Assessment of the Natural Resource Base of Nicaragua and Case Studies of its Use in Agricultural Production and Export

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Doctoral thesis
Swedish University of Agricultural Sciences
Uppsala 2005

Acta Universitatis Agriculturae Sueciae
2005: 25

ISSN 1652-6880
ISBN 91-576-7024-2

Tryck: SLU Service/Repro, Uppsala 2005

Abstract

Cuadra, M. 2005. *Assessment of the Natural Resource Base of Nicaragua and Case Studies of its Use in Agricultural Production and Export.* Doctoral dissertation.
ISSN 1652-6880, ISBN 91-576-7024-2

This is a study of the natural resource base of Nicaragua with special emphasis on some agricultural crops. The objectives of the study were: 1) To assess whether the export of refined instead of green coffee would make coffee exports more favourable for Nicaragua, and 2) to assess the economic profitability and ecological carrying capacity for important crops in tropical agriculture. Emergy synthesis (ES) methodology was used together with Cost and Return Analysis (CAR) and Ecological Footprint (EF), in order to investigate how the results differed as regards the different aims, theoretical backgrounds and differences in system boundaries of these methods. The emergy exchange ratio (EER) of coffee exports between Nicaragua and the more economically developed trading nations indicated that the trade was not in favour of Nicaragua because the country exports much more real wealth (measured in emergy) in the coffee than it imports in the money received for the coffee, *i.e.* it is thereby depleting its indigenous natural resources. These findings were supported by the emergy indices calculated at the national level (percent renewable, ratio of imports to exports, emergy to money ratio, environmental loading ratio and emergy sustainability index). Regarding the use of emergy synthesis, cost and return analysis and ecological footprint, the study indicated that cabbage and tomato were the most profitable crops, both in economic and emergy terms, and that coffee was the least profitable crop to grow. When sustainability was measured as ecological carrying capacity, beans, coffee and maize were the most sustainable crops. Comparison of the results from ES, CAR and EF indicate poor coherence between short-term economic profitability and long-term ecological sustainability. No single method or index was enough to answer all questions and to include all aspects. However, emergy synthesis and its theoretical perspective was found to be a more comprehensive tool that gave more information on the balance between the long-term ecological sustainability and economic profitability than the two other methods used. Emergy synthesis could be used to assess overall sustainability for a country and trade. It may also provide a basis for proposing changes in trade policies.

Keywords: emergy evaluation, sustainability indicators, Nicaragua

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Resumen

Evaluación de la Base de Recursos Naturales de Nicaragua y Estudios de Casos de su Uso en la Producción y Exportación de Cultivos

Introducción

Este es un estudio de la base de recursos naturales de Nicaragua, con un énfasis especial en algunos cultivos agrícolas. En vista de los profundos problemas ambientales y sociales de Nicaragua, el enfoque de mi investigación fue sugerir un uso más eficiente y sostenible de los recursos en el país, y en particular para la agricultura de la zona de estudio. Ya que los problemas ambientales y sociales en una área del país se interrelacionan con los problemas a nivel nacional y global, era necesario seleccionar un método que pudiera integrar a los humanos y a la naturaleza en diferentes escalas. Debido a su enfoque sistémico y holístíco, escogí la metodología de Síntesis de Emergía (emergy synthesis en inglés), como la metodología principal para responder a los objetivos de este estudio. Como comparación con Síntesis de Emergía, usé también los métodos de Estimación de Costos y Rentabilidad (ECR) y Huella Ecológica (HE), con el objetivo de investigar si los resultados difieren de aquellos generados por la evaluación de emergía. Esto debido a los diferentes marcos teóricos y límites de sistema de estos dos métodos.

De acuerdo a datos del Banco Central de Nicaragua (BCN, 2002), la producción agropecuaria representa un 75% del valor total de las exportaciones. También la actividad agropecuaria contribuye con un 27% del PIB y emplea cerca del 43% de la población económicamente activa (FAO, 2004). De la producción de cultivos, la producción de café (*Coffea arabica* L.), contribuye con cerca del 5% del PIB y representa un 24% de las exportaciones agrícolas (MAG, 1998; Robleto, 2000). En 1996, la Universidad Nacional Agraria—UNA, inició un proyecto de investigación en cuencas, con el objetivo de generar información sobre el uso de recursos naturales en determinadas cuencas. La UNA seleccionó la Cuenca Sur del Lago de Managua o Xolotlán debido a su proximidad al *campus* y debido a que esta área fue declarada en 1992 como de la más alta prioridad en cuanto a estudio, preservación y manejo. Esta fue la zona seleccionada para este estudio.

Los objetivos de mi estudio fueron: 1) Evaluar si la exportación de café refinado en vez de café verde resulta en mayores beneficios para Nicaragua, y 2) evaluar la rentabilidad económica y la capacidad de carga ecológica para varios cultivos importantes en Nicaragua.

Métodos

Síntesis de emergía (Emergy synthesis)

La metodología de síntesis de emergía ha sido desarrollada por Howard T. Odum y colaboradores en la Universidad de Florida. Este método está basado en ecología de sistemas y termodinámica (Brown *et al.*, 2000). La síntesis de emergía, es capaz de evaluar los recursos y servicios de los sistemas ecológicos y económicos en una base común de energía. Esto se hace por medio de la cuantificación del trabajo directo e indirecto en la generación de un recurso o un servicio (Odum, 1996). La unidad de medida es usualmente emergía solar (solar emergy), ésta se define como la energía solar disponible previamente requerida, tanto directa como indirectamente, para hacer un producto o generar un servicio. Transformidad solar (solar transformity), es la emergía solar necesaria para hacer un Joule de servicios o de producto y su unidad es emjoules solares por Joule (sej/J). La transformidad solar de un producto, es su emergía solar dividida por su energía disponible.

La síntesis de emergía tiene un enfoque ecocéntrico y holístico. Odum (1983 y 1996) y Brown & Herendeen (1996), brindan una descripción más extensa del concepto, principios y aplicaciones de la metodología. La síntesis de emergía ha sido utilizada para evaluar la sostenibilidad ecológica y la capacidad de carga por medio de la utilización de diferentes índices de emergía tales como: índice de rendimiento de emergía – IRE, porcentaje de renovables – %Ren, índice de carga ambiental – ICA, y el índice de sostenibilidad – IS (Odum, 1983, 1988 y 1996; Ulgiati *et al.*, 1995; Ulgiati & Brown, 1998, Brown & Ulgiati, 1997; 1999 y 2001).

En este estudio, la evaluación de emergía fue aplicada para poder entender de una forma integrada y holística, los problemas con el uso de recursos de la agricultura y la economía de Nicaragua. Esta metodología emplea una perspectiva de sistemas abiertos, lo que quiere decir que considera que los sistemas están abiertos a las entradas y salidas de energía y por lo tanto,, toma en cuenta todos los procesos necesarios para generar un producto o servicio. De tal manera, que seleccioné esta metodología como la central de este estudio, debido a su habilidad para evaluar los sistemas ambientales y económicos sobre una base común. Los ìndices de síntesis de emergía que se calcularon fueron: rentabilidad basada en emergía (ES_{prof} %), huella ecológica basada en emergía (ES_{EF}), porcentaje de renovables (% Ren), relación emergìa a dinero – RED (sej/USD), índice de carga ambiental (ICA), índice de sostenibilidad (IS), emprecio – Emp (sej/USD) y relación de intercambio de emergía (RIE).

Estimación de costos y rentabilidad (ECR)

La metodología económica de estimación de costos y rentabilidad (ECR), ha sido usada y desarrollada ampliamente por productores y extensionistas para obtener información sobre los costos y ganancias y con ello tomar decisiones sobre el desempeño económico en la agricultura (AAEA, 2000). Este análisis está basado en la teoría economía neoclásica y los principios de contabilidad, así como en los conceptos de utilidad y maximización de ganancias (Edwards-Jones, Davies & Hussain, 2000), conceptos que a su vez comparten una visión mecanística (Johnson, 1996 p. 288). AAEA (2000), presenta una explicación más detallada de los diferentes usos y aplicaciones de ECR.

El análisis realizado por ECR, solamente puede evaluar los aspectos de sostenibilidad económica de corto plazo, a pesar de que recientemente, su uso se ha extendido para incluir aspectos ambientales y asignarles valores económicos a través del uso de diversas herramientas de análisis económico. En este estudio, hemos usado la metodología de estimación de costos y rentabilidad, para evaluar los flujos monetarios desde y hacia los sistemas de cultivo, con el objetivo de evaluar su rentabilidad económica de corto plazo. No incluimos el cálculo de costos ambientales, ya que hasta donde tenemos conocimiento, ECR a nivel de finca no los incluye, y queríamos hacerlo más comparable a otros ECRs a nivel de cultivo. Los índices calculados fueron ganancias y rentabilidad.

Huella ecológica (HE)

Chambers, Simmons & Wackernagel (2000), definen el término "huella ecológica", como la cantidad total de tierra ecológicamente productiva, que se requiere para sostener el consumo de una población determinada, de una manera sostenible. El concepto ha sido desarrollado por William Rees y Mathis Wackernagel de la Universidad de British Columbia en Canadá (ver Wackernagel & Rees, 1996). La huella ecológica se considera una herramienta de planificación y contabilidad que es consistente con los principios ecológicos y las leyes de la termodinámica (Wackernagel & Rees, 1996; Chambers, Simmons & Wackernagel, 2000). En la misma dirección, Rees (2000), menciona que la HE está "conceptualmente relacionada con los análisis de energía secuestrada (emergía) de Howard Odum", lo cual sugiere que HE tiene una perspectiva holística.

El concepto de HE toma en cuenta los flujos de energía y materiales, desde y hacia una determinada economía y los convierte a las áreas correspondientes requeridas por la naturaleza para sostener estos flujos y asimilar los desechos producidos (Wackernagel & Rees, 1996). En el procedimiento usualmente se incluyen seis categorías de tierras: tierras degradadas o consumidas (ambiente construido), tierras de cultivo, pastos, bosques, mares, y tierra para energía. De tal manera, que la HE usualmente se expresa en área *per capita*. El área para la conservación de la biodiversidad se calcula como una fracción de las otras áreas (12%).

A diferencia de ECR, la HE no incluye una evaluación económica, aunque su enfoque sea antropocéntrico. Para hacer la HE más comparable a ECR, hemos incluido el índice de HE por 1000 USD de ganancias. Hemos usado HE para evaluar la capacidad de carga económica y ecológica para cultivos agrícolas. Los índices de HE que se calcularon fueron: HE por hectárea de cultivo, HE por 1 000 USD de ganancias y HE por giga caloría de energía alimentaria producida.

Resumen de los principales resultados

Artículos I y II

Los artículos I y II tienen en común, el uso de síntesis de emergía como el método principal para evaluar la base de recursos de la economía de Nicaragua y el sistema de producción de café, procesamiento y exportaciones.

Los datos para el estudio de Nicaragua (I), se obtuvieron de información estadística publicada en diversas fuentes (BCN, 1998; EWY, 1998; UN, 1995; WRI, 1997 y 1999) y otras bases de datos del país (INE, 1999 y, 2000; INETER, 1997a, 1997b y 1999). Los datos para el estudio sobre café, provienen de una finca de café considerada como representativa de la Cuenca Sur del Lago Xolotlán y de dos compañías procesadoras de café de la zona.

Los índices de emergía calculados, sugieren que Nicaragua exportó más emergía en comparación con sus importaciones (relación importaciones a exportaciones = 2:1 y relación emergía a dinero = 15.8 E+12 sej/USD), y que el sistema económico-ecológico del país presentó un bajo nivel de carga ambiental (ICA = 0.4) y alta sostenibilidad (% renovables = 77% e IS = 13.9).

La relación de intercambio de emergía (RIE), entre Nicaragua y las naciones más desarrolladas, muestra que el comercio con estos países no es favorable para Nicaragua, ya que el país exporta mucha más "riqueza real" (medida en emergía), en el café que vende, que la que importa en el dinero recibido por el café. De esta manera, Nicaragua está agotando sus recursos naturales. Esta conclusión es también reforzada por los otros índices calculados a nivel nacional (%Ren, relación importaciones/exportaciones, relación emergía a dinero, índice de carga ambiental e índice de sostenibilidad).

