 2014). Local level supply chains have great difficulty in adopting sustainable supply chain practices (Sarkis et al., 2011; Grimm et al., 2013), which is in part attributed to the cost of short-term investments implement changes, such as investment costs in low energy designs, and costs related to logistics alternatives (Hassini et al., 2012). It is also widely recognized that local supply chains lack resources required for performance measurements and the skills to collect and meaningfully evaluate such information (Bourlaski et al., 2014; Beske et al., 2014).

The methodology developed by Odum (1996) has been used in different countries, considering different products and production chains to evaluate and compare different models of agricultural production and industrial processes. In particular, the emergy synthesis enables understanding the balance or imbalance between the evaluated system and the ecosystems that supply resources and energy (Ulgiati et al., 1994; Brown and Ulgiati, 2004; Cuadra and Rydberg, 2006). The methodology is a powerful tool to assess the environmental direct and indirect requirements for services and products (Wang et al 2014; Giannetti et al., 2011a,b; De Barros et al, 2009). So far, emergy assessments of complete agribusiness chains are still scarce (Giannetti et al., 2011a; Cuadra and Rydberg, 2006), but it was possible to evaluate cultivation methods (conventional, organic, family farms) regarding the use of natural resources, the types of fertilizers and fuel use, as well as the social performance of units under study (Bastianoni et al., 2001). Recent studies show the usefulness of combining environmental action programs such as Life Cycle Assessment (Pizzigallo et al., 2008; Cerutti et al., 2011) and CP (Giannetti et al, 2008) with the emergy. However, the role transportation, processing, product consumption and waste disposal at the local level has not been explored.

This paper presents an empirical investigation in which emergy indicators are applied to assess a local mango supply chain's operation before and after cleaner production actions are implemented. Results may be used by policy makers, as well as researchers and focal companies to improve the chain management and its environmental performance.

2. Method

2.1 Mango supply chain characteristics and data source

The supply chain at Santiago de Cuba produces 1300 t of mango per year and the mango season oc-

curs from May to August. Losses in production reach 30%, resulting in poor low financial results, which discourage economic incentives (Cabrera, 2014). This supply chain is the largest mango producer in the country and receives support from governmental organizations and services from researching institutes.

Nine associated producers compose the primary production and follow a monoculture regimen. The plantation is approximately 13 years old, yielding 10 t/ha. 71 workers support this activity. The processor transforms the primary product into 2 t of mango pulp /d, which is sold in 3 liter cans. 38 workers supported this activity. The solid wastes are used for pigs feeding. The logistics system consists of raw material transportation to the processor and distribution to local markets by two independent companies. Tractors and trucks consume 3 l fuel/km through distances of approximately 60 km. The pulp cans are distributed in the State agricultural market, which counts with 4 sale points and 10 mobile sellers. 21 people perform this activity. Data refer to the year of 2012, and were supplied by governmental organizations that support mango production: the Ministry of Agriculture, Ministry for Food Industry, Ministry of Domestic and the National Association of Small Farmers. Supplementary data were also supplied by the Institute of Plant Protection (INISAV), the Laboratory of Hygiene and Epidemiology, the Research Institute on Tropical Fruit and State Logistics Group of the Ministry of Agriculture.

2.2. Cleaner production approach

According to the study of Santiago de Cuba supply chain, performed by the Institute on Tropical Fruit using the Industrial Value Chain Diagnostics: An Integrated Tool (ONUDI, 2011), more than 20 CP potential actions were identified (Table 1), among which the application of training programs involving all the chain actors and investments for equipment modernization both in the processor and the transportation stages. Only 10 cleaner production actions were possible to implement considering the production cost and payback period (payback = investment-cost/income) reported by the Institute on Tropical Fruit (Table 1).

Table 1. Cleaner Production actions implemented with the respective cost in US dollars, the estimated payback period.

Cleaner Production action	Priorities			Cost* (USD)	Payback Period* (year)
	Economic	Environment	Social		
Primary Producer					
Replace chemical fertilizers with compost made from agricultural waste and solid waste from small industry.	x	x		4 000	1
Build fruit containers from pruning residue on agricultural properties using local labor	x	x	x	3500	0.7
Improve harvest organization	x		x	0	Immediate
Transport raw material and pulp distribution					
Use animal traction when efficient use of vehicles is limited.	x	x	x	7000	3
Organize new routes prioritizing the most distant selling points.	x	x		0	Immediate
Pulp processing					
Use rainwater for cooling of products	x	x		2000	0.7
Reuse water in cleaning activities	x	x		750	0.3
Recirculation of water in the fruit washing machine	x	x		0	Immediate

Training programs involving energy consumption	x	x	x	500	Immediate
Sales					
Use of new sale points with simpler structure	x	x		850	0.3

* The Institute on Tropical Fruit calculated payback as investment-cost/income based on the Industrial Value Chain Diagnostics (ONUDI, 2011). Investments were obtained from the production reports of each actor.

To assess potential improvement due to CP actions (such as the implementation of good manufacture practices, the reuse and recycling of products, energy efficiency, the minimization of waste, technological changes, diversification and water and wastewater management), emergy indicators were calculated before and after the CP interventions for each actor.

2.3 Emergy synthesis

The emergy method accounts for the environmental work for the formation of a product or service (Odum, 1996). This method considers all the free nature inputs (solar radiation, wind, rain, etc.) as well as the human work and services, which are recorded in terms of solar emergy. The total emergy is defined as the total quantity of direct or indirect available solar energy required to make product or to support given service. All natural resources, materials and economic inputs used in supply chain can be expressed in terms of solar energy joules (seJ), assuring that different forms of energy can be compared and accounted for using the same standard (Odum, 1996).

The first step in an Emergy evaluation is to prepare a diagram, which sets the boundaries of the system investigated and underscores the components within the system. The diagram allows the identification of inflowing sources and products, as well as internal flows that include feedbacks and recycling. Figure 1 represents the mango supply chain where all the actors are identified: primary producer, raw material transportation, processor, distributor and market, along with storages of biomass, soil and labor, which are used internally. The payment of goods and services is shown by the dashed lines. 70 % of labor was considered as renewable resource because people live into system, is locally self-reproducing, and integrated with its surrounding systems (Rydgberg and Jansen, 2002). Cuban farmers tend to use family labor and only 30% of outside the system's boundaries is hired.

The non-renewable resources are associated with soil loss (Odum et al., 2000) and water extracted from underground. The purchased resources (hired labor, fertilizers, diesel, electricity, equipment and machinery and support services) were accounted for according to production cost sheets.

The second step is the construction of the emergy table, where the different inputs are organized and converted into emergy values with the help of transformities (seJ/J) or unit emergy values (seJ/g). Transformity was defined by Odum (1996) as the solar energy required to making one joule of a service or a product, while the unit emergy value (UEV) expands the same idea using another units (grams, liters, money). The emergy of each actor is the sum of renewable (R), non-renewable (N) and purchased resources (F). When comparing products, a smaller UEV value indicates better efficiency in production (Brown and Ulgiati, 2004).

The third step is to calculate the emergy indices that will be used to evaluate the performance of the mango supply chain. A brief description of emergy indices is shown in table 2.

