ABSTRACT

Title of Document: AN ECOLOGICAL PERSPECTIVE OF THE ENERGY BASIS OF SUSTAINABLE BOLIVIAN NATURAL RESOURCES: FORESTS AND NATURAL GAS

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Bolivia, traditionally known for being a country rich in natural resources, has suffered from a constant exploitation of its natural resources benefiting only small groups in and outside the country. The devastation of natural resources that occurred for many years was of concern to the latest government, rural communities and indigenous groups. As a result, Bolivia has a more sustainability-oriented forest law that has a strong orientation towards the utilization of natural resources at a national level and encompasses a fast-growing forestry industry than in previous years.

In this dissertation, the wealth of Bolivia's national system was evaluated using solar emergy. Emergy (spelled with "m") is the sum of all energy of one form needed to develop a flow of energy of another form, over a period of time. The basic idea is that

solar energy is our ultimate energy source and by expressing the value of products in solar emergy units, it becomes possible to compare different kinds of energy, allowing to express the value for the natural resources in Emergy Dollars. It was found out that Bolivia relies heavily in its natural resources and that its emergy exchange ratio with its international trading partners changed from 12.2 to 1 in 2001 to 6.2 to 1 in 2005. This means that Bolivia went from export 12.2 emdollars of goods for each $1 it received in 2001 to export 6.2 emdollars of products for each $1 it received in 2005. The study also showed that under forest certification practices less emergy is removed from forests (1.49E+19 sej/yr) compared to the amount of emergy removed (2.36E+19 sej/yr) under traditional uncertified practices, reflecting that forest ecology does better under certification.

The "Ecologically-based Development for the Bolivian Industrial Forestry System" (DEBBIF) simulation model constructed during this study, compared four different scenarios: the Reference Scenario, the Increased Export Scenario, the Increased Domestic Use Scenario and the National Industrialization Scenario. Using two different levels of increment for each scenario, the outcomes of six variables were analyzed: soil, wood, natural gas, assets, money and debt. It was found that if the country doubles its use of natural resources to generate finished products, this will build more assets for Bolivia, and represent more income for the country and a better rate of emergy per person.

AN ECOLOGICAL PERSPECTIVE OF THE ENERGY BASIS OF SUSTAINABLE BOLIVIAN NATURAL RESOURCES: FORESTS AND NATURAL GAS

By

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Dedication

To my parents: Isidoro and Julia

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Chapter 1: Introduction

1.1. Bolivia: A Beggar Sitting on a Golden Chair

It has always been said, at least within the country, that "Bolivia is a beggar sitting on a golden chair" (Poppe, 2005). That is: a very poor nation located in a land rich in natural resources.

Bolivia is a landlocked country, centrally located in South America. With an area of 110 million ha, the country is about the size of Texas and California combined, or twice the size of Spain. It has an immense amount of natural forests, tremendous reserves of natural gas, vast stream power potential, and unique biological diversity. Almost half of the national territory is covered by natural forests (58.7 million ha) from which, 33.5 million have the potential for timber extraction. According to the Bolivian Oil Company (Yacimientos Petroliferos Fiscales Bolivianos - YPFB) in 2005 the country had the second largest proven natural gas reserves (26.7 Tcf) in Latin America after Venezuela (YPFB, 2005); however, its production of 7,200 million m^3 represents only one third of what Argentina produces (EIA, 2005). Most of the Bolivian natural gas is exported, mainly to Brazil.

1.1.1. Studying Bolivia's Problem from an Energy Trade Perspective

Evidence from around the world indicates that countries poor in natural resources tend to do financially better than countries rich in natural resources but undeveloped economically, like Bolivia (Sachs and Warner, 1997). Natural resource rich countries also tend to have stunted manufacturing sectors (Auty, 1997), have less product diversification (Duncan, 1993), are more prone to political problems, experience slower growth of technical skills due to deficient training programs (Wood and Berge, 1997), develop less social and institutional capital, suffer higher levels of corruption and unproductive rent (Karl, 1997), and have a higher degree of economic inequality (Leamer *et al.*, 1998).

Bolivia's economic history reveals the pattern depicted by the authors cited above: a country with a single-commodity focus. From silver to tin to coca, the country has enjoyed only occasional periods of economic diversification. Its geographical characteristics (difficult topography) and its political instability have constrained efforts to modernize the main economic sectors. Another notorious constraint is the relatively low population growth and the low life expectancy (66 years) which has kept the labor supply in fluctuation and prevented industries from flourishing. Uncontrolled, long-lasting periods of inflation during 1980's and corruption have also thwarted development (Aranibar, 2000).

Agriculture, forestry, and at a very small scale, fishing accounted for 12.8 % of Bolivia's gross domestic product (GDP) in 2005 (CIA, 2006) and combined, these activities employed nearly 44% of Bolivia's workers. Most agricultural activity is carried out as subsistence farming. Agricultural production and trade are complicated by the country's topography, climate (Andersen, 2002) and lack of road infrastructure. Also, high elevations make farming difficult, as do the El Niño weather patterns and seasonal flooding (Manners *et al.*, 2007). Bolivia's agricultural GDP continues to rise but has attained only a rather modest average growth rate of 2.8 % annually since 1991 (INE, 2006).

Bolivia's most lucrative agricultural product continues to be coca leaf (*Erythroxylum coca*) ($170 million in 2004), of which Bolivia is currently the world's third largest cultivator (UNODC, 2005). The Bolivian government, in response to international pressure, has worked to restrict coca cultivation used for producing cocaine (Barrientos and Schug, 2006); however, eradication efforts have been hampered by the lack of a suitable replacement crop for rural communities that have cultivated coca for generations.

Since 2001, Bolivia's leading legal agricultural exports have been soybeans, cotton, coffee, and sugarcane, which generated $408 million in 2005 (INE, 2006). For domestic consumption, corn, wheat, and potatoes are the crops of choice of Bolivian farmers.