Artículo III

En el artículo III, se hace uso de tres diferentes métodos (síntesis de emergía, estimación de costos y rentabilidad y huella ecológica), para evaluar la viabilidad económica, capacidad de carga ecológica y sostenibilidad para cultivos de importancia en la agricultura tropical.

Los datos para este estudio, provienen de entrevistas realizadas a productores en tres sitios considerados como representativos de la producción agrícola de la Cuenca Sur del Lago Xolotlán, los cuales fueron verificados con estadísticas nacionales (INTA 1995a; 1995b, 1996, 1999a y 1999b y MAGFOR, 2001). Los cultivos estudiados fueron: frijol común (*Phaseolus vulgaris*, L.), tomate (*Lycopersicum esculentum* L. Mill), repollo (*Brassica olearaceae* L. var. *capitata*), maíz (*Zea mays* L.), piña (*Ananas comosus* L. Merr.) y café (*Coffea arabica* L.).

El cuanto al uso de síntesis de emergía, estimación de costos y rentabilidad y huella ecológica, el estudio indicó que los cultivos de repollo y tomate fueron los más rentables, tanto en términos económicos como de emergía. El cultivo de café fue el menos rentable para cultivar. Cuando la sostenibilidad fue medida como capacidad de carga ecológica, los cultivos de frijol, café y maíz, fueron los cultivos más sostenibles. La comparación de los resultados de los diferentes métodos (síntesis de emergía, estimación de costos y rentabilidad y huella ecológica) indican la tendencia hacia una pobre coherencia entre la rentabilidad económica de corto plazo y la sostenibilidad ecológica de largo plazo.

Conclusiones

Ningún método o índice es capaz de contestar todas las preguntas e incluir todos los aspectos. Sin embargo, la síntesis de emergía y su perspectiva teórica, proporcionan una herramienta más exhaustiva, que brinda más información sobre el balance entre la sostenibilidad ecológica de largo plazo y rentabilidad económica de corto plazo, que los otros dos métodos usados. La síntesis de emergía puede ser usada para evaluar la sostenibilidad total para un país y en el comercio. Puede también proporcionar una base para proponer cambios en políticas locales o nacionales de comercio.

Contents

Appendix

Papers I-III

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I. Cuadra, M. and Rydberg, T. 2000. Emergy evaluation of the environment and economy of Nicaragua. In: Emergy synthesis. Theory and applications of the emergy methodology. Proceedings of the first biennial emergy synthesis research conference. Gainesville, FL, September 1999. The Centre for Environmental Policy. Department of Environmental Engineering Sciences. University of Florida. Gainesville, FL.

II. Cuadra, M. and Rydberg, T. Emergy evaluation on the production, processing and exports of coffee in Nicaragua. Submitted to *Ecological Modelling.*

III. Cuadra, M. and Björklund, J. Using cost and return analysis, ecological footprint and emergy analysis to assess economic and ecological carrying capacity of agricultural crops – are the results a useful basis for decision? Submitted to *Ecological Indicators*.

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Preface

The southern watershed of the Xolotlán Lake in Nicaragua has large environmental problems due among other things to the poor management of the land and overuse of its capacity, especially in the high part of the watershed. As an agronomist, I chose to focus my study on the agriculture of the watershed, to study some of the most important crops of the area, such as coffee, which is the most economically important crop both for that area and for the country. In order to understand the problems at the watershed level, I also needed to do an evaluation at the country level, which helped me gain a perspective on the situation of the area.

When I began learning about emergy methodology, I had the impression that emergy synthesis had an answer for everything, that it could solve all the problems of Nicaragua and the world. This seemed very challenging to me, but I am often attracted to challenges. But what is emergy? Is it energy misspelled? In 1999, I had a hard time trying to explain to an US embassy officer what emergy was in a short and simple way (he was suspicious that emergy *was* just energy misspelled!). However I finally obtained a US visa to attend the First Biennial Emergy synthesis Research Conference in Gainesville, Florida.

Now I must confess that I was too ambitious in trying to solve all the problems of the world with one methodology. Although emergy evaluation is a strong and robust methodology with a solid scientific background, it does not have the answer for everything. For example, emergy evaluation cannot calculate ethical values in emergy terms, nor can it say why people make the choices they do.

Another of the drawbacks with the method is the difficulty to communicate it. This could be due to the scientific basis of the method in systems ecology, which is still a new and controversial paradigm. In this regard, I believe it is very important to find ways to make the method easier to understand for more people. I also believe that it is important to do more applied studies of emergy synthesis with the integration of other methodologies that can give an answer to the variety of problems we are facing at present. Collaboration among researchers of different disciplines and world views is vital.

I initiated my PhD studies because, among other things, I was not satisfied with my scientific knowledge, I wanted to learn more and have more knowledge. Now, after finishing my studies, I can honestly say that I have learned many things, but on the other hand, I know now that there are still many things to be investigated and understood. However, I hope that this thesis contributes to our understanding of the complexity of living systems and the need to find adequate tools to analyse them.

Introduction

"We can't solve problems with the same kind of thinking we used when we created them".

Albert Einstein

Nicaragua has deep economic, environmental and social problems. In the face of that, the focus of my research was to suggest more sustainable and efficient use of the resources in the country, particularly for agriculture in the study area. As the environmental and social problems in one area of the country are interrelated to the problems at the national and global scale, it was necessary to choose a method that could integrate humans and nature at different scales. I chose emergy synthesis as the main method to answer the research questions presented below because of its systemic and holistic approach. For comparison with emergy synthesis, I also used Cost and Return estimation (CAR) and Ecological Footprint (EF) in order to investigate whether the results differed from those of emergy evaluation as regards their different theoretical backgrounds and differences in system boundaries of these two methods.

Objectives and main questions addressed

The objectives of this study were: 1) To assess whether the export of refined instead of green coffee would result in an increased benefit for Nicaragua; 2) to assess economic profitability and ecological carrying capacity for crop production in Nicaragua.

Based on the objectives, the following key questions were addressed: Would a change in production to more processed coffee increase the use of non renewable resources, and would it negatively affect the local environment? How can we find a balance between economic profitability and ecological carrying capacity in agriculture? Could the evaluation tools employed give guidance in answering these questions? How can we find good indices to weigh economic profitability and ecological carrying capacity? Could the results from emergy synthesis, cost and return estimation and ecological footprint be compared? What is the usefulness of these methods for the farmers and for Nicaragua? What additional information would be needed to more fully assess economic profitability and ecological carrying capacity?

Country profile

The environment and economy of Nicaragua

Nicaragua is the largest country in Central America, located in the middle of the Central American isthmus, between 10º42' and 14º59' North and 83º24' and 87º11' West. Nicaragua is often called the "Land of the Lakes and Volcanoes" as it has two large lakes (Lago Xolotlán and Lago Cocibolca), many active volcanoes and more than 30 watersheds. Lago Cocibolca or Lago de Nicaragua (8 264 km^2 approx.) represents the largest body of fresh water in Central America.

Nicaragua has a developing economy based largely on agriculture. According to estimates of Banco Central de Nicaragua (BCN, 2002), Nicaragua's GNP for the year 2002 was 2.4 E+09 USD, equivalent to 481 USD per person per year. At present, Nicaragua is importing more than it exports; this makes the economic situation of the country highly unsustainable. This monetary gap is largely covered by the remittance of an estimated 400 to 800 MUSD per year by Nicaraguans living outside the country (El Observador Económico, 2001). In 2004, Nicaragua was finally accepted into the HIPC (Highly Indebted Poor Countries) initiative, obtaining with this the exoneration from paying approximately 80% of its foreign debt of approximately 4 GUSD.

Overview of the agricultural sector

According to the Nicaraguan Central Bank (BCN, 2002), agricultural production accounts for 75% of the total value from exports. It also contributes 27% of the GDP and employs about 43% of the economically active population (FAO, 2004).

The main agricultural products for export are coffee (*Coffea arabica* L.), meat and cattle, sugar, peanuts (*Arachis hypogea* L.) and common beans (*Phaseolus vulgaris*, L.). According to MAGFOR (2003), the contribution from crops like maize (*Zea mays* L.), common beans and rice (*Oryza sativa* L.), represents 56% of the food caloric consumption in Nicaraguan families and 67% of the protein availability per day. Another 37% is consumed as vegetable oils, sugars and wheat flour. Consumption of meat, milk and eggs represents only 7% of the daily caloric intake. Contributions from crops like tomatoes (*Lycopersicum esculentum* L. Mill), pineapple (*Ananas comosus* L. Merr.), coffee and other vegetables represent less than 1% of the daily caloric intake (FAOSTAT, 2004).

In economic terms, coffee production represents around 5% of the GNP and 24% of the agricultural exports (MAG, 1998; Robleto, 2000). In spite of its importance, coffee production has faced many limitations, such as the high dependence on imports of fuels, fertilizers and pesticides to maintain coffee yields and to process the coffee cherries and green coffee. The poor profitability of the production has caused many bankruptcies in the sector. Although the situation has improved in the past few years, the low international prices for coffee in the past 10-15 years have caused even more deterioration of this situation (MAG, 1998; Robleto, 2000).

Description of the study area

In 1996, Universidad Nacional Agraria—UNA (the National Agricultural University) initiated a research project in watershed areas with the aim of generating information about the use of natural resources in selected watersheds. UNA selected the southern watershed of Lago Xolotlán or Lake Managua (Figure 1) because of its proximity to the UNA campus and also because this area was in 1992 considered as the highest priority area in the country for watershed management due to the high risks of contamination of the water sources.

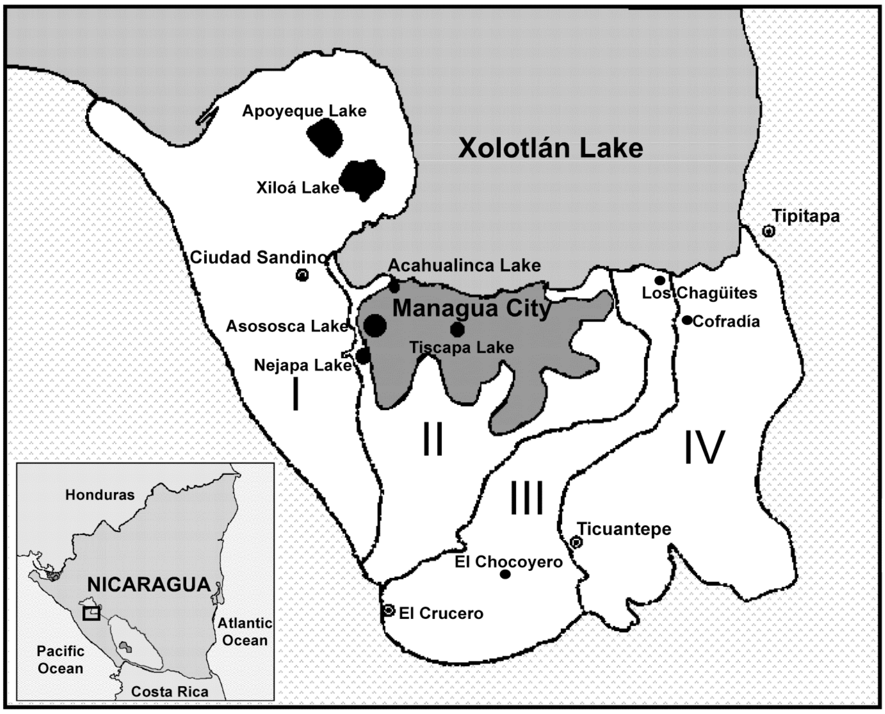


Figure 1. Map of Nicaragua and the southern watershed of Lago Xolotlán, with its four catchment areas (I-IV), where the study was performed.