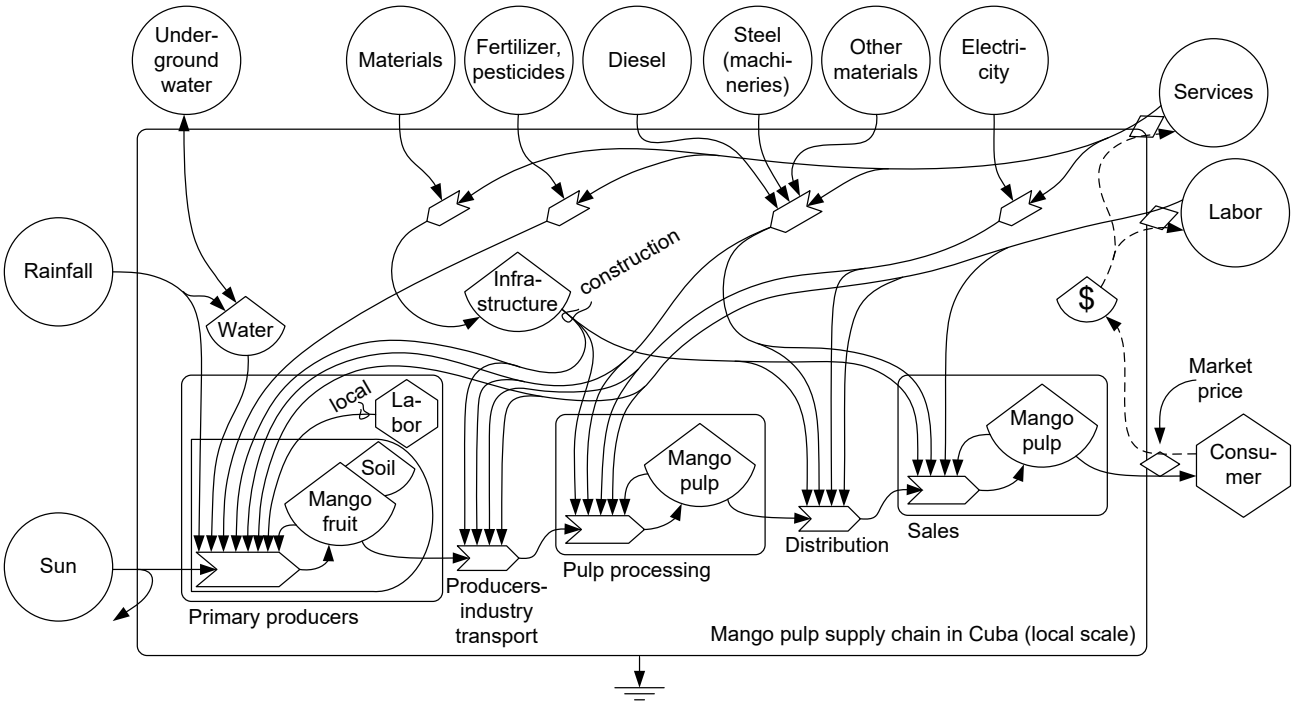

Fig. 1. Energy system diagram of the Santiago de Cuba mango supply chain.

Table 2. Emergy indicators for the evaluation of the Santiago de Cuba mango supply chain.

Indicator	Calculation*	Description
Emergy	U = R + N + F	Environmental work required for the operation of the supply chain.
Emergy Yield Ratio	EYR = (N + R + F) / F	The EYR indicates the capability of the supply chain to explore local free resources in contrast to the resources supplied by the economy.
Environmental Loading Ratio	ELR= (N+ F) / R	The ELR indicates the pressure of the supply chain on the eco-system due to its productive activity.
Emergy Investment Ratio	EIR =F/ (N+R)	The EIR quantifies the emergy investment necessary for the operation of the supply chain.
Emergy Sustainability Index	ESI=EYR/ELR	The ESI reflects the relationship between environmental performance and the pressure imposed to the environment.
Unit Emergy Value	UEV=U/unit	Gives a measure of the supply chain efficiency
Global productivity	GP= 1/UEV	Gives a measure of the supply chain global productivity, since it includes the biosphere's free inputs.

* R: renewable resources; N: non-renewable resources; F: purchased resources, U: Total Emergy, and unit: grams, liter currency, etc.

To make easy communication of the results and assist the decision-making process (Gasparatos et al., 2008), the ternary diagram (Fig. 2) is used to visually characterize the systems under study, before and after the CP interventions (Almeida et al., 2007; Giannetti et al., 2006). This tool permits to draw lines indicating constant values of the sustainability index. The sustainability lines heads off the N apex in direction to the RF axis defining sustainability areas, which are very helpful to categorize and evaluate the sustainability of products and processes.

The superior part of the diagram (white) shows the region where systems are sustainable for long

term (ESI > 5); the central part (grey) marks the area where systems are sustainable for medium term (1 < ESI < 5), and the inferior part of the diagram (dark grey) shows circumstances in which systems are not sustainable (ESI < 1). An important property of ternary diagrams is the significance of a straight line joining an apex to a point on the opposite edge (sensitivity line). Any point on the sensitivity line shown in figure 2 represents a system that is progressively richer in *F*, as it approaches the F axis, but *R* and *N* remain present at the same initial proportion. Therefore, to represent the changing conditions of a system % *F* diminishes or increases, one need to to draw a line from the apex *F* passing through the point that represents the system. Additional information concerning the analytical properties of ternary diagrams is available in (Almeida et al., 2007; Giannetti et al., 2006; Agostinho et al., 2013).

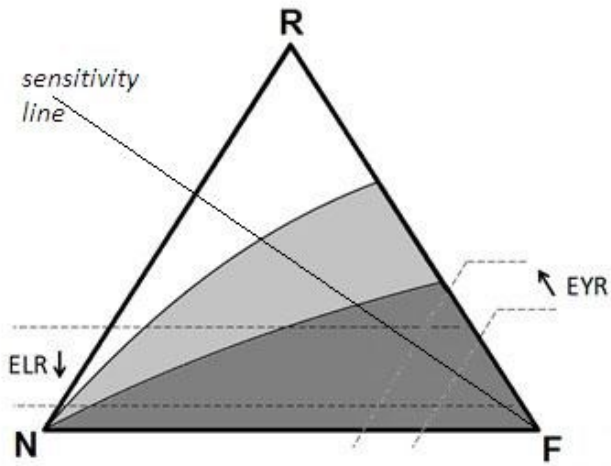

Fig. 2. Ternary emergy diagram with the sustainability lines departing from the N apex in direction to the RF axis. The white region indicates systems sustainable for long term (ESI > 5); the grey region contains medium term sustainable systems (1 < ESI < 5), and the dark grey region includes systems that are not sustainable (ESI < 1). The dashed lines show how the emergy indices (EYR and ELR) vary within the diagram.

3. Results and Discussion

3.1 Emergy accounting of the mango supply chain.

According to Fisher (1997), this supply chain could be classified as a functional, stable, low margin product that converts raw material into a finished product. As shown in Figure 1, the inter-business cooperation within the supply chain is developed in the framework of a commodity-money relationship. Each actor in the supply chain works as an independent company, connected to other actors by physical and financial material flows.

Table 3 shows the emergy environmental accounting of the primary producer. The complete tables of each actor of the supply chain are available in the Supplementary Materials (Tables S2 to S5). At the primary production stage, 42 % of the total emergy is provided by renewable sources. This value is higher those of Brazilian agriculture that ranges from 19 to 34% (Agostinho et al., 2010). About 4 % of the emergy comes from non-renewable sources and 54% is feedback by the economy. Labor contributes with 44%, fertilizers with approximately 28%. Maintenance (pruning, fertilization, plant protection, weed control and post-harvest technologies) correspond to 10% of the total emergy. Infrastructure and fuels correspond to less than 1% of the total emergy, indicating that the supply chain is little mechanized and depends mainly on manual labor.

Table 3. Emergy analysis of primary producer of mango in Santiago de Cuba. Calculation details are available at Supplementary Materials (S1). Unit emergy values (UEVs) refer to the 15.83 baseline (Odum et al., 2000).