Despite its vast forests, Bolivia has a small timber industry. In 2005 timber accounted for only 2.4 % of export earnings (INE, 2006). The Forestry Law of 1996 imposed a tax on sawn timber and consequently reduced Bolivian timber exports significantly. The tax was used to establish the Forestry Stewardship Council, which aided to increase reforestation efforts and reduce illegal logging.

Bolivia has a small fishing industry that taps the country's freshwater lakes and streams. The annual catch averages about 6,000 tons (Library of Congress, 2006) and it is all consumed internally.

The collapse of the world tin market in the 1980s led to the reform of the mining industry in Bolivia. In 1990, the country lost its first place in tin production, held since the turn of the century. In the early 1990's, it was in a relative fourth position as a world tin producer after China, Brazil, and Indonesia (Velasco, 1993), producing 16 tons (INE, 2005) of that mineral. Currently, tin continues to be very important to Bolivia's economy but the Central Government dramatically reduced its control over mining and presently operates only a small portion of mining activities, where small-scale operations, often with low productivity, employ many former state miners (Jordan and Warhurst, 1992). Although the world tin market has reemerged, Bolivia now faces stiff competition from China and Southeast Asian countries where lower-cost alluvial tin is produced. Gold and silver production has increased dramatically over the past decade. As of 2005, Bolivia extracted and exported more than 8.9 tons of gold and 461 tons of silver (ranking 29th and 11th in the world respectively) (USGS, 2007). Additionally, Bolivia has increased zinc production, extracting around 10,000 tons in 2005. Other important metals include copper, lead, antimony, iron, and tungsten (Ministerio de Minería y Metalurgia, 2005).

Natural gas emerged as another economic opportunity for Bolivia, and became the country's most valuable natural commodity after a discovery in 1997 confirmed a tenfold gain in Bolivia's known natural gas reserves. Finding markets to utilize this resource, both domestically and internationally, has been slow because of a lack of infrastructure and political conflicts over the State's role in controlling natural resources.

The manufacturing industry has accounted for approximately 18% of Bolivia's gross domestic product since 1995 and most sectors i.e., textiles, clothing, non-durable consumer goods, processed soybeans, and refined metals are small-scale business, aimed at regional markets rather than national or export markets. Inadequate credit options and competition from the black market have kept Bolivia's manufacturing sector from growing larger (Escobar and Vasquez, 2002).

Finally, the services industry in Bolivia remains undeveloped. Inhabiting one of the poorest countries in South America, Bolivians have weak purchasing power and the retail sector does not develop because of the weak demand and the unfair competition against the large black market of contraband goods. As an example, U.S. companies such as McDonald's and Domino's have pulled out of Bolivia in recent years (Library of Congress, 2006).

1.1.2. Addressing the Issues

The large amount of natural capital that exists in Bolivia's forests and natural gas resources potentially could be the base of the country's future economic wealth, if invested in to promote the development of domestic capabilities of production. Currently these two natural resources account for only a small amount of the nation's export income. This income is currently only 3% of total exports but could increase dramatically with an adequate development of the sector. During 2005, 65% of natural gas production was exported directly from the well with little value-added processing that could invigorate a domestic gas refining industry (YPFB, 2005). Certainly, the large amount of energy and matter flowing from natural ecosystems, forestry and natural industries may provide important opportunities for the development of manufacturing companies at a private, state or community level (Korhonen and Niutanen, 2003).

In order to estimate the flows of matter and energy, *Emergy* (spelled with m) was considered in this study as a practical tool since emergy concept takes into account energy from different sources that participate in a process and allowing their comparison on a common basis. Solar emergy is the most commonly used and sustains the basic idea that solar energy is our ultimate energy source and the value of products can be expressed in solar emergy units, using solar transformity. In other words, emergy expresses the cost of a process or a product in solar energy equivalents.

1.2. Research Approach

To explore how a country rich in natural resources, but low in technical/academic sophistication could develop to maximize long term benefits to the people while sustaining a robust and diverse ecological system, this dissertation will address three important questions:

- How much is the wealth of Bolivia's national system in emergy dollars? And what is the emergy exchange ratio with its international trading partners?
- What are the benefits of certified forestry for the Bolivian forest ecosystems and its national economy?
- How does the Bolivian natural capital change under different trade scenarios in a time frame of 200 years?

The study focuses on the research of present as well as the long term effects of the current forestry practices in Bolivia, recognizing the intricacy of different situations that result from implementing changes in the Bolivian forestry sector towards its eco-industrialization that would lead to further changes. Additionally, it explores different scenarios, i.e. potential alternatives that take into account the importance of forests and natural gas to the local population, its effects on their provision of ecosystem goods and services, and its influence in national economy.

Objectives

The main objectives of this research are:

1. To assess the potential of forest and natural gas resources of Bolivia to contribute to the eco-industrialization of the country's forest products industry.
2. To evaluate the net ecological and economic benefits of international wood certification programs in Bolivia.
3. To develop a simulation model that integrates the natural resources with the economy of Bolivia to understand the future dynamics of each.
4. To evaluate the trade-offs and benefits of allocating natural resources to domestic or export markets on different scenarios, using the simulation model developed in Objective #3.

Evaluation of trade-offs and benefits were performed using the following modeling scenarios:

Reference Scenario. The reference scenario simulated the future of Bolivian natural resources development keeping all the variables considered on the model constant at the same rates of use and trade as the same year (2005) of the study.

Increased Export Scenario. The simulation model was manipulated to increase the export of unprocessed wood and natural gas.

Increased Domestic Use Scenario. This scenario evaluated a situation of significant increase in the domestic use of wood and natural gas.

Increased National Industrialization Scenario. In simulating this scenario, it was intended an ideal situation, with intensive use of natural gas as a part of the national forestry industry development.

1.3. Dissertation Outline

This dissertation is organized as follows:

Chapter 2 provides an overview of the Bolivian forestry system, starting with a description of the historic background of the Bolivian forest sector. It describes the current stock and use of Bolivian natural resources within the forests: both timber and non-timber products. It also discusses the role of forestry in the national economy. It also portrays how the new forest law and the sustainable forest management, as a core part of the regulations, plays an important role in forest certification and finally, it describes the international trade situation of the sector.