The watershed of Lago Xolotlán is divided into two areas: the northern watershed and the southern watershed. Increasing pressure for land conversion has caused deforestation, soil losses and increased runoff. Inadequate cropping practices and overgrazing are common in the area. The agricultural systems in the southern watershed use high amounts of purchased inputs for crop production, with only few farmers using organic fertilizers and biological insecticides. The most important crops for the economy of the area are: coffee, pineapple and pitahaya (*Hylocereus* spp., a cactus with edible fruits). The management of these crops uses much labour, which means temporary jobs for the people in the area (UNA, 1998).

Theoretical perspective

In this section, I present the theoretical framework around the methods I used in this study, in order to understand their perspectives and different world views.

Scientific revolution

In the 16th and 17th Century, the new discoveries brought by the scientific revolution radically changed the old world view of the universe. The world as a machine replaced the idea of the organic, living and spiritual universe that had dominated previously. Founders of this new paradigm were Copernicus, Galileo, Descartes, Bacon and Newton (Capra, 1997; Edwards-Jones, Davies & Hussain, 2000).

Clockwork paradigm

Descartes established the method of analytic thinking, which consists of the dissection of the problem or phenomenon into smaller parts or pieces in order to understand the behaviour of the whole from the properties of the parts. This way of thinking is known as 'mechanism' or 'Cartesian mechanism' because it implies that everything, from the universe to the smallest living organism, could be perceived as a machine that can be understood by analysing its smallest parts (Peters, 1993). Precise mathematical laws can describe the behaviour of machines. Isaac Newton contributed to the mechanistic world view with his formulation of the laws of motion and gravity, which provided us with what is commonly known as the 'clockwork paradigm'. This is the dominant scientific paradigm up to the present day (Capra, 1997).

However, opposition to this prevailing world view came from scientists in different fields and times, *e.g.* Goethe, Henry Thoreau and Ralph Waldo Emerson from the romantic movement; Alfred North Whitehead and William Morton Wheeler from the organismic biology movement; Ludwig von Bertalanffy and William Ross Ashby from systems thinking; Werner Heisenberg and Henry Stapp from quantum physics (Checkland, 1991; Worster, 1994; Capra, 1997). All these movements have in common an emphasis on holism, interdependence and interconnections as properties of all systems. They claimed that the mechanistic philosophy of nature was reductionistic and incomplete (Checkland, 1991; Worster, 1994; Capra, 1997).

Systems thinking

At the beginning of the 20th Century, different scientists working in diverse fields formulated the main characteristics of systems thinking. von Bertalanffy (1972) defines a system as a "set of elements standing in interrelation among themselves and with the environment". Odum defines a system as a "group of parts that are interacting according to some kind of process" (Odum, 1983 p. 4). In the area of cybernetics, William Ross Ashby contributed to systems thinking with his book "An Introduction to Cybernetics" (Ashby, 1957). Ashby writes in his book that a system "may refer to the set of variables with which some given observer is concerned" (Ashby, 1957 p. 106). The most important principle of systems thinking is the shift from the parts to the whole, considering that living systems are integrated wholes with properties that cannot be reduced to those of smaller parts (Odum, 1983). A system loses its properties as a system when its elements are taken apart and isolated.

Emergy synthesis (ES), its theoretical background and use in sustainability assessments

General systems theory

General systems theory is a branch of systems thinking that emerged as an attempt to unify science and as a reaction against reductionism, over-specialization and splitting of science in numerous disciplines. Ludwig von Bertalanffy was the first scientist to formulate the concept of a general systems theory (von Bertalanffy, 1968). von Bertalanffy writes that "General System Theory is a logico-mathematical field whose task is the formulation and derivation of those general principles that are applicable to systems in general" (von Bertalanffy, 1972). In his work, he started to replace the mechanistic world view with a holistic vision. General systems theory is an interdisciplinary field of science that states the principles of all systems in general terms. It focuses on complexity, interdependence and wholeness (Odum, 1983; Wikipedia, 2004). Boulding (1956) defines general systems theory as the "skeleton of science" in the sense that it "aims to provide a framework or structure of systems on which to hang the flesh and blood of particular disciplines and particular subject matters in an orderly and coherent corpus of knowledge".

Systems ecology

A new science of ecology founded on systems thinking and in particular on general systems theory emerged as a reaction to the environmental damage brought by the World Wars and unrestrained scientific experimentation (Worster, 1994). The brothers Eugene and Howard Odum were the leaders in the development of systems ecology. Howard T. Odum (Odum, 1983) defines systems ecology "as the study of whole ecosystems and includes measurements of overall performance as well as a study of the details of systems design by which the overall behaviour is produced from separate parts and mechanisms". Although there are other definitions of "systems ecology" (Hagen, 1992, p. 131), I use the name to refer to Odum's theory. Systems ecology is a science of the ecosystem, which emphasizes the structure and processes at the ecosystem level. Odum (1983) gives a broader definition of ecosystems, considering as ecosystems all systems, including human systems. Systems ecology quantifies the flows of energy and materials as a way to understand the ecological problems. Odum (1983) envisioned systems ecology as the unifying theory "to consolidate the understanding of systems of many kinds".

Björklund (2000) wrote a synthesis of what she considers to be the most important contributions and principles of systems ecology. These principles are: 1) the Maximum Empower Principle, proposed as the fourth law of thermodynamics (Odum, 1996 p. 16); 2) the presence of autocatalytic feedback designs (Odum, 1983 p. 141); 3) the recognition of an energy transformation hierarchy, proposed as the fifth law of thermodynamics (Odum, 1987); 4) a theory of pulsing paradigm (Odum, 1988a); 5) acknowledgement of different spatial, temporal and ecological scales in the occurrence of phenomena (Odum, 1983 p. 253). These are called "design" principles because they are proposed to be general for all systems irrespective of their scale (Odum, 1983). They are important because the "existence of common designs and similar patterns with time provides a starting place for modelling with a unified theory of systems" (Odum, 1983 p. 572).

Systems thinking, general systems theory and systems ecology have in common a systemic and holistic world view. The concept of "holism" means that the properties of a system cannot be determined or explained by the sum of its components alone, this way of thinking is often considered as the opposite to reductionism. Reductionism, on the other hand, is a number of theories that consider that the nature of complex things can be reduced or explained by more basic ones (Wikipedia, 2004).

Emergy synthesis

Howard T. Odum and his collaborators at the University of Florida developed the methodology of emergy synthesis as a tool for systems understanding. The emergy method is grounded in systems ecology and thermodynamics (Brown *et al.,* 2000). Thermodynamics is defined as the physics of energy, heat, work, entropy and the spontaneity of processes (Wikipedia, 2004).

Emergy synthesis evaluates resources and services both in ecological and economic systems on a common energy basis, by quantifying the direct and indirect environmental work for generating a resource or a service (Odum, 1996). The measure is usually solar emergy and it is defined as the solar available energy previously required directly and indirectly to make a product or service. Solar transformity is defined as the solar emergy required to make one joule of a service or a product. Its unit is solar emjoules per Joule (sej/J). A product's solar transformity is its solar emergy divided by its available energy.

Emergy synthesis (ES) has an eco-centric approach, in other words, the "valuation of ecosystems or species without regard to their impact on human welfare" (Hansen, 1996). With the use of emergy evaluation, it is possible to evaluate the main inputs from the human economy and include also those inputs that are usually considered to be "free" from the environment, *e.g*. it is possible to include mineral resources that result from bio-geological processes, biological resources such as wood and economic products such as machines that result from industrial processes. In the case of raw agricultural products in particular, the market price may underestimate the real contribution to an economy's welfare, because the market price does not represent the environmental work involved in making that product. A more comprehensive description of the concept, principles and applications of the methodology can be found in Odum (1983), Odum (1996) and Brown & Herendeen (1996).

Emergy synthesis has been applied to studies in a variety of both temporal and spatial scales, including the evaluation of history (Sundberg *et al*., 1994), the assessment of environmental policies and management (Odum, 1980; Brown & McClanahan, 1996), trade (Brown, 2003; Cuadra & Rydberg, manuscript), energy policies (Brown & Ulgiati, 2002; Rydberg & Jansén, 2002), agriculture and agricultural products (Odum, 1984; Ulgiati, Odum & Bastianoni, 1993; Brandt-Williams, 2001) and simulation models as decision support (Odum, 1971).

Sustainability is a concept difficult to define; the efforts to do so have resulted in many different definitions (Hansen, 1996). However, sustainability definitions usually involve economic, social, ecological and institutional concepts (UN, 2003). According to the World Commission on Environment and Development (WCED, 1987), sustainable development may be defined as "development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations". This definition is human centred, as it does not take into account the needs of other species. In agriculture, sustainability is considered as the "ability of an agroecosystem to maintain production through time in the face of long-term ecological constraints and socio-economic pressures" (Altieri, 1995). Contrary to the vision of sustainability as a steady state to be reached (Daly, 1993), Odum (1994) envisions sustainability as the process of adapting to the oscillations of natural capital, recognizing that pulsing and oscillating states are "possibly the most general patterns in nature" (Odum, 1983 p.117). Odum's definition of sustainability is also more comprehensive than other definitions, as it considers the whole ecosystem dynamics into account, and also because its definition of ecosystem is much wider: "in the broadest modern usage, systems that include humans, such as farms, industries and cities, are also regarded as ecosystems" (Odum, 1983 p.17).

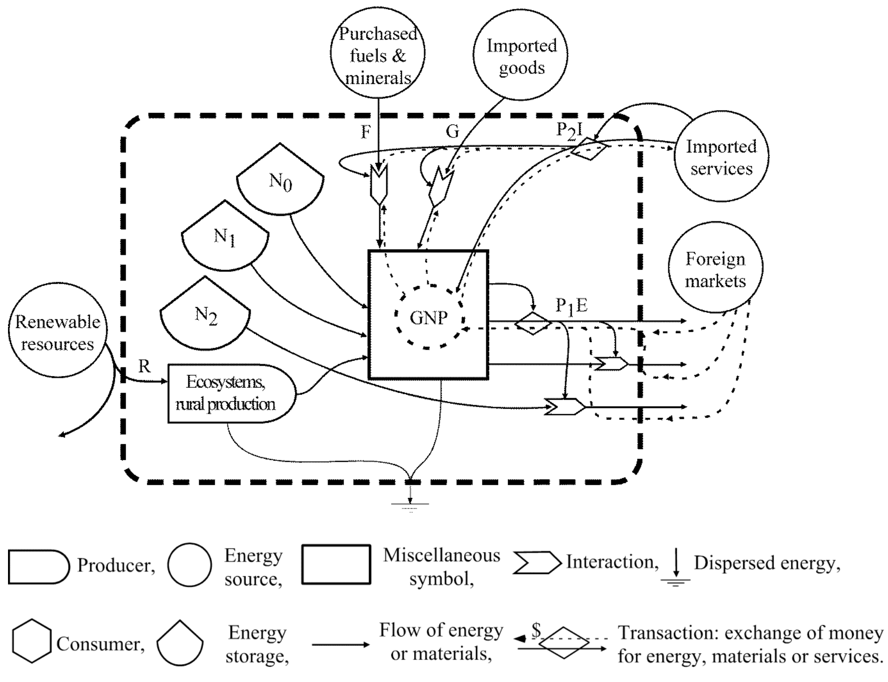


Figure 2. Aggregated system diagram for Nicaragua, summarizing renewable resource flows (R); non-renewable energy storages from within the system (N_0 = non-renewable rural resources, N_1 = non-renewables used internally, and N_2 = non-renewables exported without use); imported fuels and minerals (F); imported goods (G); emergy in services in imported goods and fuels (P_2I) and emergy value of goods and services in exports (P_1E). Symbols from the energy systems language in Odum (1983).

Emergy synthesis has been employed to assess ecological sustainability and carrying capacity by utilizing different emergy indices such as the emergy yield ratio (EYR), percent renewable (%Ren), environmental loading ratio (ELR) and sustainability index (ESI). These indices have been proposed and used in different papers by Odum (1983, 1988, 1996) as well as by Mark T. Brown and Sergio Ulgiati (*e.g.* Ulgiati *et al.*, 1995; Brown & Ulgiati, 1997; Ulgiati & Brown, 1998; Brown & Ulgiati, 1999; Brown & Ulgiati, 2001).