		Quantity	Unit	UEV seJ/unit	Refs.***	Emergy (seJ/yr)	% (seJ/seJ)
	Renewable resources (R)					**2.49×10^{17}**	**42**
1	Chemical rain*	2.34×10^{12}	J	3.06×10^{4}	(a)	7.16×10^{16}	12
2	Labor (70%)**	4.52×10^{10}	J	3.93×10^{6}	(b)	1.78×10^{17}	30
	Non renewable resources (N)					**2.48×10^{16}**	**4**
3	Soil loss	8.23×10^{5}	J	1.24×10^{5}	(a)	1.02×10^{11}	<1
4	Water	3.50×10^{10}	J	7.06×10^{5}	(c)	2.47×10^{16}	4
	Purchased resources (F)					**3.21×10^{17}**	**54**
5	Fuel oil	6.93×10^{10}	J	1.11×10^{5}	(a)	7.69×10^{15}	1
6	Nitrogen	2.18×10^{7}	g	6.62×10^{9}	(c)	1.44×10^{17}	24
7	Potassium	1.77×10^{7}	g	9.32×10^{8}	(d)	1.65×10^{16}	3
8	Phosphate	8.71×10^{5}	g	9.35×10^{9}	(d)	8.14×10^{15}	1
9	Pesticides	1.33×10^{0}	g	9.42×10^{4}	(d)	1.25×10^{05}	<1
10	Organic fertilizer	3.69×10^{5}	g	1.21×10^{5}	(d)	4.46×10^{10}	<1
11	Wood	3.33×10^{5}	g	8.19×10^{3}	(c)	2.73×10^{9}	<1
12	Labor (30%)	2.10×10^{10}	J	3.93×10^{6}	(b)	8.25×10^{16}	14
13	Machinery	8.76×10^{4}	g	2.42×10^{9}	(e)	2.12×10^{14}	<1
14	Maintenance	1.43×10^{4}	USD	4.30×10^{12}	(f)	6.15×10^{16}	10
	Emergy		**seJ/yr**			**5.95×10^{17}**	**100**
	Mango production	1.30×10^{9}	g				
	UEV		**sej/g**	**4.58×10^{8}**			

* Raw data (insulation, annual cumulative rainfall) were obtained from the Institute of meteorology of Cuba IMET (available at http://www.met.inf.cu).
** 70% of labor was identified as renewable because farmers live in the property. The system is self-sufficient and relies on the use of family labor. Only 30% of workers are hired from outside the system's boundaries (Rydberg et al., 2002).
***(a) Odum et al.,2000; (b) calculated: (1.50 x 1016 seJ/person (NEAD, 2004) / 8 h / person d* 280 d/y)* 2500 kcal / pers.d * 4186 J / kcal; (c) Bastianoni et al., 2001; (d) Brand Williams et al., 2002;(e) Rydberg and Jansen, 2002; (f) NEAD, 2004.

The UEV calculated for the mango production was 4.58×10^{8} seJ/g lower than those for other fruit cultivations, such as bananas (14.35×10^{8} seJ/g; Lu et al., 2009) and oranges in Italy (1.5×10^{9} seJ/g; La Rosa (2002). These results are, however, expected since both cultivations use more chemical fertilizers and support services due to their susceptibility to pests and diseases compared to mango cultivation. The fruit production corresponds to 28% of the total emergy of the whole supply chain, and the remaining 72% are related to the inputs required to transform the fruit into canned pulp.

The aggregation of new purchased resources along the supply chain results in increased environmental stress along with decreased environmental yield. The ability to convert local resources into marketable products is translated by the EYR that decreases from 1.5 (mango production), to 1.2 (pulp processing), and to 1.1 in the market, indicating that the contribution of this chain to the economy is quite small. The environmental loading increases at the same rate. Consequently, the ESI and the global productivity decrease along the chain (Fig. 3). The results evidence that in adding economic value to the product, it is necessary invest resources provided by the economy, increasing the product´s environmental cost, and decreasing the relative amount of renewables at each link that is added to the chain.

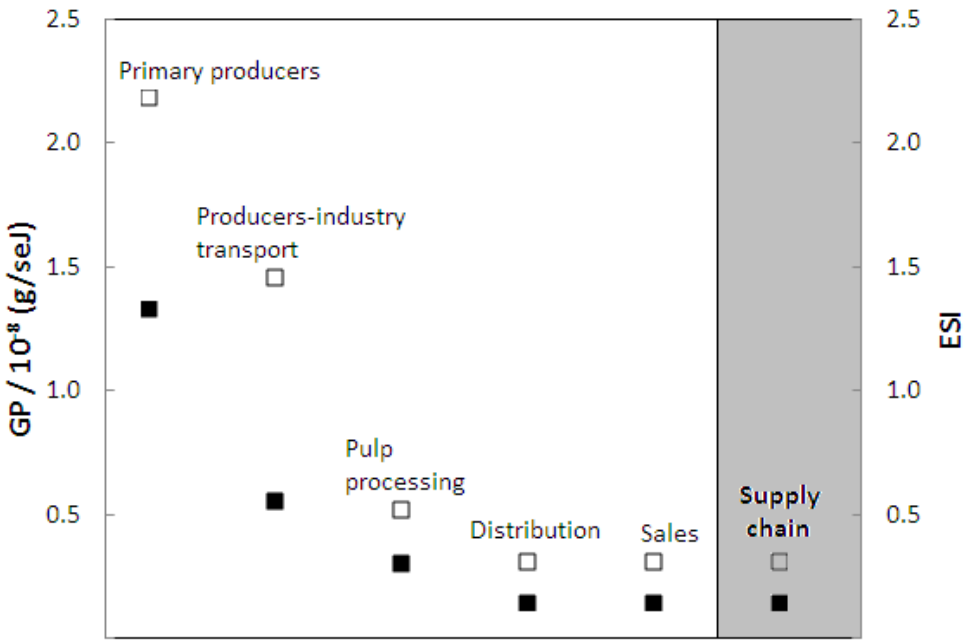

Fig. 3. Global productivity (GP, □) and Environmental Sustainability Index (ESI, ■) along the mango supply chain.

3.2 Improving the supply chain performance with the aid of CP practices

Cleaner production practices such as rationalizing the use of raw materials, water and energy, may prevent the loss of materials and reduce operational costs (Almeida et al., 2015). Some simple CP initiatives were applied along the supply chain aiming to enhance its environmental performance. An analysis of the key inputs of each link was made and is shown in Table 4. These results are consistent with the domestic producer's costs sheets, in which fertilizer inputs accounted for 62%, followed by labor at 20%, and support services at 16%. Lu et al. (2009) also found that agricultural systems spend more than 60% of total costs in the purchasing of non-renewable resources. This analysis allows establishing priorities to the application of the CP interventions.

Table 4. Summary of the relative contribution of the main inputs provided by the economy to each actor in the supply chain.

	Primary producers	Producers-industry transport	Pulp processing	Distributor	Sales
	% / (seJ/seJ)				
Water	-	1	14	-	-
Fertilizers	53	-	-	-	
Fuel	2	79	77	84	-
Electricity	-	1	1	-	-
Equipment	-	5	8	12	33
Labor	26	12	-	4	67

Table 4 makes clear that the main external resources of the primary production are fertilizers and labor, and that the following steps are mostly based on fuel. The importance of the abor contribution in the sales step is remarkable, and may indicate that the creation of jobs may justify the use of resources and energy during the preceding steps.