Chapter 3 describes the principles of energy and the way these participate in the production of goods from nature. It provides concepts of energy principles and flows of energy in relation to forestry systems, giving the theoretical framework for the concepts and ideas used along the study. The concepts are presented using symbols and energy system diagrams.

Chapter 4 explains the methodology for performing the emergy analysis of a country and briefly describes the methodology for numerical simulation modeling.

Chapter 5 describes the results for the emergy analysis of Bolivia's forestry and natural gas sectors. Results for the forestry sector include emergy analysis of the national forestry system and the evaluation of three individual segments: forest growth, logging industry, and wood-based panel industry. The final part of the chapter presents the results for the emergy analysis of coca leaf production.

Chapter 6 presents the emergy analysis of forest certification in Bolivia and compares certified and uncertified forestry practices utilizing emergy-based indicators.

Chapter 7 describes the development of the simulation model, considering the theoretical and mathematical approach followed during the process. The chapter portrays the calibration for the "Ecologically-based Development for the Bolivian Industrial Forestry System" model (DEBBIF) based on historical data, and ends with the simulation of four different scenarios for the Bolivian natural resources utilization.

Chapter 8 presents the results, focusing on answers to the research questions. It also includes the conclusions, focused on the outcomes of the variables simulated under the reference scenario and the three alternative scenarios. This chapter discusses caveats of the work and point out opportunities for future research.

Chapter 2: Bolivian Forest Resources

Bolivia's natural forests are a traditional source of multiple resources for the country at various levels: local communities and indigenous people use them as part of their daily lives; many small towns and villages are involved in the commercial extraction of forest resources (timber and non-timber products) and the rest of the country having access to different forest products through the fast-growing forestry industry, which also provides an important source of employment. National and local governments receive important revenues for the use of forest resources.

Being part of the Amazon basin, Bolivian forests hold an important international recognition for both its natural function and the environmental services mitigating climatic changes, providing opportunities to develop ecotourism, serving as a source of biodiversity and hydrologic regulation (Fearnside, 2000). Its unique geographical, ethnic, cultural, social and economic diversity makes of Bolivia a country with a complex forestry system. This is reflected on the different ways to access the resources and different ways to manage the forest resources based on different historic values.

All the forests provide different goods and services, and the most appreciated are those that have an economic value; for example timber and non-timber products (e.g., Brazil nuts, palm hearts, bamboo, etc.) that can be traded or used by local people. In general, according to their components, forests can provide: a) goods and services with extractive value, b) goods and services without extractive value (e.g., ecological value as watershed protection, erosion and sedimentation control, carbon sinks and recreation), c) small forest products (e.g. fruits and medicinal plants) and d) forest's services with preservation value given by people (e.g., protected areas) (Lampietti and Dixon, 1995).

2.1. Historic Background of the Bolivian Forest Sector

Exploitation of Bolivian forest resources was limited to extraction of wood to be used as fuel or converted to charcoal. In 1952, the year of the National Revolution, the government stimulated occupation of forest lands by small farmers and timber companies in order to promote agricultural development and expand forestry activities to satisfy the internal demand for logs and timber. Road construction that connected production zones with commercial centers played a key role during this process (Gutiérrez *et al.*, 2005).

For many years, the forest sector did not have a relevant significance in the national economy, but in the 1990's the country went through a series of structural changes focused on improving the administrative body for the forest sector, and incorporating new policies and institutions. Before those changes, money collections were made based on deforestation rights and volume of wood extracted, which allowed the selective extraction of species highly valued such as mahogany (*Swietenia macrophylla*), spanish cedar (*Cedrela fissilis*) and roble (*Amburana cearensis*) (Pacheco, 1998).

In 1992, the Bolivian Environmental Law was promulgated. Its main purpose was to regulate the sustainable use of natural resources and especially the forest. By July 1996, the New Forest Law (Law No. 1700) was passed. The regulations that rule the access rights to forest resources, and its sustainable development put a great deal of emphasis on international agreements such as Biological diversity, CITES (the

Convention on International Trade in Endangered Species of Wild Fauna and Flora), and the Kyoto Protocol. The new law re-affirmed the authority of the national government over the forests, and encouraged the active participation of indigenous groups, Original Community Lands (TCO's), Social Communal Groups (ASL's), and Base Territorial Organizations (OTB's). In addition, the law provided incentives for a more diversified use of wood, a better efficiency in exploration and use of resources. It also established a new land tenure and concession system. New concessions were for 40 years with opportunities to renew every five years based on the results of a forest audit.

With promulgation of the Forest Law, Bolivia established new strategies regarding sustainable forestry management. The main goal is to restrict forestry operations within a series of regulations assuring sustainable forestry production. Two main management instruments were designed to achieve sustainable forestry management: the Forestry Management General Plan (PGMF) and the Annual Forestry Operating Plan (POAF).

The Forestry Management General Plan (named PGMF after its acronym in Spanish) is a medium and long-term plan, with procedures that every forest company must follow to be able to take advantage of the area under exploitation. Figure 2.1 shows the steps to be followed in the preparation of the PGMF.