In the present study, emergy evaluation was applied to enable us to understand, in a more holistic way, the problems with the use of resources of agriculture and the economy of Nicaragua. Emergy synthesis employs an open system perspective, which means that it considers that systems are open to inflows and outflows of energies and therefore takes into account all processes needed to make a service or product. Open systems are the most common type of system in the real world (Odum, 1983 p. 4). I chose emergy evaluation as the main method because of its ability to assess the environmental and economic systems on a common basis. The different emergy indices calculated are presented in Table 1, while Figure 2 presents a summarized diagram of the resource flows and emergy indices calculated for Nicaragua.

Cost and Return Estimation (CAR), its theoretical background and use in sustainability assessments

Cost and return estimation (CAR) has been developed and used by farmers and extensionists to gain information about costs and returns to be used in taking decisions about economic performance in agriculture (AAEA, 2000). The statistics generated by CARs have also been used to characterize performance in the agricultural sector. The analysis is based on neoclassical economic theory and accounting principles, based on the concepts of utility and profit maximization (Edwards-Jones, Davies & Hussain, 2000). Neoclassical economic theory has its basis in the mechanistic world view (Johnson, 1996 p. 288). In a CAR, market prices are used to assign values to different inputs to a studied agricultural system (Pearce, 1983; Perkins, 1994; Edwards-Jones, Davies & Hussain, 2000)

The procedures for calculating the economic indices, the sources of data and the format to present the indices vary depending on the questions and the audience. Among the many purposes of CAR estimates are: decision making at the farm level, analysis of programmes and policies, analysis of performance and studies of resource allocation. In the CAR analysis, the inputs considered are the costs for all resources consumed, the costs for transportation, labour and for other services. In the analysis, the costs and returns can be aggregated in different categories, but one of the most common ways to aggregate CAR is at the enterprise, farm or crop level. CAR estimates can also be reported for different periods or points in time, most usually for the previous or the next production period, commonly a year. The unit of analysis can be for example a hectare, a head or a farm. Spreadsheets are used for the calculation of the different indices. AAEA (2000) presents a more detailed explanation on the different uses and applications of CAR.

Economic analysis (as performed by CAR) can assess only short-term economic aspects of sustainability. For example, cost analysis has been used in scientific studies in various countries to assess the economic feasibility of different crops, *e.g.* maize in the Philippines (Nelson *et al.*, 1998); beans in Nicaragua, (Alemán, 2001); tomatoes in Israel (Taylor *et al.*, 2001); cabbage in India (Gangwar, Katyal & Anand, 2003). However, economic analysis has been extended to include environmental aspects and to assign economic values for soil erosion (Alfsen *et al.*, 1996); land-use change (Münier, Birr-Pedersen & Schou, 2004); air pollution impacts on environmental systems (Adams & Horst, 2003); conservation of biodiversity (Pimentel *et al.*, 1997; Bräuer, 2003) and the value of ecosystem services (Costanza *et al.*, 1997; Zhao *et al.*, 2004), with the use of tools such as extended cost-benefit analysis, economic environmental valuation, ecological environmental evaluation, environmental impact assessment and multicriteria appraisal among others (Pearce, 1983; Perkins, 1994; Edwards-Jones, Davies & Hussain, 2000).

As I have previously mentioned, sustainability definitions involve economic, social, ecological and institutional aspects. Gliessman (2001) states that one important economic parameter considered to indicate agroecosystem sustainability is the estimation of farm profitability, while Altieri (1995 p. 92) relates agroecosystem sustainability to a reduction in the "costs and increase in the efficiency and economic viability of small and medium sized farms". For example, van Calker *et al.*, (2004) calculated the indices of gross revenues, costs and net farm income as economic indicators of sustainability. Thus, the estimation of CAR indices at farm level provides important information to assess economic viability of the farm and crops, as one aspect to determine sustainability.

In this study, we used the economic cost and return analysis to evaluate the money flows to and from the agricultural crop systems in order to assess their short-term economic profitability. We have not included any calculation on the environmental costs, as CAR at farm and crop level does not to our knowledge include these considerations, and we wanted to make it comparable to other CARs at crop level. The economic indices calculated were revenues and profitability (Table 1).

Ecological footprint (EF), its theoretical background and use in sustainability assessments

Chambers, Simmons & Wackernagel (2000) defined the term "ecological footprint" as the total amount of ecologically productive land that is required to support the consumption of a given population in a sustainable way. The concept has been developed by William Rees and Mathis Wackernagel from the University of British Columbia in Canada (see Wackernagel & Rees, 1996).

The ecological footprint is regarded as a planning and accounting tool consistent with ecological principles and the laws of thermodynamics (Wackernagel & Rees, 1996; Chambers, Simmons & Wackernagel, 2000). In the same regard, Rees (2000) mentions that EF is "conceptually related to the embodied energy (emergy) analyses of Howard Odum"; this statement suggests that EF has a holistic perspective.

The EF concept accounts for the flows of energy and matter to and from any defined economy and converts these into the corresponding land area required from nature to support these flows and to assimilate the wastes produced (Wackernagel & Rees, 1996). Six land categories are usually included in the procedure: consumed or degraded land (built-up environment), cropland, pasture land and grasslands, productive forest, productive sea space and energy land. As a result, the EF is usually expressed in area per capita basis. In the EF, clean air or fresh water are, for example, not implicitly considered as only resources or processes easily converted to an area are measured. This means that only direct demands on cropland, land for energy use and land for biological conservation are included. The system boundaries in EF are sometimes arbitrary as it focuses only on biological resources. For example, the contribution of fresh water has recently been included (Chambers, Simmons & Wackernagel, 2000, p. 98-100), but the calculation clearly underestimates its contribution, as it only represented the embodied energy for the economic part of the supply of water, or it was calculated by the use of the catchment areas, in both cases only considering groundwater and not evapotranspiration.

Biodiversity land is calculated as a fraction of the other area requirements and is an estimation of the area needed for conservation of biodiversity. Chambers, Simmons & Wackernagel (2000) set the biodiversity land as 12% of the area requirement. This figure is an estimate from the Brundtland report (WCED, 1987), which mentions that at least 12% of land area should be preserved for protection of biodiversity. However, Chambers, Simmons & Wackernagel (2000, p. 65) argue that this figure might not be enough and that other authors in their review discuss percentages of 25 to 75% that should be set aside for conservation purposes. Although the 12% estimate might be a coarse number, we used it in our study, as it is the most widely used figure.

The theoretical basis for the analysis is to be found in the biological concept of carrying capacity, which has its basis in accounting of the maximum size of a population of a given species an area can support indefinitely, according to its capacity of biomass production and waste assimilation (Catton, 1986; Wackernagel & Rees, 1996).

Ecological footprint is proposed as a measure to evaluate some issues relevant to sustainability such as: the reduction of our carrying capacity and consumption of renewable resources, and the concepts of overshoot and equity (Wackernagel & Rees, 1996; Chambers, Simmons & Wackernagel, 2000). However, van de Bergh & Verbruggen (1999) object that the use of the EF creates confusion on some aspects of sustainability, such as spatial sustainability, regional sustainable development and sustainable trade. For example, the proponents of the method recommend the use of national ecological deficits as indicators of sustainable development, and suggest that each nation or group of nations should live within its own ecological capacity (Wackernagel & Rees, 1997; Ferguson, 2001). This is a special elaboration of the sustainability concept, which has been criticized as having an anti-trade bias (van de Bergh & Verbruggen, 1999; Costanza, 2000) and leading to the conclusion that trade is ecologically unfriendly and consequently, unsustainable (Ayres, 2000; van Vuuren & Smeets, 2001). However, Andersson & Lindroth (2001) argue that the comparison of the EFs and the biocapacities of every nation provides valuable information on a country's dependence on others and on ecological sustainability in trade.

Computations of the EF have been made to calculate the impact at different scales, from personal (Redefining Progress, 1999), to city (Wackernagel and Rees, 1996), regional (Wackernagel and Yount, 1998), country (Bicknell *et al*., 1998; Brown, Hall & Wackernagel, 2000), and global (WWF, 2002) levels. EF has been utilized in the assessment of products such as cola drink packaging, recycled paper, materials and waste, various foods and passenger transportation (Chambers, Simmons & Wackernagel, 2000). EF has been applied to assess the impact of organizations and services, ranging from energy sources and water services to education (Chambers, Simmons & Wackernagel, 2000). EF has also been used to study the sustainability of food systems and agriculture (Deumling, Wackernagel & Monfreda, 2003).

In comparison to CAR, the Ecological Footprint does not include an economic evaluation, although its approach is still human centred. To make the EF more comparable to the CAR analysis, we included the index of EF per 1 000 USD revenues. We have used EF to assess the economic and ecological carrying capacity for agricultural crops. The ecological footprint indices (Table 1) calculated were: ecological footprint per ha of crop (EF_{crop}), ecological footprint per 1 000 USD revenues (EF_{rev}) and ecological footprint per gigacalorie of food energy produced (EF_{Gcal}).

Indices used

An indicator can be defined as "something observed or calculated that is used to show the presence or state of a condition or trend" (Encarta World English Dictionary, 1999). The need for the development of indicators of sustainable development is stated in Agenda 21 (Agenda 21 web page: http-//www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter40.htm. Accessed 10-01-05). Agenda 21 recognizes that an integration of the social, economic and ecological spheres is vital for the development of indicators and urges countries to develop systems for the "monitoring and evaluation of progress towards achieving sustainable development" (Agenda 21 web page: http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter8.ht m. Accessed 10-01-05).

Indices of Emergy synthesis

The %Ren index can be considered a measure of the sustainability of a system, the higher the value, the higher the ability of the system to make use of the local available resources. Brown & Ulgiati (1997) mention that "in the long run, only processes with high %Ren are sustainable". This statement assumes that long-term sustainability is related to a low dependence on non-renewable sources. The calculation of this index for Nicaragua and in the coffee study indicates the sustainability of the systems in a long-time perspective.

If we want to consider the local renewable emergy and the renewable portion of the purchased emergy in labour and services, then we need to include the renewable emergy that supports labour and services. In the case of Nicaragua, 77% of its total emergy budget stems from renewable sources (Cuadra & Rydberg, 2000) and that portion has been considered in the calculation of an adjusted %Ren for coffee production and the processing steps.

The environmental loading ratio (ELR) is another index that might be used to assess the sustainability of a system (Brown & Ulgiati, 1997). The ELR is a measure of the pressure on the systems because it evaluates the relationship between the purchased from outside (F) and locally non-renewable emergies (N) to the locally renewable emergy (R). High values of ELR mean a large flow of emergy due to human activities, resulting in a high "load" on the ecosystem. This indicator has been used widely in different emergy evaluations to assess the long-term sustainability of the systems (Brown & Ulgiati, 1997; Ulgiati & Brown, 1998; Brown & Ulgiati, 1999; Brown & Ulgiati, 2001). In my case studies, the ELR was useful in assessing the long-term sustainability of the systems studied.

The ELR can also be considered as an expression of the relation between non-renewable emergy to renewable local emergy. In this case, labour (L) and services (S) have to be considered as partly renewable and partly non-renewable and the ratio has to be adjusted accordingly. This ratio does not need to be adjusted if the ELR is considered as an indicator of the amount of pressure or load that the production process places on the local environment regardless its background.

A third index assessing sustainability was used, the emergy sustainability index (ESI), which is an aggregate measure of yield and environmental loading of a system (Ulgiati & Brown, 1998). This ratio relies on the assumption that "sustainability is a function of yield, renewability and load on the environment" (Brown & Ulgiati, 1997). To be sustainable, a process or system must obtain the highest yield ratio (EYR) at the lowest environmental loading (Ulgiati & Brown, 1998). The emergy sustainability index-ESI is considered to be an aggregate measure of yield and environmental loading of a system (Ulgiati & Brown, 1998), because it incorporates two indices in its calculation: the emergy yield ratio (EYR)[1] and the environmental loading ratio (ELR). This aggregate index assumes that to achieve sustainability it is necessary to obtain the highest yield ratio at the lowest environmental loading.