Table 5 summarizes the results along the supply chain before and after the application of CP interventions. At the stage of primary production, fertilizers contribute with approximately half of the total emergy, confirming that the increase in productivity in conventional agriculture has been historically achieved through the purchasing of non-renewable resources used in place of the resources available locally (Lu et al., 2009; De Barrios et al., 2009). However, this practice results in increased environmental costs, noticed by the worsening of emergy indicators (Giannetti et al., 2011a, Giannetti et al., 2013). To improve the performance of primary producers, 25% of chemical fertilizers were replaced by compost made from agricultural waste and solid waste from the small industry. In addition, fruit containers for agricultural and processing activities were built from pruning residues on the agricultural properties using local labor. Improvements in harvest organization allowed a 50% reduction in the recruited labor force and 25% reduction in fuel consumption. These actions increased the renewability percentage from 42% to 56%, and decreased the requirements for external resources by 15% (Table 5). CP actions were taken within the production stage (replacing fertilizers) and between stages (with the use of solid waste from processor to produce compost and replacing the packages used for transport), supporting Seuring's ideas that state that the benefits of planning efforts among chain members will be evident through the measurement of economic and environmental costs of the whole chain (Seuring, 2012, 2013).

At the subsequent stages, fuel labor and equipments are the main purchased inputs to the supply chain. In the transportation stage, fuel consumption corresponds to 79% of the purchased emergy, confirming that the occurrence of complex chains of collection and distribution or intermediation between small producers and consumers helps to diminish their income (Bourlakis et al., 2014).The nine producers composing the primary mango production implemented animal traction when efficient use of vehicles is limited considering the poor state of the roads. The replacement of 50% of trucks by animal traction allowed a reduction in the use of machinery and fuel consumption. The use of animals also introduces renewable resources in a stage of the supply chain where purchased resources were the only inputs. To reduce transportation costs, new routes were organized and trucks were used prioritizing the most distant selling points and eliminating intermediaries. These changes increased the renewability from 28% to 40% in the transportation stage. As expected, ELR decreased by approximately 40% for the transport of raw fruit and by 35% for the pulp distribution (Table 5). The changes to the mango supply chain logistics may improve not only the chain environmental performance, but also their income by simplifying transport logistics (Bourlakis et al., 2014) changing the mode of transport and the route planning systems (Lee et al., 2010; Min and Kim, 2012).

In the processor stage, water corresponds to 14% of the purchased emergy (Table 3). The use of rainwater for cooling the products, its reuse in cleaning activities, and the recirculation of water in the fruit washing machine, reduced water consumption by 50%, and 40% of wood were saved due to the CP actions at the first stage, and a reduction of 25% of electricity was achieved after a one day cleaner production and management training program. An increase of renewability from 19% to 26% was obtained, resulting in a decrease of pressure on the environment from 4.1 to 2.8 (Table 5). For future interventions, the processor is planning waste minimization measures (Yakovlevna et al., 2012; Bourlakis et al., 2014) and the implementation of Good Manufacturing Practices, which may bring potential savings in resource consumption with low investments (Zanoni and Zavanella, 2012). Since the mango pulp can be preserved without refrigeration, new and simpler sale points were chosen in order to diminish the use of equipment and electricity.

Table 5. Summary results of each actor of the local supply chain before and after the Cleaner Production interventions.

	Primary producers		Producers-industry transport		Pulp processing		Distributor		Sales		Supply chain	
	before	*after*	*before*	*after*	*before*	*after*	*before*	*after*	*before*	*after*	*before*	*after*
U / 10^{17} (seJ)	5.9	4.5	8.9	6.2	12.7	9.6	21.2	15.2	21.5	15.4	**21.5**	**15.4**
UEV / 10^{8} (seJ/g)	0.5	0.3	0.7	0.5	1.9	1.4	3.2	2.3	3.2	2.3	**3.2**	**2.3**
GP / 10^{-8} (g/seJ)	2.2	2.9	1.5	2.1	0.5	0.7	0.3	0.4	0.3	0.4	**0.3**	**0.4**
R / (%)	41.9	55.6	28.0	40.2	19.7	26.1	11.8	16.4	11.6	16.2	**11.6**	**16.2**
N / (%)	4.2	5.5	2.8	4.0	2.0	2.6	1.2	1.6	1.2	1.6	**1.2**	**1.6**
F/ (%)	53.9	38.8	69.2	55.8	78.3	71.3	87.0	82.0	87.2	82.2	**87.2**	**82.2**
ELR	1.4	0.8	2.6	1.5	4.1	2.8	7.5	5.1	7.6	5.2	**7.6**	**5.2**
EYR	1.9	2.6	1.4	1.8	1.3	1.4	1.1	1.2	1.1	1.2	**1.1**	**1.2**
EIR	1.2	0.6	2.2	1.3	3.6	2.5	6.7	4.6	6.8	4.6	**6.8**	**4.6**
ESI	1.3	3.2	0.6	1.2	0.3	0.5	0.2	0.2	0.2	0.2	**0.2**	**0.2**

Where: R renewable resources; N non-renewable resources; F purchased resources; U: Total Emergy; UEV the unit emergy value and GP the global productivity. EYR is the Emergy Yield Ratio, ELR the Environmental Load Ratio, EIR the Environmental Investment Ratio; and ESI Environmental Sustainability Index.

Some of the implemented actions had direct influence on the emergy indices (Table 5) while others were taken to improve the social aspects and staff awareness. Training exerts a positive impact on employee satisfaction (Longoni et al., 2014) and promotes higher commitment towards health and safety (Manzini and Accorsi, 2013). The training courses for each actor in the supply chain and cleaner production issues allowed increased knowledge and motivation in finding sustainable solutions to increase production efficiency, and reduce costs and risks to the natural and human environment. Furthermore, an extra payment to primary producers awarding the quality of the fruit to be supplied to the processor increased the production yield in the processing stage from 2.3 to 1.9 t of fruit per ton of pulp as well as the income of primary producers. Paying more for quality and increasing employment opportunities with the creation of new activities, such as the construction and maintenance of containers for raw fruit transport, production of compost on agricultural properties improved families' income, the incorporation of woman into labor, and the stability of jobs out of the mango season. In the long term, incentives may have a direct impact on employee satisfaction and encourage socially responsible behavior improving image and reputation (Longoni et al., 2014).

An analysis with the use of the emergy ternary diagram helps understanding and adds information about priorities and the extent of CP actions in each actor of the supply chain (Fig. 4). The sensitivity line clearly shows that, to aggregate economic value to the fruit, each actor called upon the usage of economic inputs, worsening step by step the environmental performance of the product. At the beginning of the chain, the primary producers are located in the medium term sustainability region, and as the chain builds up with the help of imported resources, the systems appear in the short term sustainability region. It is also clear that CP actions in the primary production were more effective than in all others. Actions taken at the end of the chain (distributor and sale points) had little effect. It is worth to note that the substitution of part of the fruit transport by animal traction resulted in an important increase in sustainability. The central diagram in figure 4 shows the environmental performance of the whole supply chain, and that despite the improvement achieved by the CP interventions in the two first links are noteworthy, the overall improvement of the whole chain was not significant. This indicates that, despite the simplicity of the mango chain, which only aggregates economic value to the fruit by turning it into canned pulp, the aggregated value relies heavily on exter-

nal resources.