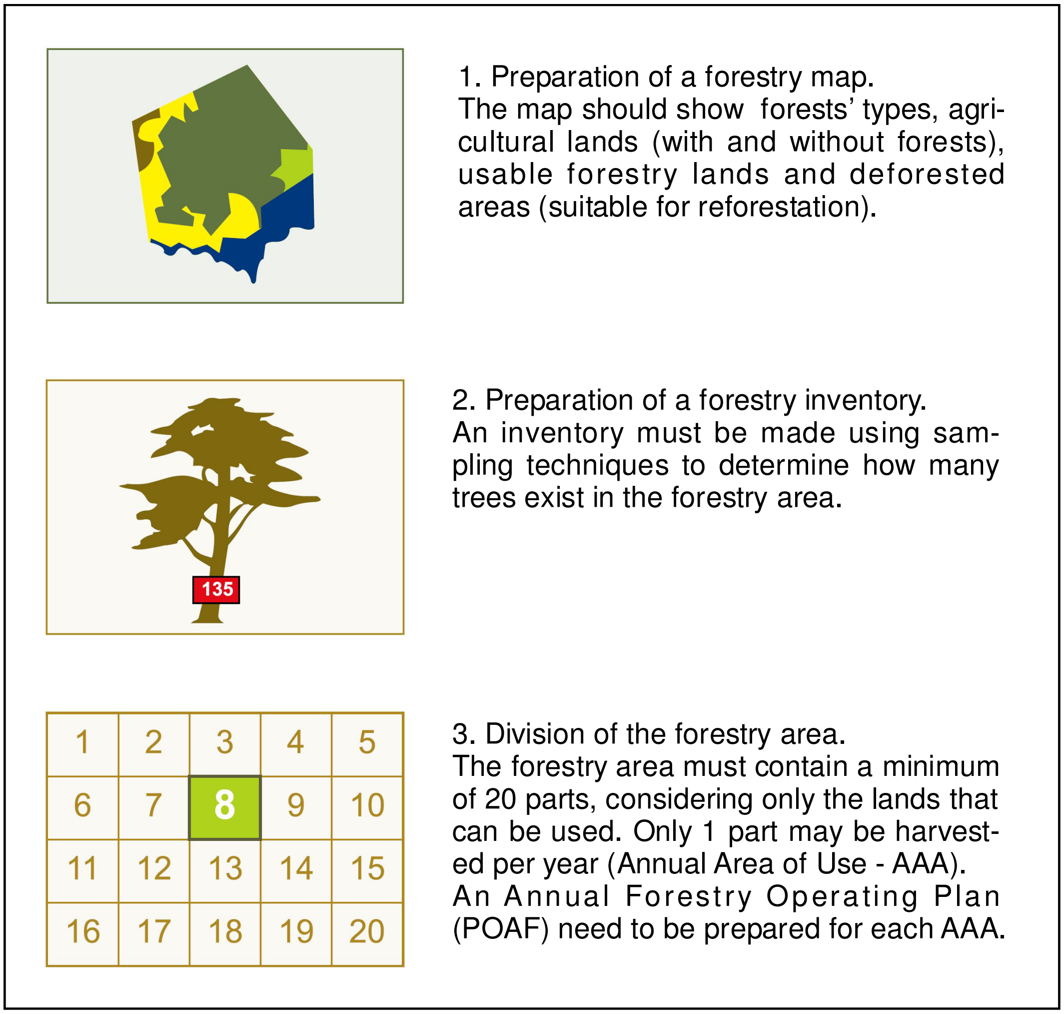


Figure 2.1. Steps for preparation of the forestry management general plan (PGMF)

Source: (Paz *et al.*, 2004)

The Annual Forestry Operating Plan (POAF) is an annual strategic working plan prepared for each Annual Area of Use (AAA) to be harvested. It has to comply with the steps mentioned in Figure 2.2

The new law also created a Forest Superintendent at the national level that oversees the correct application of the technical instruments have been designed to facilitate the control and inspection of forestry use and all wood transformation processes (Paz *et al.*, 2004).