Even though the ELR has been proposed in several studies as an indicator of sustainability (Brown & Ulgiati, 1997; Ulgiati & Brown, 1998; Brown & Ulgiati, 1999), the %Ren index has also been suggested as an indicator of the stress on the ecosystem (Ulgiati & Brown, 1998), in the sense that a low value of %Ren means a high pressure on the environment. At country level, %Ren and ELR give more or less the same information, with %Ren not only providing information on the reliance on renewable resources (a measure of sustainability), but also indicating the relative pressure of a process on the ecosystem, as another measure to assess sustainability (Brown & Ulgiati, 1997). The %Ren index is able to provide more information about the sustainability in the use of local resources, while ELR can reveal something about the ecological sustainability of the actual local system due to the human activities. For example, the ELR could provide information on the

[1] The emergy yield ratio (EYR) is an indicator of the yield of a process compared to inputs other than local, giving a measure of the ability of a process to make use of local resources (Brown & Ulgiati, 1997)

dependence of a local system on the renewable and external (non-local) part of the feedback from the society. This dependence might be high and contribute to an increase in the environmental load and reduce the integrity of a local system. The %Ren index is not able to capture this aspect. The ESI is a more complex index, as it aggregates emergy yield and environmental stress, so it claims to inform about both economic and ecological sustainability.

Although the %Ren and ELR are usually treated as two different indicators, they are actually the same index expressed in a different way, *e.g.* %Ren = R / (R+N+F) = 1 / [(R+N+F) / R] = 1 / [1+ (N+F)] = 1 / (1+ELR). And the same applies for the relation between emergy investment ratio – EIR[2] and EYR, where EYR = (N+R+F) / F = 1 + (N+R) / F = 1 + 1 / [F / (N+R)] = 1 + 1 / EIR.

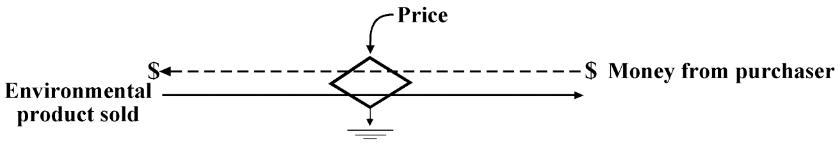
The emergy to money ratio (EMR) indicates the status of the economy of Nicaragua and its relation to the environmental system. In this ratio, the emergy due to local environmental resources and imports is divided by the gross domestic product (GDP). The EMR indicates how much emergy it takes to generate one unit of GDP. If the structure of the economy is not developed, the amount of resources needed is large (high EMR). A high EMR therefore indicates a too small size of the economic activity in the country compared with the available environmental resource basis. One may say that these countries are rich in real wealth but poor in an economic sense. These countries are mainly the countries considered as "poor" or "undeveloped". The calculated EMR for Nicaragua was useful in our case studies in allowing all monetary flows of the different activities to be converted to emergy. This is done by multiplying all monetary flows by the EMR. Each nation's EMR is compared with the world average EMR for the year 1995, which was 1.1E+12 sej/USD (Brown, 2003). Some examples of countries with small economies and high EMR are Guyana (EMR= 51 E+12 sej/USD, Brown, 2003) and Ecuador (EMR = 8.7 +12 sej/USD, Odum & Arding, 1991).

Emprice (Emp) is the emergy to money ratio (EMR) for individual commodities and is evaluated separately by calculating their emergy per money based on price. It is estimated by dividing the emergy of the commodity by the money paid for the commodity (Brown, 2003). This measure relates to each good or service individually. It has the same units as the EMR (sej/USD), which estimates the average buying power of the currency.

The emergy exchange ratio (EER) is the ratio of emergy exchange in a trade or purchase (Figure 3). 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 expressed in emergy. 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 the ratio between their EMRs. In trade between two nations, the country with the

[2] Emergy investment ratio, EIR = F / (R+N). This is the ratio of emergy fed back from outside a system to the local emergy inputs (renewable and non-renewable) (Brown & McClanahan, 1996; Brown & Ulgiati, 2001).

lowest EMR gains an average in emergy over those nations with higher EMR. The money buys more emergy abroad than it does at home.



$$\frac{\textbf{Emergy in product}}{\textbf{Emergy in money paid}} = \frac{\textbf{(Energy flow) (Transformity)}}{\textbf{(money paid) (Emergy/Currency)}} = \textbf{Emergy Exchange Ratio}$$

Figure 3. Diagram showing the solar emergy exchange (EER) of an economic transaction in the sales of an environmental product and the way it is calculated.

Indices of Cost and Return estimation

The economic indices used in Paper III are revenues and profitability. Revenues represent the amount of money received by the farmer after all costs have been paid and is expressed in USD/ha. Profitability is the economic benefit received by the farmer and expressed as a percentage of the total cost.

CAR analysis is easy to understand and use by farmers and extensionists as the results are expressed in monetary terms. The indices of revenues and profitability are useful for revealing economic profitability in a short-term perspective. It is possible to include CAR aspects such as soil erosion, loss of biodiversity, nutrient or pesticide discharge, *etc.* expressed in monetary terms, although that it is not usually done at farm level.

Indices of Ecological Footprint

The index of EF_{crop} is an indicator of ecological carrying capacity. Odum (1988b) defines the carrying capacity of an area as the amount of different types of organisms that can live in that area without harming its resource base. The ecological footprint is usually expressed on an area per capita basis. However, we thought it was more relevant in the present study to express EF as the area of direct and indirect land required per hectare of crop grown per year.

In order to address the importance of these crops as food for the farmer, the purchaser and the society, we added the index of EF_{Gcal}, as it roughly indicates the area needed to feed a certain number of people according to estimated daily caloric needs. This index has been used before by Deumling, Wackernagel & Monfreda (2003), and it indicates the EF per crop to produce 1E+09 food calories (Gcal) per year. Although this comparison is somewhat unfair because it does not recognize the different nutrient composition between the crops, we argue that it can still be useful for taking into account the farmer's and consumer's concerns on getting enough calories into their diets and the area claimed for this.

As ecological footprint does not consider the economy we added the index of EF per 1 000 USD revenues (EF_{rev}), in order to include economic considerations into the EF concept. The index of EF_{rev} indicates the area needed for every crop to obtain revenues of 1 000 USD. The index provides a clear idea of how much area of a crop is needed to produce a certain amount of revenue. The lower the index, the less support area is needed to generate income. In an environmental-economic sense, land is a scarce resource, both in respect to cropland, land for energy generation, for conservation purposes and for sequestration of emissions.

Table 1. *Summary of the indices calculated for the different papers and methods*

Method and index	Description	Paper
Cost and Return Estimation (CAR)		
1. Revenues (USD • ha of crop^{-1})	Represents the amount of money retained by the farmer after all costs have been paid.	III
2. Profitability (%)	The economic benefit received by the farmer and expressed as a percentage of the total cost.	III
Ecological Footprint (EF)		
3. EF_{crop} (ha•ha of crop^{-1}•yr^{-1})	Expresses the direct and indirect land area required per hectare of crop grown per year.	III
4. EF_{Gcal} (ha•Gcal^{-1})	Indicates the EF per crop to produce 1E+09 food calories (Gcal) per year.	III
5. EF_{rev} (ha•1000 USD revenues $^{-1}$)	Indicates the area needed for a crop to obtain revenue of 1000 USD.	III
Emergy synthesis (ES)		
6. Emergy based profitability–ES_{prof} (%)	Indicates the net gain in emergy for the producer in relation to emergy used.	III
7. Emergy based ecological footprint–ES_{EF} (ha•ha of crop^{-1}•yr^{-1})	Expresses the direct and indirect land area required per hectare of crop grown per year.	III
8. Percent renewable–% Ren	The ratio of renewable emergy to total emergy use.	I, II
9. Emergy to money ratio–EMR (sej/USD)	An average measure of the purchasing power of a nation, and relates the human economy to its biophysical basis.	I, II,III
10. Environmental loading ratio–ELR	The ratio of purchased from outside (F) and locally non-renewable emergy (N) to free environmental or locally renewable emergy (R).	I, II
11. Emergy sustainability index–ESI	The ratio of the Emergy Yield Ratio (EYR) to the Environmental Loading Ratio (ELR).	I
12. Emprice (sej/USD)	The emprice of a product is the emergy one receives for the money spent to buy it.	II
13. Emergy exchange ratio–EER	The ratio of emergy exchange in trade.	II

Summary of findings

Papers I-III contain full descriptions of the data and methods used, the results and discussion of the different studies carried out, but in this section I provide a brief account of some of the most important findings as a background for the discussion in the next section.

Papers I and II

Papers I and II both have in common the use of emergy synthesis as the method for evaluating the resource basis of the economy of Nicaragua and the system of coffee production, processing and export in the nation.

Raw data for the country study was obtained from published statistical information (BCN, 1998; EWY, 1998; UN, 1995; WRI, 1997, 1999) and other databases (INE, 1999, 2000; INETER, 1997a, 1997b, 1999). Basic data for the coffee study were collected in the year 2001 from one representative coffee farm and from two private coffee processing companies in the southern watershed of Lago Xolotlán.

Figure 4 presents an energy systems diagram of Nicaragua with the main energy sources, storages, processes, pathways and flows of energy to the system. Assessed in emergy terms, rain was the most significant inflowing energy to the country. On the other hand, the most important local renewable resources from within the country were agricultural production, forests and coastal systems. Earth cycle was also an important source, responsible for the frequent seismic activity. Earthquakes, volcanoes and hurricanes were important examples of this activity, which exerts a great impact on the ecological-economic system of the nation. Topsoil losses accounted for the most important non-renewable resource. Non-metal and metal production were also significant emergy sources.

The mining, industrial and commercial sectors used the renewable and non-renewable resources to support the urban areas. The cities with the industrial and commercial sectors, besides producing goods and services, generated wastes that were discharged into the rivers and lakes without any prior treatment; the most polluted example is Lago Xolotlán.

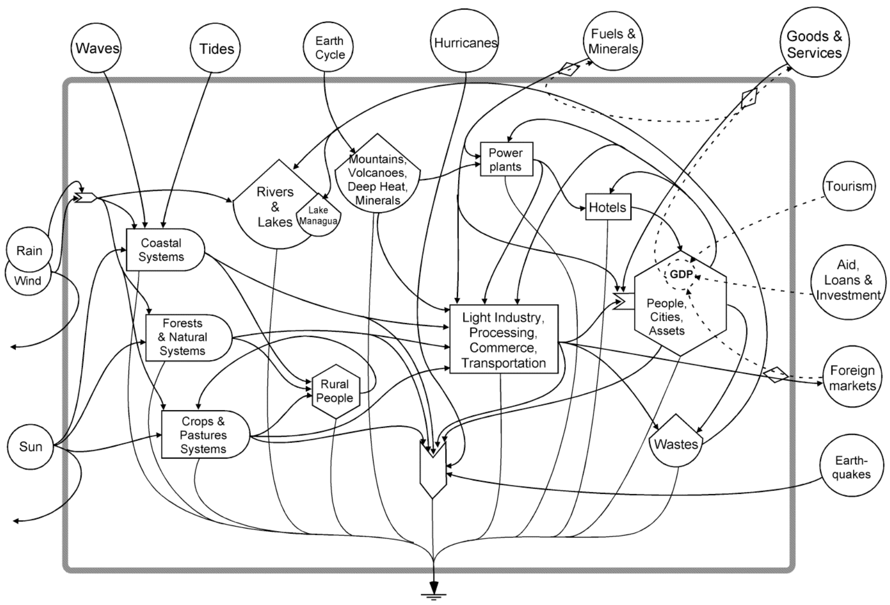


Figure 4. Overview diagram of the economic and environmental system of Nicaragua.

The emergy indices calculated (Table 2) suggest that Nicaragua was exporting more emergy than it imported (ratio of imports to exports = 2:1 and EMR = 15.8 E+12 sej/USD[3]), and that the environmental-economic system of the country still presented a low environmental load (ELR = 0.4) and high sustainability (%Ren = 77% and ESI = 13.9).