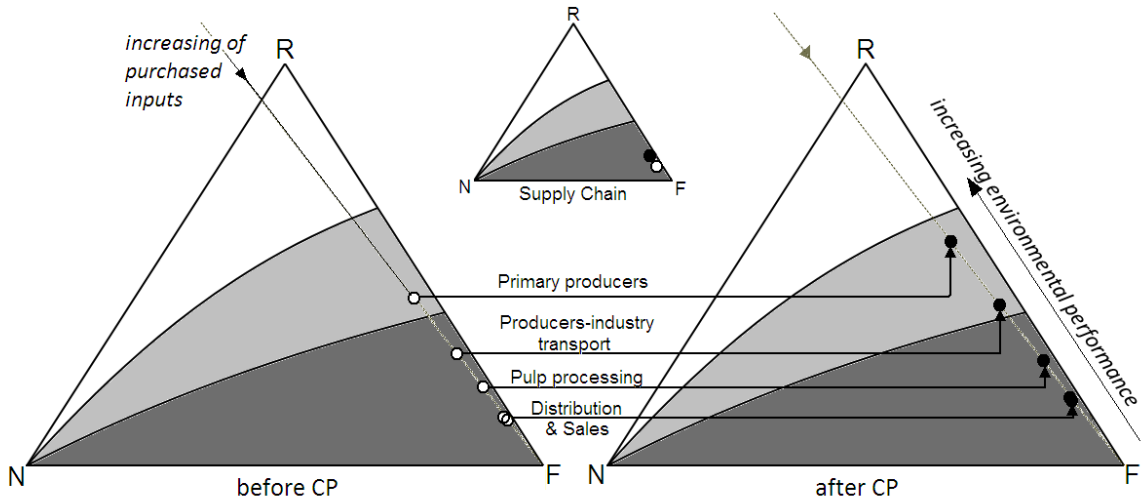

Fig. 4. Emergy ternary diagram for the mango supply chain positioning each member of the supply chain before (○) and after (●) the CP interventions. The central diagram shows the overall result of the supply chain.

4. Conclusions

The redesigning of traditional interactions is rarely spontaneous, and the share of the institutional setting for the mango production case study was fundamental to promote knowledge circulation and the requirements for reshaping the Santiago de Cuba mango supply chain, at both individual and chain levels. The results of this study show that cleaner production strategies applied to local level supply chains benefit the ecosystem and the society. Emergy indices pointed towards higher efficiency, lower energy consumption, lesser pressure on the environment, and a greater contribution to the local economy. The importance of the performance of the agricultural stage in the system as a whole encourages the adoption of more sustainable agricultural practices.

The emergy accounting methodology made it possible to determine the actual impact on resources use by each actor of the mango supply chain and by the whole system before and after the application of a cleaner production program. The emergy indices have a positive correlation with sustainability dimensions (environmental, social and economic) (Giannetti et al., 2011a), and the procedure applied to the mango supply chain can be adapted for analyzing the sustainability in other supply chains aiming the optimization of each actor, of the whole chain, and to evaluate and monitor the effect that isolated actions may have in the total chain. Based on the findings of the mango supply chain case study, additional research using emergy accounting may help to assess similar dynamics in other agricultural chains and, especially, where supply chains have effectively undergone the introduction of CP practices.

The exploratory case study of the mango supply chain offers new insights into the interaction dynamics between producers, processors and distributors. In addition, the results obtained may provide some suggestions for greening supply chains depending on the competence of the diverse actors to set up a shared environment supported by collaborative environmental and economic management.

Acknowledgments

We would like to thank the financial support from FAPESP (Fundação de Amparo à Pesquisa do

Estado de São Paulo), process no 2012/25492-0 and Post-Graduation Program of University Paulista (UNIP), Brazil. We also thank the all actors of local supply chain for supplying the production data.

References

Acosta, L. (2006), *Agro-chain Value and Business Partnerships: Tools to Support Family Agriculture in the Context of Globalization*. FAO Regional Office for Latin America and the Caribbean. http://s3.esoft.com.mx/esofthands/include/upload_files/4/Archivos/AN00034.pdf (accessed 2013).

Agostinho, F., Almeida, C.M.V.B., Bonilla, S.H., Sacomano, J.B. and Giannetti, B.F. (2013), Urban solid waste plant treatment in Brazil: is there a net emergy yield on the recovered materials? *Resources, Conservation and Recycling* **73**, 143-155.

Agostinho, F., Ambrosio, L. and Ortega, E. (2010), Assessment of a large watershed in Brazil using Emergy evaluation and Geographical Information System, *Ecological Modeling* **221**, 1209-1220.

Almeida, C.M.V.B., Agostinho, F., Giannetti, B.F. and Huisingh, D. (2015), Integrating cleaner production into sustainability strategies: an introduction to this special volume, *Journal of Cleaner Production* **96**, 1-9.

Almeida, C.M.V.B., Barrella, F.A. and Giannetti, B.F. (2007), Emergetic ternary diagrams: five examples for application in environmental accounting for decision-making, *Journal of Cleaner Production* **15,** 63-74.

Bastianoni, S., Marchettini, N., Panzieri, M. and Tiezzi, E. (2001), Sustainability assessment of a farm in the Chianti area (Italy), *Journal of Cleaner Production* **9**, 365-373.

Beske, P., Land, A. and Seuring, S. (2014), Sustainable Supply Chain Management Practices and Dynamic Capabilities in the Food Industry: A Critical Analysis of the Literature, *International Journal of Production Economics* **152**, 131-143.

Bourlakis, M., Maglaras G., Aktas E., Gallear D. and Fotopoulos, C. (2014), Firm size and sustainable performance in food supply chains: Insights from Greek SMEs, *International Journal of Production Economics* **152**, 112-130.

Brandenburg, M., Govindan, K., Sarkis, J. and Seuring, S. (2014), Quantitative models for sustainable supply chain management: Developments and directions, *European Journal of Operational Research* **233**, 299-312.

Brandt-Williams, S.L. (2002), *Folio 4: Emergy of Florida agriculture (2nd printing). In: Handbook of Emergy Evaluation*. Center for Environmental Policy, Environmental Engineering Science. University of Florida, Gainesville, Florida, USA.

Brown, M.T. and Buranakarn, V. (2003), Emergy indices e ratios for sustainable material cycles options, *Resources Conservation & Recycling* **38**, 1-22.

Brown, M.T. and Ulgiati, S. (2004), Emergy analysis and environmental accounting, *Encyclopedia of Energy* **2**, 329-359.

Cabrera, J. (2014), *Producción de frutales avanza en Cuba.* Available in http://www.radiorebelde.cu/noticia/cuba-produccion-frutales-20140118/. Last access 26.02.2014.

Cerutti, A., Beccaro, G., Bagliani, M., Contu, S., Donno, D. and Bounous, G. (2011), A review of studies applying environmental impact assessment methods on fruit production systems, *Journal of Environmental Management* **92**, 2277-2286.

Chen, C., Zhang, J. and Delaurenti, T. (2014), Quality control in food supply chain management: An analytical model and case study of the adulterated milk incident in China, *International Journal of Production Economics* **152**, 188-199.

Chen, R.Y. (2015), Autonomous tracing system for backward design in food supply chain, *Food Control* **51**, 70-84.

Cuadra, M. and Rydberg, T. (2006), Emergy evaluation on the production, processing and export of coffee in Nicaragua, *Ecological Modelling* **196**(3-4), 421-433.

De Barros, I., Blazy, J.M., Rodrigues, G.S., Tournebize, R. and Cinna, J.P. (2009), Emergy evaluation and economic performance of banana cropping systems in Guadeloupe (French West Indies), *Agriculture, Ecosystems & Environment* **129**, 437-449.

Fisher, M. (1997), What is the right supply chain for your product? *Harvard Business Review* **75**, 105-117.

Gasparatos, A., El-Haram, M. and Horner, M. (2008), A critical review of reductionist approaches for assessing the progress towards sustainability, *Environmental Impact Assessment Review* **28,** 286-311.

Giannetti, B.F., Barrella, F.A. and Almeida, C.M.V.B. (2006), A combined tool for environmental scientists and decision makers: ternary diagrams and emergy accounting, *Journal of Cleaner Production* **14**, 201-210.

Giannetti, B.F., Almeida, C.M.V.B., Agostinho, F., Bonilla, S.H. and Ulgiati S. (2013), Primary evidences on the robustness of environmental accounting from emergy, *Journal of Environmental Accounting and Management* **3**(2), 203-212.

Giannetti, B., Bonilla, S., Silva I. and Almeida, C. (2008), Cleaner production practices in a medium size gold-plated jewelry company in Brazil: when little changes make the difference, *Journal of Cleaner Production* **16**, 1106-1117.