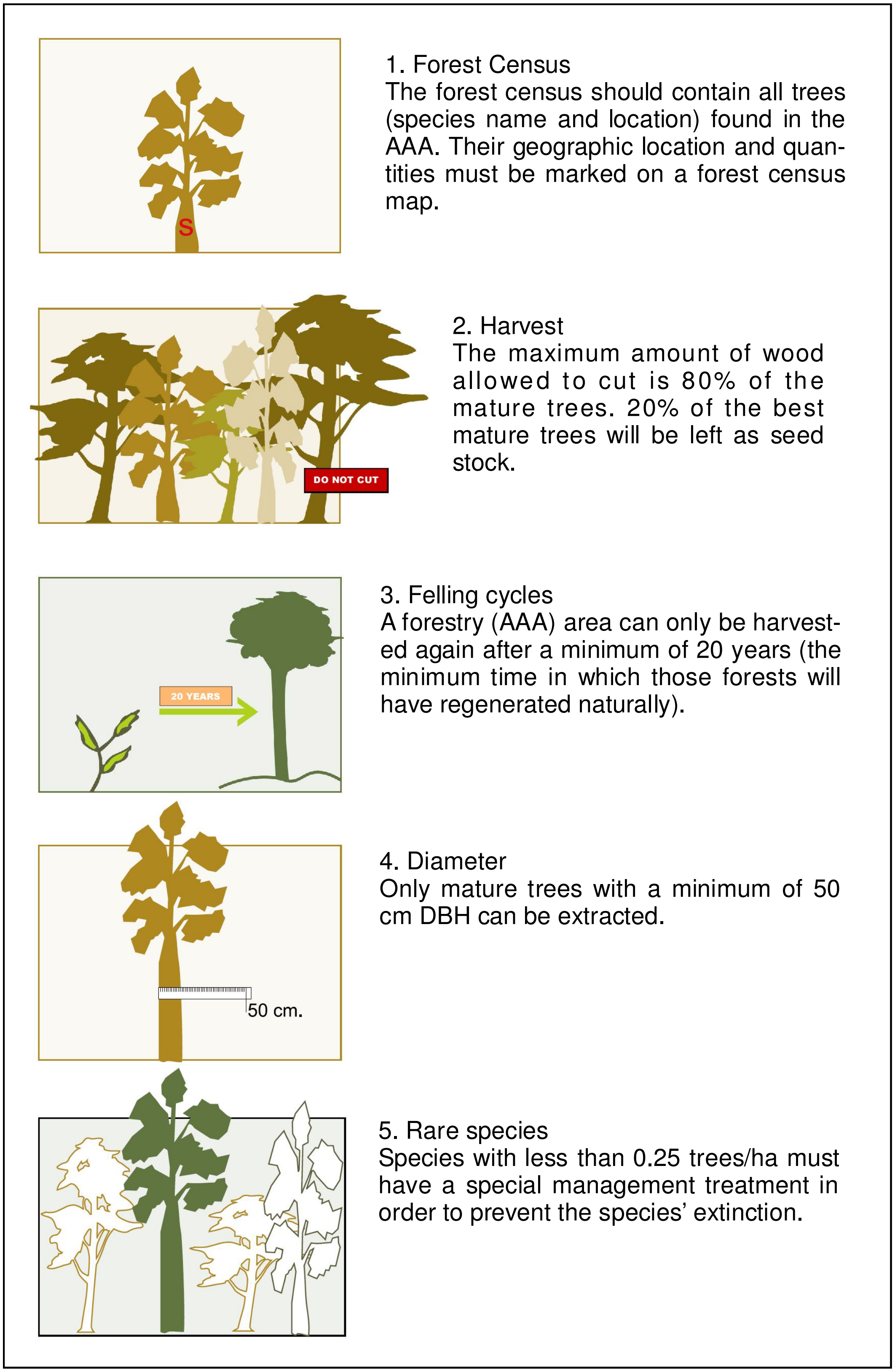


Figure 2.2. Steps for the preparation of the annual forestry operating plan (POAF)
Source: (Paz *et al.*, 2004)

2.2. Stock and Use of the Bolivian Forest Resources

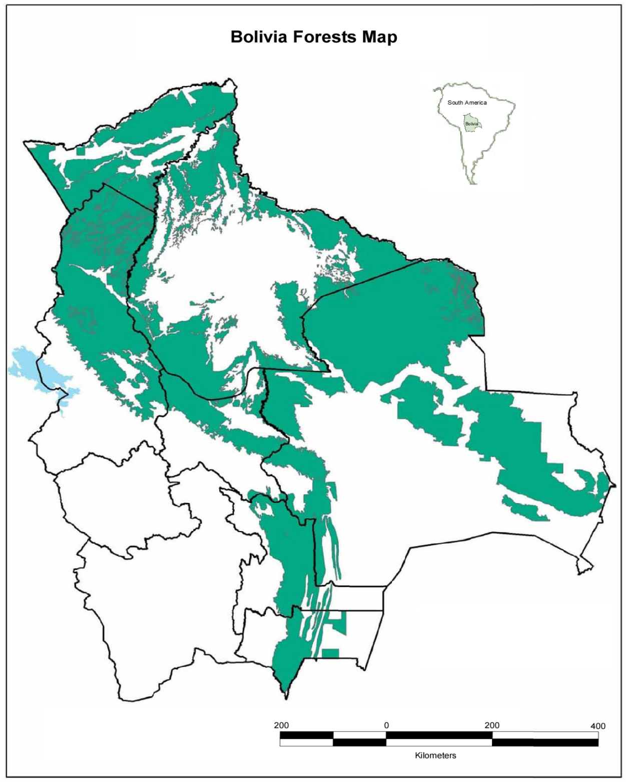
All natural forests in Bolivia are national property. Even forests in private lands under concession to private parties remain national property. Of the 58.7 million ha of forests in Bolivia, 63% (33.5 million ha) is classified as timberland available for extraction (FAO, 2006).

Without considering forest land in protected areas, indigenous territories, national parks, and any other forest land under protection, it has been estimated that 33.5 million ha of forests could potentially be permanent under timber production (CFB, 2004). Eight million ha are under sustainable forest management (SFM) representing almost 28% of the total. In addition, at the end of 2005, more than 2 million ha were certified according to international certification standards (WWF, 2005).

The current exploitation rate timber in Bolivia is approximately 3 m^3/ha, but according to the Ministry for Sustainable Development and Planning, its potential production could reach up to 15 $m^3$of timber per ha.

The Forest Map of Bolivia (Figure 2.3a) shows where most of the forests are located in the country and Figure 2.3b illustrates the timber production regions. Table 2.1 shows the area of forest cover stem density and potential volume of wood that could be extracted in each region annually. All these forests contain hundreds of species (more than 200 species of trees) that could be exploited commercially; however, the forest industry is concentrated on extracting few high valued species (UDAPE, 2005).

a



b

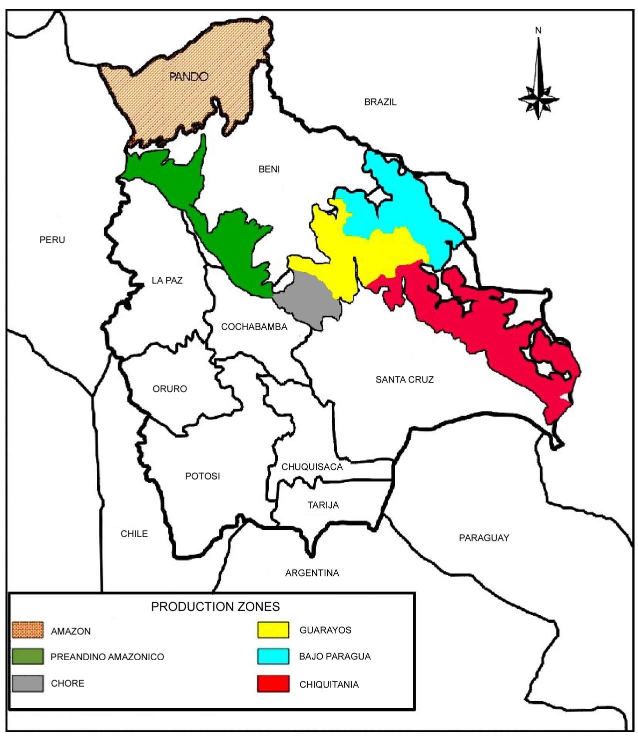


Figure 2.3. a) Bolivia's forest map b) Timber production zones map

Sources: a) (MDSP, 2001); b) (CADEFOR, 2004)

Table 2.1. Area, density and volume of wood attainable, by region, 2004

Region	Area (million ha)	Density (trees/ha)	Volume (m^3/ha)
Bajo Paraguá	3.8	5.1	15.8
Chiquitanía	6.2	23.5	19.3
Choré	1.6	13.0	33.2
Guarayos	4.1	9.8	19.2
Preandino - Amazónico	4.1	8.8	29.8
Amazonía	8.7	6.9	26.7
Total	**28.4**		**24.0**

Source: (Pattie *et al.*, 2003)

2.2.1. Timber Products

According to a survey conducted by the Food and Agriculture Organization of the United Nations, Bolivia's annual total production of logs was 3 million m^3 in 2005, while the total standing stock was 317 million m^3. The largest portion of the logs produced (2.25 million m^3) were used as fuel wood (FAO, 2006). The remaining portion was converted into sawnwood, used either as industrial wood or went into a process to obtain panels, molding, furniture, flooring, decking and plywood/veneer (PIERS, 2005). Panels were used to manufacture doors, windows, furniture and accessories and total residues account for 402,000 m^3 (FAO, 2006).