Table 2. *Summary of emergy indices for Nicaragua*

Item	Description	Value
Fraction used locally renewable (%Ren) [1)]	R/U	77%
Ratio of exports to imports	$(N_2+P_1E)/(F+G+P_2I)$	2.1
Emergy/USD ratio (EMR), sej/USD [1)]	U/GNP	1.58 E+13
Environmental loading ratio (ELR)	$(N+F+G+P_2I)/R$	0.4
Emergy sustainability index (ESI) [2)]	EYR/ELR	13.9

[1)] Total emergy used, $U = N_1+R+F+G+P_2I$. [2)] Emergy Yield Ratio, $EYR = U/(F+G+P_2I)$. For explanation on indices, see Figure 3.

The emergy advantage or emergy exchange ratio (EER) when trading with nine different countries that buy coffee from Nicaragua (Figure 5) reflects the overall advantage of those countries when trading with Nicaragua. In this case, the highest overall advantage was gained by Switzerland (23) and the lowest by Costa Rica

[3] 1996 baseline (Odum, 1996)

(3.3). This means that Nicaragua is transferring 3 to 23 times more "wealth potential" (by wealth potential is meant the natural resource base, local and imported, that is supporting a country and when used here it is the amount of the natural resources used directly and indirectly in the production of the exports assessed by emergy) than in the money received when trading with those countries. This is due to Nicaragua's small economy and large natural resource base compared to the importing economies.

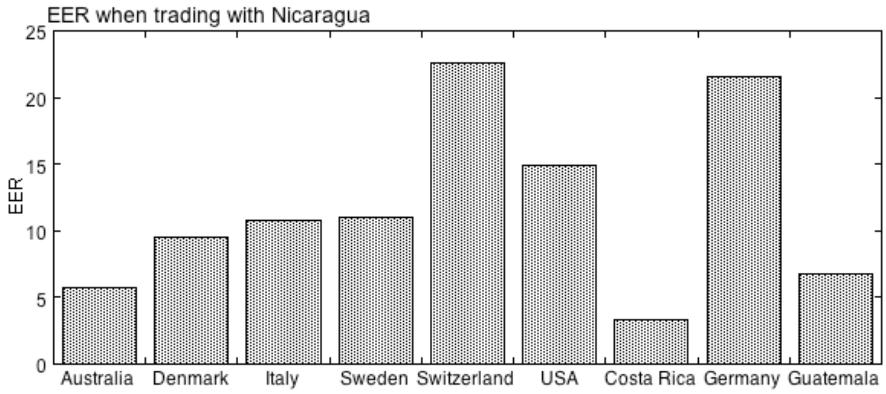


Figure 5. Emergy exchange ratio of overall trade for nine different countries when trading with Nicaragua.

Percent renewable (%Ren) and environmental loading ratio (ELR) indices for the different coffee alternatives

Table 3 presents the results for the emergy indices %Ren and ELR for the different coffee alternatives. Coffee production in the field presented the highest value of %Ren (6.6) and instant coffee the lowest value (4). On the contrary, for the environmental loading ratio (ELR), coffee production in the field presented the lowest value (14), while instant coffee produced the highest (48). These emergy indices reflect that the systems of coffee production, processing and industrialization as they are now performed cannot be considered sustainable in the long run because a large proportion of their inputs derives from non-renewable sources. One may think that these results are strange regarding the case of the coffee production in the field, as crop production is normally considered as being to a large extent dependent on renewable resources (*e.g.* sun, rain, wind, *etc.*), but this is not the case here. In fact, several emergy analyses of agricultural systems correspond to our results (Ulgiati, Brown & Bastianoni, 1993; Johansson, Doherty & Rydberg, 2000; Lefroy & Rydberg, 2003). Some possible ways to make the coffee production systems more sustainable would be for example: the recycling of nutrients from organic matter (Schroth *et al.*, 2001) with cover crops, applications of manure or compost, mulching (Afrifa *et al.*, 2003), crop rotations and mixed agricultural systems. Soil conservation practices and reductions in the use of water, energy and biological resources are also important strategies for these systems to reach a higher degree of sustainability and reliance on renewable resources (Altieri, 1995; Gliessman, 2001). The information generated from an emergy synthesis is an important tool to assess what would be needed to increase the reliance on renewable sources and how much non-renewable is required to make these systems sustainable as a way to increase long-term sustainability.

Table 3. *Summary table for the emergy indices % renewable (%Ren) and environmental loading ratio (ELR) for the different coffee alternatives*

Coffee alternative	% Ren [1)]	ELR [2)]
Cherries [i)]	6.6	14
Green coffee [i)]	6.2	15
Roasted coffee [ii)]	4.2	23
Instant coffee [ii)]	4.0	48

[1)] %Renewable (R/Y), [2)] Environmental loading ratio (F+G+L+S)/R, [i)] Local market, [ii)] International market.

If we consider that labour and services have a high portion of renewable emergy (adjusted %Ren), the results ranged between 2.4 to 2.8 times higher than with %Ren. For the ELR, the adjusted values were between 1/5 to 1/3 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 totally non-renewable, while in the case of Nicaragua it has been calculated by Cuadra & Rydberg (2000) that 77% of total emergy use is from renewables, and this includes labour and services.

Emergy exchange ratio (EER) for Nicaragua when selling coffee

The emergy benefit for the purchaser of coffee or EER is dependent on the emergy in the product, the price of the product and the emergy to money ratio (EMR) of the country purchasing the product, and it can be calculated or expressed in relation to the purchaser or the producer. The EMR for Nicaragua was calculated from a ratio of the average emergy flow per unit money flow for the country, resulting in 15.8 E+12 sej/USD (Cuadra & Rydberg, 2000). The results for the EER suggest that there were emergy benefits for most of the countries purchasing coffee in all alternatives. Emergy benefit means here that these countries are importing into their countries more emergy than is exported as associated to the payment for the coffee. This extra emergy is used to increase the emergy use per person and their standard of living. Even though a more processed product decreased the emergy benefit for the purchaser, it still represented a significant advantage for the purchaser.

There is a clear tendency for a decrease in the emergy exchange ratio (EER) as coffee undergoes more processing (Table 4). A decrease in the EER means less disadvantages for Nicaragua, as the purchasers of refined coffee receive less wealth potential than the purchasers of green coffee. The EER for coffee cherries at the local market (3.49) was more than 5 times higher than the EER for instant coffee at the international market (0.65). This is because the refinement of coffee increases the price paid for coffee, thus decreasing the emergy per unit money in the coffee and also reducing the EER in favour of Nicaragua.

Table 4. *Summary table for the emergy exchange ratio calculated for the production, processing and exports of coffee*

Coffee alternative	Emergy Exchange Ratio-EER [1)]
Local market	
Coffee cherries	3.49
Green coffee	1.44
International market	
Green coffee [i)]	3.19
Roasted coffee [ii)]	1.24
Instant coffee [iii)]	0.65
Green coffee sales to:	
Australia	1.23
Denmark	1.52
Italy	3.23
Sweden	3.65
Switzerland	5.18
USA	4.68
Instant coffee sales to:	
Costa Rica	0.31
Germany	3.88
Guatemala	0.58
USA	1.26

Footnotes to Table 4. [1)] EER = emergy exchange ratio for the price received = emergy in product/(price in USD • emergy/USD ratio for country); [i)] average price received, EMR used is average of countries that buy green coffee in sample of nine countries presented here (1.51E+12 sej/USD); [ii)] average price received, EMR used is average of countries that buy green and instant coffee in sample (1.87E+12 sej/USD); [iii)] average price received, EMR used is average for countries that buy instant coffee in sample (2.24E+12 sej/USD).

Of the different countries in the study that buy coffee from Nicaragua, Germany is the country with the highest gain in emergy when purchasing instant coffee (3.88), while Costa Rica and Guatemala actually showed a disadvantage in emergy exchange (0.31 and 0.58 respectively). These unfavourable conditions for Costa Rica and Guatemala were caused by the comparatively high prices they paid for instant coffee (7 459 and 8 409 USD/ton, respectively), and by the EMR of these two countries being relatively high (4.83 and 2.34 sej/USD respectively) compared to the world average EMR of 1.85 E+12 sej/USD (Brown, 2003). The emergy theory suggests that countries with high EMR (above world average) lose emergy when trading with countries with low EMR. This is because countries with a high EMR have abundant and high quality resources that are sold with a low purchasing power in exchange for money (Odum, 1996. p. 210).

Emprice for coffee alternatives and countries

The evaluation of the emprice for coffee sold in the different levels (Figure 6) showed a clear tendency for decreasing emprice as coffee undergoes more processing. This is because the USD cost increased faster than the additional emergy invested for processing. The emprice for coffee cherries sold in the local market (78.4 E+12 sej/USD) was more than 32 times higher than the emprice for instant coffee sold on the international market (2.4 E+12 sej/USD).

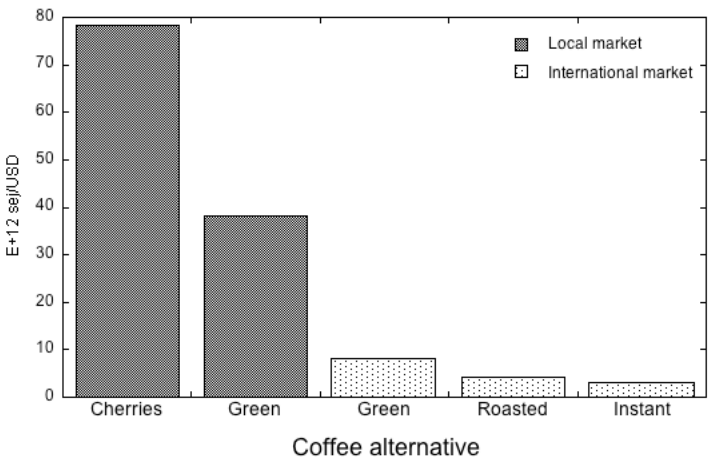


Figure 6. Emprice calculated for the different coffee alternatives.

The emprice for the individual countries studied (Figure 7) showed that Sweden obtained the highest emprice (8.8 E+12 sej/USD) when purchasing green coffee from Nicaragua. This was almost 4 times the emprice obtained by the USA when purchasing instant coffee (2.2 E+12 sej/USD) from Nicaragua.

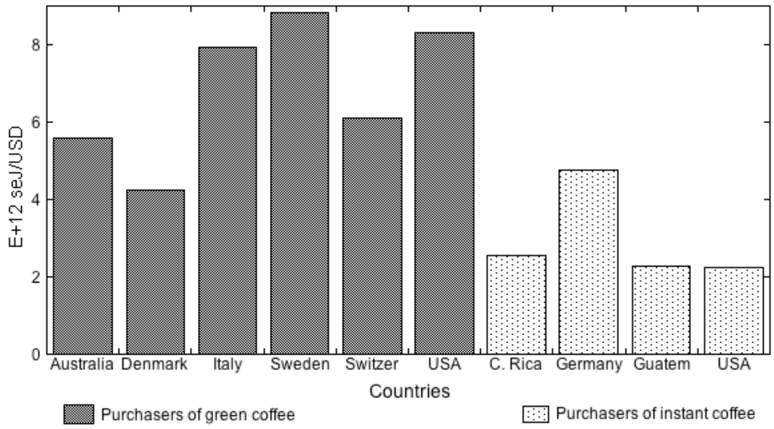


Figure 7. Emprice calculation for a sample of nine different countries that buy coffee from Nicaragua. Switzer = Switzerland; C. Rica = Costa Rica; Guatem = Guatemala.

Paper III

Paper III deals with three different analysis methods (emergy synthesis, cost and return estimation and ecological footprint) for assessing economic viability, ecological carrying capacity and sustainability for important crops in tropical agriculture.