Giannetti, B.F., Demétrio J.F.C., Bonilla, S.H., Agostinho, F. and Almeida, C.M.V.B. (2013), Emergy diagnosis and reflections towards Brazilian sustainable development, *Energy Policy* **63**, 1002-1012.

Giannetti, B.F., Ogura Y., Bonilla, S.H. and Almeida, C.M.V.B. (2011a), Emergy assessment of a coffee farm in Brazilian Cerrado considering in a broad form the environmental services, negative externalities and fair price, *Agricultural Systems* **104**(9), 679-688.

Giannetti, B.F., Ogura Y., Bonilla, S.H. and Almeida, C.M.V.B. (2011b), Accounting emergy flows to determine the best production model of a coffee plantation, *Energy Policy* **39**(11), 7399-7407.

Grimm, J.H., Joerg, S., Hofstetter and Sarkis, J. (2013), Critical Factors for Sub-Supplier Management: A Sustainable Food Supply Chains Perspective, *International Journal of Production Economics* **152**, 159-173, (OJO).

Hall, M. and Purchase, D. (2006), Building or bodging? Attitudes to sustainability in UK public sector housing construction development, *Sustainable Development* **14**, 205-218.

Hassini, E., Surti, C. and Searcy, C. (2012), A literature review and a case study of sustainable supply chains with a focus on metrics,

International Journal of Production Economics **140**(1), 69-82.
IMET. *Instituto de Meteorología de Cuba*. Available in http://www.met.inf.cu.
La Rosa, A.D., Siracusa, G. and Cavallaro, R. (2008), Emergy evaluation of Sicilian red orange production. A comparison between organic and conventional farming, *Journal of Cleaner Production* **16**, 1907-1914.
Lee, D.H., Dong, M. and Bian, W. (2010), The design of sustainable logistics network under uncertainty, *International Journal of Production Economics* **128**, 159-166.
Longoni, A., Golini, R. and Cagliano, R. (2014), The role of New Forms of Work Organization in developing sustainability strategies in operations, *International Journal of Production Economics* **147**, 147-160.
Lu, H., Kang W., Campbell D.E., Hai, R., Tan, Y., Feng, R., Luo, J. and Chen, F. (2009), Emergy and economic evaluations of four fruit production systems on reclaimed wetlands surrounding the Pearl River Estuary, China, *Ecological Engineering* **35**, 1743-1757.
Manzini, R. and Accorsi, R. (2013), The new conceptual framework for food supply chain assessment, *Journal of Food Engineering* **115**, 251-263.
Martikainen, A., Niemi, P. and Pekkanen, P. (2014), Developing a service offering for a logistical service provider—Case of local food supply chain, *International Journal of Production Economics* **157**, 318-326.
Min, H. and Kim, I. (2012), Green supply chain research: Past, present, and future, *Logistics Research* **4**, 39-47.
NEAD, The National Environmental Accounting Database (NEAD), available in http://www.cep.ees.ufl.edu/nead/ (Access 2013).
Nissinen, A., Parikka-Alholaa, K. and Ritab, H. (2009), Environmental criteria in the public purchases above the EU threshold values by three Nordic countries: 2003 and 2005, *Ecological Economics* **68**, 1838-1849.
Odum, H.T. (1996), *Environmental Accounting. Emergy and Environmental Decision Making*. John Wiley & Sons, New York, USA.
Odum, H.T., Brown, M.T. and Brandt-Williams, S.L. (2000), *Folio 4: Introduction and global budget. Handbook of Emergy Evaluation: A compendium of data for emergy computation issued in a series of folios*. Acceded in 2013. Available at http://www.emergysystems.org/folio.php
ONUDI (2011). *Industrial Value Chain Diagnostics: An Integrated Tool.* Organización de las Naciones Unidas para el Desarrollo Industrial (ONUDI). Viena, Austria
Parikka-Alhola, K. (2008), Promoting environmentally sound furniture by green public procurement, *Ecological Economics* **68**, 472-485.
Pizzigallo A.C.I., Granai C. and Borsa S. (2008), The joint use of LCA and emergy evaluation for the analysis of two Italian wine farms, *Journal of Environmental Management* **86**, 396-406.
Rydbergy, T. and Jansen, J. (2002), Comparison of horse and tractor traction using emergy analysis, *Ecological Engineering* **19**(1), 13-28.
Sarkis, J., Zhu, Q. and Lai, K.H. (2011), An organizational theoretic review of green supply chain management literature, *International Journal of Production Economics* **130**(1), 1-15.
Searcy, C., Karapetrovic, S. and McCartney, D. (2009), Designing corporate sustainable development indicators: reflections on a process, *Environmental Quality Management* **19**(1), 31-42.
Seuring, S. (2013), A review of modeling approaches for sustainable supply chain management, *Decision Support Systems* **54**, 1513-1520.
Seuring, S. and Gold, S. (2012), Conducting content-analysis based literature reviews in supply chain management, *Supply Chain Management: An International Journal* **17**(5), 544-555.
Silvestre, B.S. (2015), A hard nut to crack! Implementing supply chain sustainability in an emerging economy, *Journal of Cleaner Production* **96**, 171-181.
Swanson, M., Weissman, A., Davis, G., Socolof, M. and Davis, K. (2005), Developing priorities for greener state government purchasing: a California case study, *Journal of Cleaner Production* **13**, 669-677.
Testa, F., Iraldo, F., Frey, M. and Daddi, T. (2012), What factors influence the uptake of GPP (green public procurement) practices? New evidence from an Italian survey, *Ecological Economics* **82**, 88-96.
Tukker, A., Emmert, S., Charter, M., Vezzoli, C., Sto, E., Andersen, M.M., Geerken, T., Tischner, U. and Lahlou, S. (2008), Fostering change to sustainable consumption and production: an evidence based view, *Journal of Cleaner Production* **16**, 1218-1225.
Tweed, K. (2010), *Sustainability practices are really risk management.* /http://www. greentechmedia.com/articles/read/sustainability-is-really-risk-management/S. September 29, last accesses in May 2015.
Ulgiati, S., Odum, H.T. and Bastianoni, S. (1994), Emergy use environmental loading and sustainability: an emergy analysis of Italy, *Ecological Modelling* **73**, 215-268.
Van der Heyden, D. and Camacho, P. (2006), *Guía metodológica para el análisis de cadenas productivas.* available in http://www.ruralter.org/index.php?option=com_content&task=view&id=38&I (acceded January 2014).
Walker, H. and Brammer, S. (2009), Sustainable procurement in the United Kingdom public sector, *Supply Chain Management, International Journal* **14**, 128-137.
Wallgren, C. and Höjer, M. (2009), Eating energy—Identifying possibilities for reduced energy use in the future food supply system, *Energy Policy* **37**, 5803-5813.
Wang, X., Chen, Y., Sui, P., Gao, W., Qin, F., Zhang, J. and Wu X. (2014), Emergy analysis of grain production systems on large-scale farms in the North China Plain based on LCA, *Agricultural Systems* **128**, 66-78.
Yakovleva, N., Sarkis, J., Sloan, T. (2012), Sustainable benchmarking of supply chains: The case of the food industry, *International Journal of Production Research* **50**(5), 1297-1317.
Zanoni, S. and Zavanella, L. (2012), Chilled or frozen? Decision strategies for sustainable food supply chains, *International Journal of Production Economics* **140**, 731-736.