From more than 2,000 tree species present in Bolivia, at least 220 have been used commercially in different parts of the country (STCP, 2000). However, in the last few decades, almost 60% of the forest operations were concentrated on the selective logging of a few valuable species, such as mahogany (*Switenia sp*.). In recent years, the number of harvested species has increased to include: ochoó (*Hura crepitans*), tajibo (*Tabebuia ipe*), roble (*Amburana cearensis*), and cedro (*Cedrela odorata*) (SIF, 2004).

Some studies conclude that the sustainable harvest is 20 million m^3 per year out of the standing stock of 317 million m^3 of wood. Presently, official records indicate that less than 5% of that potential is harvested (CFB, 2004).

2.2.2. Planted Forests

Planted forests in Bolivia reach about 41,000 hectares and they are mostly in higher-altitude areas. The major species planted are *Eucalyptus globulus* and *Pinus patula*, which represent around 90% of the total area planted. Both species were planted with the purpose of controlling soil erosion and because they were considered suitable for cool climates. At the moment, these plantations are major providers of fuelwood and timber for local use.

2.2.3. Non-Timber Forest Products

Brazil nut is by far the most important non-timber forest product (NTFP) exported by Bolivia, while palm hearts and cacao are also significant. During the last decade Bolivia was the number one exporter of processed Brazil nut. In year 2004 the production of Brazil nut reached 52,723 MT coming mostly from the Amazon (UDAPE, 2005).

Palm hearts production is currently a growing activity limited mostly to privately owned forests and subject to a management plans. Palm heart's production is dramatically decreasing. For example, in 2004, its production was about 128 MT, which is 68% of the total production of non-timber products, and in 2002 it was about

400 MT (UDAPE, 2005). This is unfortunate because growing palm heart, especially Açaí palm (*Euterpe oleracea Mart.*) the main species of palm used, is well suited for management because of its abundance, rapid growth, and multistemmed life form (Pollak *et al.*, 1995) and also it offers to the farmers a profitable alternative crop to the coca leaf production.

Another important NTFP produced in Bolivia is the coca leaf (*Erythroxylum coca*). According to the Bolivia's counter-narcotics police force (FELCN), in 2005 the coca leaf plantations took up 27,113 hectares producing approximately 49,000 MT of coca leaves (Harman, 2005; UNODC, 2005).

Many other NTFP, such as bamboo, palm leaves and cebil's peel are used locally and nationally but make little contribution to exports.

2.3. The Forest Sector in the Bolivian Economy

2.3.1. Forestry and GDP

Since 1990, forest activities have generated for the country around $27 million annually and total wood production and timber industry represents 3% of the national GDP (Table 2.2). Additionally, around 90,000 people work in the different processes: extraction, transportation, and processing, and around 250,000 people are involved indirectly in the sector (UDAPE, 2005).

Non-timber products also have an important participation in the Bolivian economy. Brazil nuts industry represents 0.35% of GDP and generates employment for around 22,000 people and palm heart industry produce 0.02% of Bolivian GDP employing around 2,800 people (UDAPE, 2005).

Table 2.2. Wood and wood products participation in the Bolivian GDP

Year	Million $	Annual growth
1990	22.66	
1991	21.71	-4.21%
1992	21.62	-0.40%
1993	22.62	4.59%
1994	23.87	5.55%
1995	25.02	4.82%
1996	25.49	1.86%
1997	26.99	5.92%
1998	27.28	1.06%
1999	28.89	5.90%
2000	30.48	5.51%
2001	31.50	3.32%
2002	31.93	1.39%
2003	32.46	1.66%
2004	33.34	2.71%

Source: (INE, 2006)

2.3.2. Forest Productive Chain

All the forest activity in Bolivia takes place in the tropical forests; therefore, the process is mostly oriented to the wood extraction and responds to these sequence of activities: 1) forest management planning; 2) forest exploitation, which includes trees census, harvesting, and transport from the stump area to the mill; 3) primary processing that is related to storage, sawing, drying and transport from the mill to the kiln drying facility. If the wood comes from a certified forest, it is in this phase where the chain of custody supervision takes place. 4) secondary processing; and 5) trade (MDSP, 1997).

2.3.3. Costs for the Forest Sector

Costs of wood production from the stumpage to the wood processing centers have been estimated at $43.20/m^3$, from which, harvest ($19.73/m^3$) and transport

($\$10.77/m^3$) represent the largest portions. Other important components of the cost structure are skidding and piling ($\$9.94/m^3$), the cost of the patent ($\$6.67/m^3$), and the construction of roads and woodyards ($\$6.23/m^3$). Details are given in Appendix 1. In comparison to neighboring countries, these costs are high due to the lack or poor condition of roads and the low harvest rate of 3 m^3/ha.

The processes of wood industrialization represent a larger cost to Bolivia ($\$200/m^3$) than production. Transformation losses and transport from saw mill to the kiln drying facility are the largest ones with ($\$52.8/m^3$) each. Losses in transformation are closely related to the level of technology used and the size of the processing plants that are obsolete and small. Additionally, the industrial processing cost is around ($\$50/m^3$) and the cost of drying process for each m^3 is around $45 (MDSP, 2002).