Data were collected in 2001, through interviews with farmers at three sites considered to be representative of the agricultural production in the southern watershed of Lago Xolotlán and verified with national statistics (INTA 1995a; 1995b, 1996, 1999a, 1999b; MAGFOR, 2001). The crops studied were: common beans, tomato, cabbage, (*Brassica olearaceae* L. var. *capitata*), maize, pineapple and coffee.

Revenues, Profitability, Ecological footprint per 1000 USD revenues (EF_{rev}) and Emergy based profitability (ES_{prof})

Cabbage followed by tomato obtained the best values for the economic indices of revenues and profitability, the ecological footprint index of EF_{rev}, and the emergy based profitability ES_{prof} (Table 5). On the other hand, growing coffee resulted in economic losses for the farmer.

Table 5. *Summary table for the cost and return analysis (CAR), ecological footprint (EF) and emergy synthesis (ES) for beans, tomato, cabbage, maize, pineapple and coffee calculated per hectare and year. For description on equations and indices see Table 1*

Crop	Revenues i)	Profitability i)	ES_{prof} i)	EF_{rev} ii)	EF_{Gcal} ii)	EF_{crop} ii)	ES_{EF} ii)
Beans	1 057	134	94	2.3	0.23	2.4	13
Tomato	5 084	200	165	1.3	0.96	6.5	36
Cabbage	11 450	304	262	0.7	0.37	7.5	56
Maize	1 188	66	40	3.2	0.17	3.9	27
Pineapple	567	36	13	6.5	0.29	3.7	36
Coffee	-818	-62	-72	∞	0.31	3.8	19

Notes to Table 5: Revenues in USD ha^{-1}; Profitability and ES_{prof} in percentage; EF_{rev} in ha • 1000 USD^{-1}, EF_{Gcal} in ha • $Gcal^{-1}$, EF_{crop} and ES_{EF} in ha • ha of $crop^{-1}$. i) The highest value is the best. ii) The lowest value is the best.

The index of economic profitability was always higher than profitability based on emergy (ES_{prof}), in a range of 42 (for cabbage) to 10 (for coffee) percentage units. This difference is because the plain economic profitability only considers those inputs with a monetary value on the market, while ES also includes the work of the environment in the generation of the crops. This is because the farmers are not paid for the local renewable and non-renewable resources used in the production.

To compare the economic indices of revenues and ecological footprint indices considering support area related to the production of revenues, we calculated EF_{rev}, which is the area needed to obtain 1000 USD revenue, using the economic index of revenues. The results ranged from 0.09 ha (to obtain 1000 USD revenue) in the case of cabbage to 1.76 ha in the case of pineapple. This means that if we were to estimate the areas needed to obtain 1000 USD revenue for every crop, using only the plain economic index, such areas would be around 1/2 to 1/8 the size of the EF_{rev}. This difference is because the economic index of revenues (as mentioned in the previous section) only considers the inputs with a monetary value in the market, while EF also includes some environmental considerations, by taking into account for example the embodied energy in the production of the purchased goods, the area needed for the support of labour and the area needed for the conservation of biodiversity.

The indices Ecological Footprint per gigacalorie (EF_{Gcal}), Ecological Footprint per hectare of crop (EF_{crop}) and Emergy based ecological footprint (ES_{EF})

When the crops were compared using the index EF_{Gcal} (Table 5), maize was the most favourable crop, with the lowest EF_{Gcal} (0.17 ha • $Gcal^{-1}$), which was almost 6 times lower than the EF_{Gcal} for tomato (0.96 ha • $Gcal^{-1}$).

The indices EF_{crop} and ES_{EF} show that the bean crop was the most ecologically sustainable, with an area demand of 1/3 to 1/4 the area required for cabbage or tomato, the least ecologically sustainable crops. Although the results from both indices point in the same direction, the relative size of the areas was different (Table 5). The size of the ES_{EF} was in all cases higher than the EF_{crop}, in a range of 5 times (for coffee) to almost 10 times (for pineapple). The difference is caused by the discrepancy in the items included in both analyses and the difference in system boundaries. ES has an open systems perspective, trying with this to take into account all processes involved in making a product, whereas the EF has its system boundary only around biological resources. This leads to ES including the work of the environment in the generation of all resources, while EF only includes those resources that can be converted to land area. Furthermore, EF assesses resource use as appropriated areas, while ES also includes the work of the environment in the generation of the raw resources.

On average for all crops, the relative importance of the resources used in EF_{crop} and ES_{EF} (Figure 8) shows that the most important resources were the area needed for the support of labour (48 and 30% respectively) and the area needed for the production of purchased goods (19 and 41% respectively).

It is interesting to note that the relative weight of the different items included was different in both indices. For example, in EF_{crop} the relative weight of the growing area (21%) was much larger than the relative weight of the same item for the ES_{EF} (3.2%). The large value for labour in the EF_{crop} was caused by the very low values for other inputs such as built-up land and transportation of harvest, increasing with this the relative importance of labour.

The very low value for transportation of harvest in EF_{crop} (<1) was caused by EF only including the embodied energy in the fuel used for transportation, plus an estimated 45% more for the indirect carbon consumption for car manufacturing and road maintenance. On the other hand, transportation represents a larger area in ES_{EF} (23%) because it considers the work of the environment in the generation of the raw materials used in the car and the support of the human labour that built the car. On the other hand, in the case of purchased goods, the relative weight for the EF_{crop} was 19%; this value is significantly lower than the value for purchased goods considered in the ES_{EF} (41%).

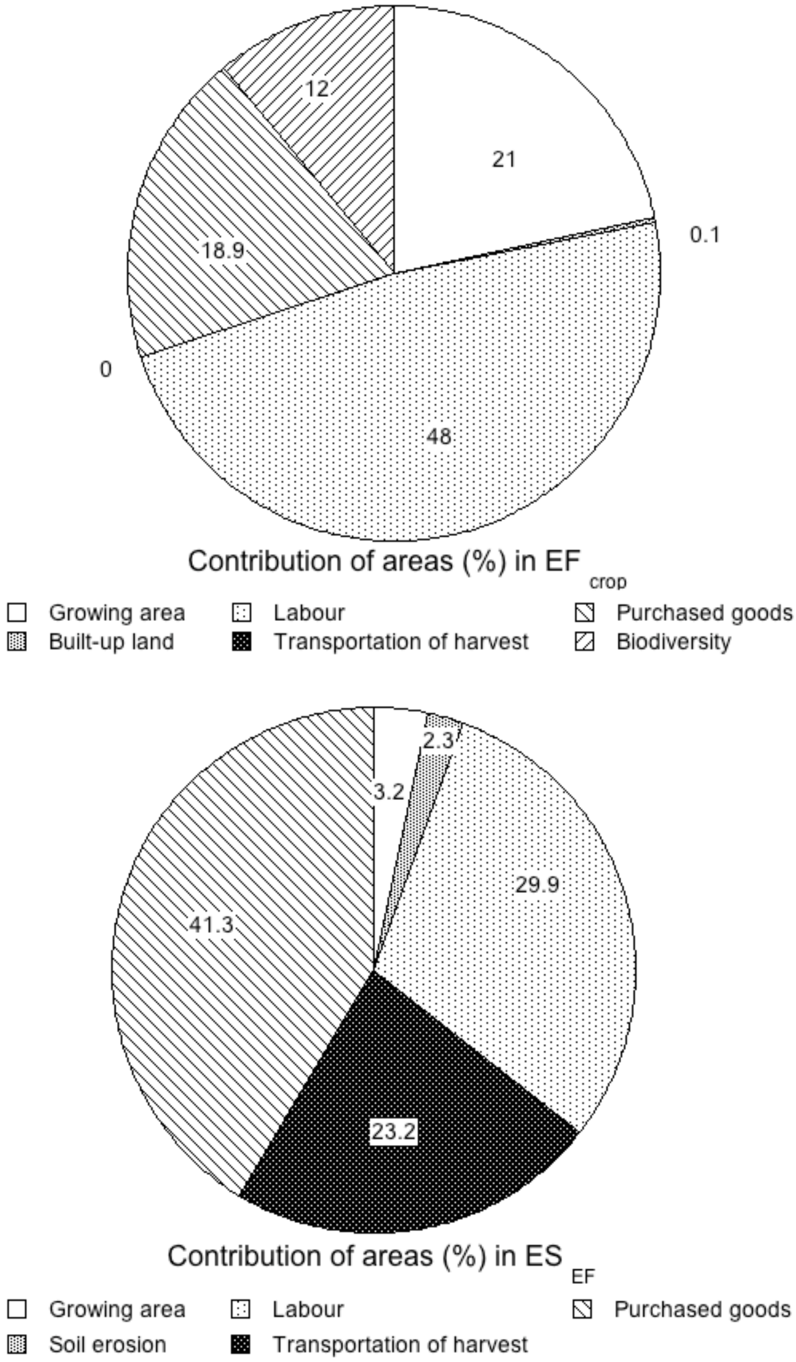


Figure 8. Relative importance (%) of the different resources used in average for all crops, for EF_{crop} and ES_{EF}.

Discussion

The emergy indices used to assess national resource use and trade

The percent renewable emergy use index (%Ren), together with other emergy indices such as environmental loading ratio (ELR) and emergy sustainability index (ESI), have been extensively used and proposed as indicators of long-term ecological sustainability of economies and processes (Brown & Ulgiati, 1997; Brown & Ulgiati, 2002; Brown, 2003; Brown, Ferreyra & Bardi, 2003; Lefroy & Rydberg, 2003). Accordingly, the calculation of this index was used for Nicaragua (I) and in the coffee study (II) to indicate the sustainability of the systems in a long-time perspective. This index confirms what has already been presented in the findings, *i.e.* that Nicaragua is a country rich in natural renewable resources (%Ren in Nicaragua study was 88%). In the coffee study (Paper II), the %Ren index showed that processes like coffee production, processing and industrialization are intensive activities with a high proportion of use of non-renewable emergy (%Ren in coffee study was between 6.6 to 2.5%). Even though coffee production is a primary activity with renewable energies as driving forces, the value of %Ren was low (6.6%), indicating that this process makes use of relatively high amounts of non-renewable resources.

Contrary to common knowledge, the use of %Ren in the coffee study added new information on the low use of renewable resources by primary coffee production. I argue that this index gives a more complete picture of the relationship between the environment and the economy at all levels, because with emergy evaluation it is possible to include all renewable and non-renewable resources, not usually considered in other analyses (*e.g.* energy analysis (Herendeen, 2004)). I believe this is very important if we want to find a balance between the desired long-term ecological sustainability and economic profitability.

We used the environmental loading ratio (ELR) to assess the long-term sustainability of the systems studied. ELR evaluates the use of purchased and non-renewable emergy sources in relation to the use of free environmental emergy, and by that it is able to give information on the reliance on purchased and non-renewable emergies (one aspect of sustainability) of a process, information that is not easily captured in the %Ren. The ELR for Nicaragua (0.39) is less than 1/5 of the world average environmental loading ratio of 2.17 (Brown, 2003). This result points in the same direction as the other emergy indices, indicating that Nicaragua has an abundance of renewable resources with a low environmental load. At the country level it is necessary to find a balance between short-term economic sustainability and long-term ecological sustainability.

Different agricultural activities have different intensities, and therefore the values for environmental load ratios are not the same. For example, sunflower cultivation in Italy showed an ELR of 27.8 (Ulgiati, Odum & Bastianoni, 1993, 1994), while tree fodder in a tagasaste plantation in Australia showed an ELR of 0.7 (Lefroy & Rydberg, 2003). The ELR for coffee production in this study is comparable to the ELR for wood powder-heated greenhouse tomatoes in Sweden (ELR = 14.1), an agricultural system considered to be relatively intensive (Lagerberg & Brown, 1999). The relative intensity of a process can also be assessed by the %Ren index.