Supplementary material

S.1. Notes for the conventional mango production, Table 1

1.Chemical rain: Annual energy= Accumulated rain (0.36 m/year)* Gibbs Energy (5000 J/kg)* water density (1000 kg/m^3)* (10000 m^2 /ha)* area (130 ha); 2. Labor: Annual energy =257 pers*72 d/yr*8 h/d*(2500 kcal/pers.24 h)*4186 J/kcal)*0.7; 3. Soil losses: Annual energy= Erosion rate (7 t/ha/yr) *130 ha* % organic in soil (0, 04)* Energy cont./g organic (5,40 kcal/g)* 4186 J/kcal; 4. Water: Annual energy= Annual consumption (7000 m3 /yr)* Gibbs energy (5000 J/kg)*water Density (1000 kg/m3); 5. Fuel oil and lubricants without services: Annual energy = annual consumption (1948.5 l/yr)* density (0,85 kg/l)*10,000 kcal/kg*4186 J/kcal; 6. Nitrogen: Annual energy= annual consumption (1,68*10^5 g/ha)* 130 ha; 7. Potassium: Annual energy= annual consumption (1.36*10^5 g/ha)* 130 ha; 8. Phosphate: Annual energy= annual consumption (0,67 *10^5 g/ha)* 130 ha; 9. Pesticides, insecticides: Annual energy= annual consumption 1.33 g; 10. Organic fertilizer: Annual energy= annual consumption 2838 g/ha*130 ha; 11. Wood boxes: Annual energy= annual consumption (333 u)* box weight (2000 g/u)/ life time (2 yr); 12. Labor 30%.: Annual energy =257 pers*72 d/yr*8 h/d*(2500 kcal/pers.24 h)*4186 J/kcal) *0.30; 13. Machinery: Annual energy= Tractor weight (6*10^6 g/u)*quantity (1 u)* 15% use for mango plantation/ life time (10 yr); 14. Maintenance: (Cabrera, 2014).

S.2. Transport of raw material from producers to industry.

Table S.2. Emergy analysis of the transportation stage of the mango supply chain in Cuba.

		Quantity	Unit	UEV* seJ/unit	Emergy (seJ/yr)	% (seJ/seJ)
	Renewable resouces (R)				**1.55 x 10^{17}**	**19**
1	Mango (29%)	3.77 x 10^8	g	4.10 x 10^8	1.55 x 10^{17}	19
	Non renewable resources (N)				**2.67 x 10^{16}**	**3**
2	Mango (5%)	6.50 x 10^7	J	4.10 x 10^8	2.67 x 10^{16}	3
	Purchased resources (F)				**6.46 x 10^{17}**	**78**
3	Mango (66%)	8.58 x 10^8	g	4.10 x 10^8	3.52 x 10^{17}	43
4	Water	2.16 x 10^{10}	J	8.06 x 10^4	1.74 x 10^{15}	<1
5	Fuel	2.10 x 10^{12}	J	1.11 x 10^5	2.33 x 10^{17}	28
6	Electricity	2.25 x 10^{10}	J	1.05 x 10^5	2.36 x 10^{15}	<1
7	Trucks	2.01 x 10^6	g	6.89 x 10^9	1.39 x 10^{16}	2
8	Labor	8.79 x 10^9	J	3.93 x 10^6	3.45 x 10^{16}	4
9	Wood	8.33 x 10^4	J	8.19 x 10^3	6.82 x 10^8	<1
10	Infrastructure	3.61 x 10^6	g	1.54 x 10^9	8.74 x 10^{15}	1
11	Mantainance	1.53 x 10^2	USD	4.30 x 10^{12}	6.58 x 10^{14}	<1
	Emergy		**sej/yr**		**8.28 x 10^{17}**	**100**
	Mango	1.30 x 10^9	g			
	UEV mango transported		**seJ/g**	**6.37 x 10^8**		

1. Mango fruit: Annual energy= Annual production 1.3 x 10^9 g * 0.29; 2. Mango fruit 1.3 x 10^9 g * 0.05; 3. Mango fruit 1.3 x 10^9 g * 0.66; 4. Water: Annual energy= Annual consumption (4320m^3/yr)*Gibbsr energy (5000 J/kg)*Density (1000 kg/m3); 5. Fuel oil and lubricants without services: Annual energy = Annual consumption (5852.5 l/yr)* density (0,85 kg/l)*10,000 kcal/kg*4186 J/kcal; 6. Electricity: Annual energy = Annual consumption (6250 kWh/yr)* 3.60*10^6 J/kWh; 7. Trucks: Annual energy = (Truck weight (10050 kg/u)*quantity (2u)/ life time (10 yr); 8. Labor: Annual energy =18 pers*140 d/yr*8 h/d*(2500 kcal/pers.24 h)*4186 J/kcal); 9. Wood boxes: Annual energy= Annual consumption (333 u)* box weight (2000 g/u)/ life time (2 yr); 10. Infrastructure: concrete volume =33.59 m^3: (33.59 m^3 * 2.65x10^{6}g/m^3/ life time (25 yr); UEV retrieved from Brown and Buranakharn (2003); 11. Maintenance: (Cabrera, 2014).
*UEVs References: 1,2,3 - Calculated in this work; 4 - Bastianoni et al., 2001; 5,6 - Odum et al.,200; 7 - Brown et al., 2000; 8 - Calculated in this work; 9 - Bastianoni et al., 2001; 10 – Rydbergy and Jansen, 2002; 11 - NEAD, 2004.

S.3. Pulp processing

Table S.3. Emergy analysis of the processing stage of the mango supply chain in Cuba.

		Quantity	Unit	UEV* seJ/unit	Emergy (seJ/yr)	% (seJ/seJ)
	Renewable resouces (R)				**1.57 X 10^{17}**	**13**
1	Mango (19%)	2.47 x 10^{8}	g	6.37 x 10^{8}	1.57 x 10^{17}	13
	Non renewable resources (N)				**2.48 x 10^{16}**	**2**
2	Mango (3%)	3.90 x 10^{7}	J	6.37 x 10^{8}	2.48 x 10^{16}	2
	Purchased resources (F)				**1.02 x 10^{18}**	**85**
3	Mango (78%)	1.01 x 10^{9}	g	6.37 x 10^{8}	6.46 x 10^{17}	54
4	Water	6.65 x 10^{11}	J	8.06 x 10^{4}	5.36 x 10^{16}	4
5	Fuel	2.62 x 10^{12}	J	1.11 x 10^{5}	2.91 x 10^{17}	24
6	Electricity	1.90 x 10^{10}	J	1.05 x 10^{5}	2.00 x 10^{15}	<1
7	Wood	2.96 x 10^{12}	J	8.19 x 10^{3}	2.42 x 10^{16}	**2**
8	Machinery	6.30 x 10^{5}	g	2.42 x 10^{9}	1.52 x 10^{15}	<1
9	Cans	2.17 x 10^{7}	g	6.89 x 10^{9}	1.49 x 10^{16}	<1
10	Paper	4.43 x 10^{5}	g	3.80 x 10^{8}	1.68 x 10^{14}	<1
11	Labor	3.67 x 10^{7}	J	3.93 x 10^{6}	1.44 x 10^{14}	<1
12	Infrastructure	4.11 x 10^{6}	g	1.54 x 10^{9}	9.95 x 10^{15}	<1
13	Maintenance	1.45 x 10^{2}	USD	4.30 x 10^{12}	6.24 x 10^{14}	<1
	Emergy		**seJ/yr**		**1.20 x 10^{18}**	**100**
	Mango pulp	6.65 x 10^{8}	g			
	UEV mango pulp		**seJ/g**	**1.81 X 10^{9}**		