The costs for the commercial component include basically the cost of transportation from the kiln drying facility to the selling points, which is around 28% of the total production cost ($\$70/m^3$). Thus, when wood export is considered, transportation is by far the highest cost of the whole process (Appendix 1).

2.3.4. The Bolivian Forest Industry

The forest industry in Bolivia is based on the processing of solid wood by small to medium size companies. In 2002, there were 369 sawing mills, 181 carpentry companies, 6 charcoal factories, 2 flooring manufacturers, only 1 panel factory and 196 export companies operating in the country (MDSP, 2002).

The Bolivian forest industry is very deficient in using its installed capacity, mainly operating only at 50% of its potential (Quevedo, 2004). This, in addition to other factors already mentioned like the lack of roads and up-to-date machinery, appears to make the Bolivian wood producing chain have higher costs than their close competitors. For instance, wood process cost in Brazil is $\$141/m^3$, while in Bolivia it is $\$316/m^3$ (MACIA, 2003).

Recently, Bolivia has focused on developing low value-added products manufactured with wood from certified forests (Gutiérrez *et al.*, 2005); however, the development of this initiative is related to the development of the whole productive chain since it depends on the same infrastructure as the non-certified wood.

2.4. Sustainable Forest Management and Administration of Forest Resources

In 1996, new forestry legislation was formulated to replace older legislation that had been in effect for 20 years but rarely enforced due to political interference and high-level corruption (Pacheco, 2003).

The new Forestry Law assumed that sustainable forest management was possible by means of implementing appropriate management practices. To that end, a monitoring system was created for forest management and timber extraction, together with some market regulations and tax reforms to make unsustainable and illegal forest operations less attractive. That same year (1996) a new National Agrarian Reform Service Law (known as INRA - Law No. 1715) was approved, aimed at clarifying the rights of agrarian ownership through a process of write-offs and land ownership titling. These two new laws, plus the Law of Popular Participation (LPP No. 1551), and the Administrative Decentralization Law (LDA No. 1654), both approved in 1994, expanded the municipal governments' jurisdiction beyond the urban centers to all territory covered by the state's sections that correspond to a municipal jurisdiction giving them control over the forests. All these changes implied modifications on the functions of the municipal and state governments.

2.4.1. Forest Management Regulations

The new Forestry Law established what was called the “forestry regimen of the nation,” which is defined as “a set of norms that regulate the sustainable use and protection of forests and forestland, and the legal system that defines the rights of private individuals, clearly stipulating the defined rights and obligations” (Forestry Law, art. 3e) (Government of Bolivia, 1996).

The public institutional system is made up of the Ministry of Sustainable Development and Planning (MDSP) as the normative entity, the Forestry Superintendence (SIF) as the regulatory entity, and the Forest Development Fund (FONABOSQUE). The Forestry Law also created the Natural Resource Regulatory System (SIRENARE) to regulate and control natural resource use. The SIF is a key piece in the system given that it is in charge of assigning forest concessions, authorizing forestry permits, monitoring the transport of forest products and confiscating illegal timber, as well as supervising forest management (SIF, 2004).

All the forest production areas are property of the country and are given under concession by three different ways to different type of agents: timber companies, Local Social Associations (ASLs), research institutions, Private owners and Designated Indigenous Territories (TCOs). Figure 2.4 shows a map with the distribution of forest concessions in the country.