At a national level, the higher the value of ESI, the more sustainable the economy. Brown (2003) argues that values higher than 4 indicate countries with "sustaining" economies. The ESI for Nicaragua was 13.9, which according to the author cited indicates that it could be classified as a sustaining economy. Even though very high values of ESI, like those obtained by Nicaragua, would suggest a more sustainable economy in the long term, this might not be the case if the emergy use per capita in the country is low[4] compared to the world average of 8.5 E+15 sej/capita/year (Brown, 2003). The ESI is more appropriate to be used at the national level, as its focus is on the global performance of the economic system and not on the level of individual members of a population. In fact, a high EYR means that it is easy to exploit a local resource by means of a small emergy investment, and a low ELR suggests that non-renewable inputs are not excessive compared with locally available renewable resources. Both of these two conditions do not necessarily depend on population size. Instead, the emergy per capita ratio introduces a focus on population dynamics.

The EMR for Nicaragua (15.8 E+12 sej/USD) is almost 9 times higher than the world's EMR of 1.85 E+12 sej/USD (Brown, 2003). This indicates that the economy of Nicaragua is small compared to the size of its natural resources and compared to the world average EMR. This is not new, as I previously mentioned that, for example, the GDP per capita for the year 2002 was only around 481 USD/person. However, I argue that this index has added new insights into the understanding of the relationship between the economic and environmental system of the country, because it incorporates into its accounting not only the monetary flows measured by GDP, but also the renewable and non-renewable resources not usually (and never fully) included in economic analysis. This makes this index more complete and comprehensive than, for example, GDP, Green national accounting[5] or the Genuine Progress Indicator-GPI[6] as it tells very clearly how much resource base there is in a country, in relation to the monetary flows of the economy. By using emergy it is possible to capture information that is not usually accounted for in other methods, such as the "free" services from the environment (solar radiation, wind or rain) that are necessary for the productive processes.

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[4] Nicaragua's emergy use per capita was 8.2 E+15 sej/year (Cuadra & Rydberg, 2000).

[5] Green national accounting is an economic index that tries to take into account the changes in the stocks of natural and environmental resources, and by that serve as a welfare measure (Asheim, 2000).

[6] The GPI is an indicator that tries to make the GDP measure more comprehensive by including social and environmental factors (Venetoulis & Cobb, 2004).

Emergy can also account for the contribution of human labour, services and information (Brown & Ulgiati, 2004).

In the coffee study (Paper II), we used the calculated EMR for Nicaragua to compare it to the EMRs of nine nations that purchase significant amounts of coffee from Nicaragua. This analysis shows that all nine countries had higher EMR than Nicaragua. The results from this comparison show that Nicaragua is giving away 23 to 3 times more resources measured in emergy than the resources Nicaragua can buy with the money received when trading with those countries. By comparing the EMRs of the different countries, we are able to say something about the emergy exchange ratio (EER) between those countries. These findings are contrary to what has been widely discussed and publicized in the local media about free trade helping the region to strengthen its economy. To that end, for example, Central America has signed a free trade agreement with the USA (Central American Free Trade Agreement or CAFTA) which is regarded as an opportunity for the producers to increase their production, for the unemployed to find jobs and in general as an opportunity for the development of the economy of the region (Monge-González, Loría-Sagot & González-Vega, 2003; BCIE, 2004). The results from this study could contribute a scientific explanation to why although Nicaragua is a country rich in natural resources, its economy remains relatively small, highly indebted, dependent on remittances and with a low standard of living for the Nicaraguans. This situation is not sustainable in the long run for the country. The results from this study could play an important role and contribute for example to changes in trade policies for Nicaragua and other similar countries. Further studies on international trade using emergy and emergy indices ought to be performed in order to find a balance in trade with the use of the information generated by emergy synthesis and the emergy indices in exchange instead of money.

The index of emergy exchange ratio or emergy advantage was a central index in Paper II for the assessment of the potential advantages for Nicaragua of the export of more refined coffee. To discuss and illustrate my findings, I present the following excerpt from Ulgiati (2004, p. 249) about the ethics in emergy and equity in trade:

"When a developed country imports primary resources from a less-developed country, their cost is low, because labour cost is generally low in countries exporting primary resources. Money is in turn used to purchase emergy in the form of manufactured goods from the developed country. Since money pays for labour and labour cost in developed countries is high, only a small amount of real wealth goes to the less-developed country in exchange for the primary resource. Therefore, the emergy exchange (real wealth received versus real wealth exported) is uneven. Benefits only go to the already-developed nations, which become day-by-day wealthier."

The above implies that money is not real wealth. Real wealth, or wealth potential, is food, minerals, fuels, information, art, biodiversity, etc., and can be scientifically measured using emergy (Odum, 1996 p. 6). I believe that the above excerpt clearly explains the results from this study concerning the situation of Nicaragua and other similar countries that export more real wealth than is received in the payment, thus depleting their indigenous renewable resources, which could instead be used internally.

However, one may ask: what does this all mean in practice? If, for example, Nicaragua sells one bag of green coffee to the USA or to Costa Rica at the same price, is not the same amount of money received by Nicaragua? Emergy evaluation shows that the amounts or money are the same, but the buying power of those currencies in the two countries is different and by that, trade is unbalanced. For example, the purchaser from the USA gets more natural resources (emergy) in a bag of coffee than they would get if they bought products for the same amount of money in the USA (or another country with similar EMR to the USA); and also the USA gets more emergy than Nicaragua would get if Nicaragua bought from the USA. When Nicaragua trades with Costa Rica, the trade in indirect natural resources is more even. According to these results, it would be better for Nicaragua to trade with countries with a similar EMR to itself. However, that does not seem possible, as Nicaragua also needs to buy goods such as oil or medicines that are vital for the development of the economy and the well-being of its people. The information generated from an emergy synthesis could be used in finding more equitable and even relationships for Nicaragua when trading with other countries.

Comparison of Cost and Return Analysis, Ecological Footprint and Emergy synthesis in crop production

Based on their different frameworks and system boundaries, the indices studied express different things. The CAR economic indices of revenues and profitability reflect profitability in a short-time perspective. This is important for farmers, as they are interested on the crops that provide them with the best economic benefits in a short time. However, these indices do not say anything about what would happen in the long term if farmers only concentrated on the most profitable crops. For example, it is well known from research that farmers using all of their area for the most profitable crops grown as sole crops over time obtain lower and lower yield and less profitability, due to increasing problems with pests and diseases caused by the monoculture. At the end, such farmers will probably get very little yield from the crop.

The EF_{rev} takes into consideration that production in the field is dependent on support from outside auxiliary energies, and on functioning surrounding ecosystems, *e.g.* to sequester carbon dioxide released by the use of the auxiliary energy; it uses wider system boundaries. The ES_{prof} claims to include the total environmental support needed to maintain the production in the long term and thus uses even wider system boundaries. Therefore, both the EF_{rev} and ES_{prof} give a much broader view by including environmental and social support aspects not considered in the economic analysis. The values for profitability based on emergy (ES_{prof}) were between 10 and 42 percentage units lower than the plain economic profitability. This is because there are more aspects considered by emergy synthesis compared to the plain economic evaluation, and consequently, the values for profitability based on emergy will always be lower.

A comparison between the indices of revenues and EF_{rev} shows that the plain index of revenues includes, on average, only about 1/4 of the support area needed per crop to obtain 1000 USD revenue. This support area is included in the calculation of the EF_{rev}. The comparisons between the economic indices of revenues, profitability, the emergy index of ES_{prof} and the ecological footprint index of EF_{rev} point in the same direction: that due to its theoretical framework (based on a mechanistic and reductionist approach), the plain economic analysis underestimates the contribution from the environment and the society, while the EF and ES indices express profitability in a long-time perspective, giving a measure of sustainability. ES and EF also differ in the degree to which they are able to express long-term sustainability. ES is able to provide information on all the direct and indirect environmental work and services needed to transform the raw resources, and by that offers a more comprehensive measure of sustainability than EF.

In order to find a balance between short-term economic profitability and long-term ecological sustainability, I propose the use of the economic index of profitability, together with the emergy indices of ES_{prof} and ES_{EF}, since as I have demonstrated here, those are the indices that can provide us with the best information on the trade-offs between economic profitability and ecological sustainability. In the case of the economic profitability index, this is because the method is widely known and understood at different levels, and in the case of the emergy indices, it is because they provide us with a more comprehensive perspective about the long-term sustainability. A possible advantage with the EF is that it may be easier to comprehend than the ES and thus an easier pedagogic tool but strictly seen, it is only an intermediary between the CAR and the ES. Economic viability in the short run is a prerequisite for the production system to exist, while the ES can serve as policy tool to indicate measures to be taken to favour the necessary long-term sustainability of the systems.

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Acknowledgements

Doing this PhD thesis has been a long, lonely and winding road. However, during these years I have made many good friends and I have received a lot of support and encouragement through difficult times, I want to thank all of you.

First, I would like to thank my supervisors for their support and encouragement throughout these years, they have treated me as a colleague and a friend. My main supervisor and coordinator of the PhD Programme UNA-SLU, Lars Ohlander, has been my friend and also my teacher, teaching me many important things from science and everyday life. Torbjörn Rydberg has been a good friend; it has been very nice for me to have him as my supervisor for his great enthusiasm on emergy synthesis and his support. Johanna Björklund has been my friend, her critical and sharp mind has taught me to rely more on my own knowledge and wisdom.

Thanks to colleagues in the SLU Faculty Research Theme "Resource Efficient Agricultural and Horticultural Systems" (Terejot in Swedish) for friendship and support during the first years of my studies.

Thanks to my good friend and colleague Susanne Johansson-Juston, for delicious food and relaxed talks about our lives as PhD students, women and mothers.

Hearty thanks to my friend María Cristina Muñoz, who has been a great support through all these years, I will really miss our talks and weekly visits to the pool and the flea market at Vaksalatorg.

Thanks to Gloria Gallardo for her friendship and never failing support in many practical as well as scientific matters, I will miss our pleasant lunch talks. Thanks to Linley Chiwona-Karltun for valuable ideas on the thesis discussion.

Thanks to Ulrika Geber, Eva Ohlsson and Lena Karlsson, I spent some very nice evenings with you, remembering some old and past days.

Karl-Gustav Ursberg has been a great support in many of my computer problems, especially for me, being a Mac person.

The Centre for Sustainable Agriculture – CUL received me with open arms when I needed to sit there for my work. Many thanks to all the CUL people who helped me with different practical things: Karin Svanäng, Karin Ullvén, Gunnela, Kiki, María, Lennart, and Lotta.

The Department of Rural Development and Agroecology and the people there were very helpful and friendly. Åsa Constanda helped me with practical matters. The PhD students Målin, Seema, Paolo, Teddy, Sen, Nha and Kristina provided me with good company and friendship in these long years of lonely work.

Thanks to my colleagues from the UNA-SLU PhD Programme, Oscar, Aldo, Francisco, Guillermo, Roldán and Nadir, for their nice chat and the tasty Nicaraguan food they offered me in our lunches together in Sweden.

To my colleague at UNA, Moisés Blanco, I thank him for his help and support and for keeping me updated about the department news. Many thanks to Dr. Elgin Vivas Viachica, Dean of the Facultad de Desarrollo Rural at UNA, who helped me with the basic concepts of the economic analysis for the crops.

Many thanks to the Department of Crop Production (Departamento de Producción Vegetal) and the Faculty of Agronomy (Facultad de Agronomía) at UNA. My thanks to all the academic staff and personnel for help with teaching duties while I have been away.

My gratitude to the people of Sweden, the Swedish International Development Cooperation Agency (Sida) and its Department for Research Cooperation (SAREC) for providing financial support to the cooperation programme "UNA-SLU PhD Programme" which financed my PhD studies.

My deepest thanks to my mother and my late father, they have been a great support all these years that I have been away from Nicaragua. My mother has been not only a grandmother, but also a second mother to my children, and they are her children as much as mine. To Arlen, my niece, she has been a great support not only for my mother, but also for me, helping with household chores. To my beloved Peter, you have been not only my devoted husband, but also a good father, a great friend and a reliable source for help with problematic data and computer troubles. Thanks to my dear son Juan José, you are now almost a grown-up, but you have been patient with me in my quest for knowledge since you were just a baby. My little Gabriel, "la cosa lindísima", I have missed you so much, I have missed many of your first steps in life, but I hope you can forgive me and that I can be with you more in the future.