1. Mango fruit: Annual energy= Annual production 1.3 x 10^{9} g * 0.19; 2. Mango fruit 1.3 x 10^{9} g * 0.03; 3. Mango fruit 1.3 x 10^{9} g * 0.78; 4. Water (industrial use): Annual energy= Annual consumption (1330 m^3 /yr)* Gibbs energy (5000 J/kg)*water Density (1000 kg/m^3); 5. Diesel: Annual energy = Annual consumption (736.3 l/yr)* density (0,85 kg/l)*10,000 kcal/kg*4186 J/kcal; 6. Electricity: Annual energy = Annual consumption (5500 kWh)* 3.60.10^{6} J/kWh; 7. Wood: Annual energy = Annual consumption (1827m^3/yr)* 12%*density (850 kg/m^3)* caloric power (3800kcal/ kg)*4186 J/kcal; *. Machinery: Fruit washer machine: (250 kg/u)*quantity (2 u)* 10^{3} g/kg/ life time (10 yr), Pulper (85 kg/u)*quantity (1 u)* 10^{3} g/kg/ life time (10 yr), Vacuum concentrator (35 kg/u)*quantity (4 u)* 10^{3} g/kg/ life time (10 yr), Pumps and valves (31 kg/u)*quantity (4 u)* 10^{-3} g/kg/ life time (10 yr), Boiler (2000 kg/u)*quantity (2 u) / life time (10 yr), Stainless steel table (10 kg/u)*quantity (2 u)* 10^{-3} g/kg/ life time (10 yr), Cold storage (670 kg/u)*quantity (2 u)* 10^{3} g/kg/ life time (10 yr); 9 Cans: Annual energy = Annual consumption 221667 cans * 50g/can; 19. label (papers and glue) 221667 labels * 2g/label; 11. Labor: Annual energy =4 pers*72 d/yr*8 h/d*(2500 kcal/pers.24 h)*4186 J/kcal); 12. Infrastructure: concrete volume =33.59 m^3: (33.59 m^3 * 2.65x10^{6}g/m^3/ life time (25 yr); UEV retrieved from Brown and Buranakharn (2003); 13. Maintenance: (Cabrera, 2014).
*UEVs References: 1,2,3,11 - Calculated in this work; 4,7, 10 - Bastianoni et al., 2001; 5,6 - Odum et al.,2000; 8 - Brown et al., 2000; 9 - Castellini et al., 2003; 12 – Rydbergy and Jansen, 2002; 13 - NEAD, 2004

S.4. Distributor

Table S.4. Emergy analysis of the pulp distribution stage of the mango supply chain in Cuba.

		Quantity	Unit	UEV seJ/unit	Emergy (seJ/yr)	% (seJ/seJ)
	Renewable resouces (R)				1,56 X 10^{17}	**11**
1	Mango pulp (13%)	8.65 x 10^{7}	g	1.81 x 10^{9}	1.56 x 10^{17}	11
	Non renewable resources (N)				**2.40 x 10^{16}**	**2**
2	Mango pulp (2%)	1.33 x 10^{7}	J	1.81 x 10^{9}	2.40 x 10^{16}	2
	Purchased resources (F)				**1.23 x 10^{18}**	**87**

3	Mango pulp (85%)	5.65×10^{8}	g	1.81×10^{9}	1.02×10^{18}	72
4	Water	2.16×10^{10}	J	8.06×10^{4}	1.74×10^{15}	<1
5	Fuel	6.40×10^{11}	J	1.11×10^{5}	7.10×10^{16}	5
6	Electricity	4.50×10^{9}	J	1.05×10^{5}	4.73×10^{14}	<1
7	Trucks	1.50×10^{7}	g	6.89×10^{9}	1.03×10^{17}	7
8	Labor	9.77×10^{9}	J	3.93×10^{6}	3.84×10^{16}	2
9	Wood	2.60×10^{4}	J	8.19×10^{3}	2.13×10^{8}	<1
10	Infrastructure	6.84×10^{6}	g	2.42×10^{9}	1.66×10^{16}	<1
11	Maintenance	1.53×10^{2}	USD	4.30×10^{12}	6.58×10^{14}	<1
	Emergy		**sej/yr**		**1.41×10^{18}**	**100**
	Mango pulp	6.65×10^{8}	g/y			
	UEV mango pulp distributed		**sej/g**	**2.12×10^{9}**		

1. Mango fruit: Annual energy= Annual production 1.3×10^{9} g * 0.13; 2. Mango fruit 1.3×10^{9} g * 0.02; 3. Mango fruit 1.3×10^{9} g * 0.85; 4. Water: Annual energy= Annual consumption (4320 m^3/yr)* Gibbs energy (5000 J/kg)*water Density (1000 kg/m^3); 5. Fuel and lubricant: Annual energy = Annual consumption (18000 l/yr)* density (0.85 kg/l)*10,000 kcal/kg*4186 J/kcal; 6. Electricity: Annual energy = Annual consumption (1250 kWh/yr)* $3.60*10^{6}$ J/kWh; ; 7. Trucks: Annual energy = (Truck weight (7500 kg/u)*quantity (20u)/ life time (10 yr); 8. Labor: Annual energy =20 pers*140 d/yr*8 h/d*(2500 kcal/pers.24 h)*4186 J/kcal); 9. Wood Pallets: Annual energy = Annual consumption (26 u)* weight (2000 g)/2 yr; 10. Infrastructure: concrete volume =64.5 m^3: (64.5 m^3 * 2.65×10^{6}g/m^3/ life time (25 yr); UEV retrieved from Brown and Buranakharn (2003); 11. Maintenance: (Cabrera, 2014).
*UEVs References: 1,2,3,8 - Calculated in this work; 4,7, 10 - Bastianoni et al., 2001; 5,6 - Odum et al.,2000; 9 - Brown et al., 2000; 12 – Rydbergy and Jansen, 2002; 11 - NEAD, 2004

S.5. Sales

Table S.5. Emergy analysis of the sales stage of the mango supply chain in Cuba.

		Quantity	Unit	UEV seJ/unit	Emergy (seJ/yr)	% (seJ/seJ)
	Market					
	Renewable resouces (R)				**1.13×10^{17}**	**8**
1	Mango pulp (8%)	5.32×10^{7}	g	2.12×10^{9}	1.13×10^{17}	8
	Non renewable resources (N)				**1.41×10^{16}**	**1**
2	Mango pulp (1%)	6.65×10^{6}	J	2.12×10^{9}	1.41×10^{16}	1
	Purchased resources (F)				**1.30×10^{18}**	**91**
3	Mango pulp (91%)	6.05×10^{8}	g	2.12×10^{9}	1.28×10^{18}	90
4	Equipment	1.50×10^{3}	g	6.89×10^{9}	1.03×10^{13}	<1
5	Labor	5.27×10^{9}	J	3.93×10^{6}	2.07×10^{16}	1
6	Infrastructure	1.20×10^{7}	g	8.19×10^{3}	$9.83 \times 10^{1}2$	<1
7	Maintenance	1.83×10^{-4}	USD	4.30×10^{12}	7.87×10^{8}	<1
	Emergy		**sej/yr**		**1.43×10^{18}**	**100**
	Mango pulp	6.65×10^{8}	g			
	UEV mango pulp for sale		**sej/g**	**2.15×10^{9}**		

1. Mango fruit: Annual energy= Annual production 1.3×10^{9} g * 0.11; 2. Mango fruit 1.3×10^{9} g * 0.02; 3. Mango fruit 1.3×10^{9} g * 0.87; 4. Equipment: Cash register 3000 g/u*quantity (5u)/ life time (10 yr). 5. Labor: Annual energy =21 pers*72 d/yr*8 h/d*(2500 kcal/pers.24 h)*4186 J/kcal); 6. Infrastructure: concrete volume =113.2 m^3: (113.2 m^3 * 2.65×10^{6}g/m^3/ life time (25 yr); UEV retrieved from Brown and Buranakharn (2003); 7. Maintenance: (Cabrera, 2014).
*UEVs References: 1,2,3,5 - Calculated in this work; 4,7– Rydbergy and Jansen, 2002; 7 - NEAD, 2004