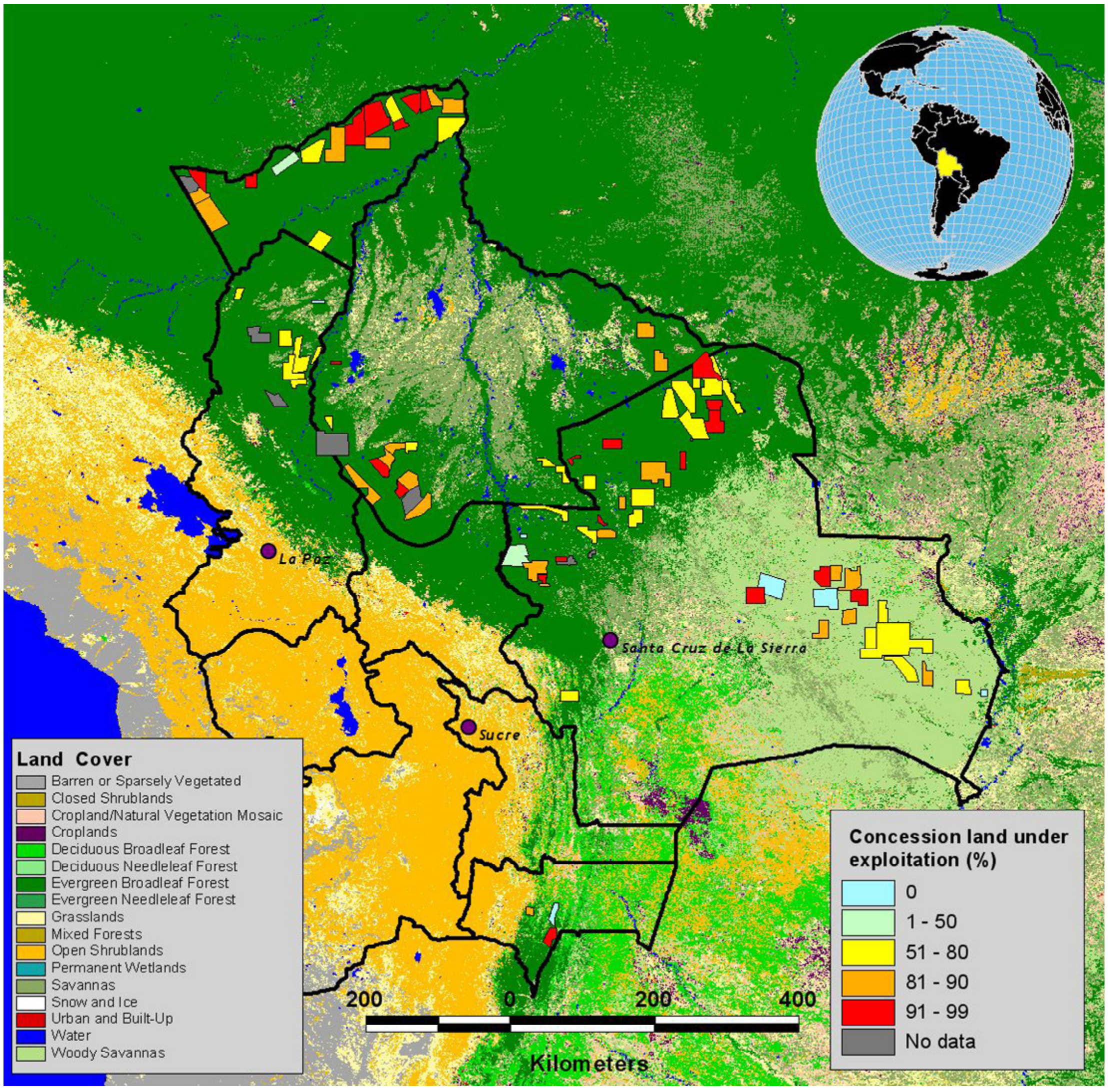


Figure 2.4. Distribution of forest concessions and degree of exploitation

The following are the main regulations for the Bolivian forestry activities:

1. Public forests may be assigned to companies through a system of long-term concessions for a 40-year period, renewable every 5 years.
2. Small-scale loggers may apply for concessions within the areas to be declared municipal forest reserves, which correspond to up to 20% of the total public forests existing within each municipal jurisdiction, although

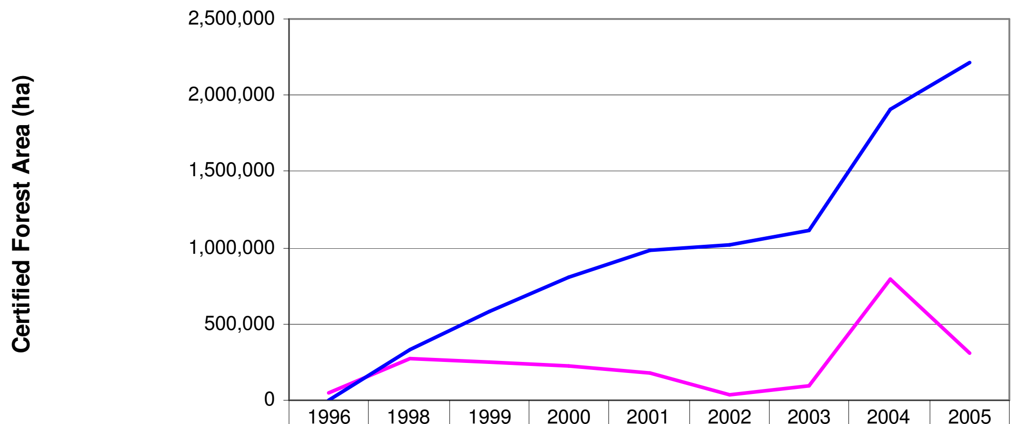
to do so they must organize into what are called Local Social Associations (ASLs).

3. Indigenous peoples have the exclusive right to use the forest resources within their territories.
4. Individual landowners acquire ownership rights to the forest resources on their property.
5. All forest users must pay a forest license fee ($1 per hectare/year), which applies to all forested areas in the case of forest concessions, the area intervened in the case of private owners (including indigenous communities) and a combination of the two in the case of ASL concessions.

2.4.2. Forest certification

The severe destruction and degradation of forest ecosystems both in tropical and temperate regions of the world caught the attention of the international community starting in the late 1970s, instigating numerous concerns at national and international levels. Many forest-related worldwide institutions developed initiatives for new processes to address the crisis of forests and implemented a common set of principles and criteria to promote the sustainable management of forests (Segura, 2004). Forest certification emerged as a mechanism to reduce tropical deforestation (Cote, 1999), to decrease trading of wood products coming from illegal logging (Duery and Vlosky, 2006), and as policy instrument. During the 1990s, it was promoted by environmental NGOs as an indirect economic incentive to induce sustainable forest management; and to provide better market access for forest products. One of the most important bases for forest certification is the need for consumers to be assured by a neutral third-party organization (called a certifier or certification body) (Rametsteiner and Simula, 2003) that forest products companies are employing sound practices that will ensure sustainable forest management (Ozanne and Vlosky, 1997).

The previously mentioned changes adopted with the new Bolivian forest law since 1996 show similarities with the standards of Forest Stewardship Council (FSC) standards, which helped Bolivia to have the largest area of FSC-certified tropical forest in the world, and much of the forest land in Bolivia can easily be certified (Duery and Vlosky, 2005).



	1996	1998	1999	2000	2001	2002	2003	2004	2005
Certified area per year	53,000	274,494	249,200	226,683	181,750	38,000	89,888	789,937	307,048
Accumulated certified area	0	327,494	576,694	803,377	985,127	1,023,12	1,113,01	1,902,95	2,210,00

Figure 2.5. Evolution of certified area under FSC standards
Source: (CFB, 2007; SIF, 2004)

Over the last decade this has made Bolivia a leader in FSC certification of tropical forests with more than 2.2 million ha of certified forest land by 2005 (Figure 2.5) (CFB, 2007; United Nations, 2005).

In addition to certified forest management, there are 17 companies in Bolivia with chain-of-custody (CoC) certification. CoC is an inventory control process in the wood manufacturing industry developed to monitor and track certified forest products through various stages of the manufacturing and distribution chain. Managing both certified and non-certified wood products concurrently in the same manufacturing facility can add complexity to inventory management. From those 17 companies, 14 are factories producing a range of products (e.g., flooring, furniture, doors, and windows), two handcraft factories and one trading agency (CFB, 2004; CFV, 2006).

Certification has been implemented in Bolivia primarily to gain market share. In 2004 export of certified products reached $16.5 million; an amount that has been increasing since the late 1990's. Export of certified wood products now accounts for 26% of the total wood exports (CADEFOR, 2004).

Even though the new forestry law and certification programs encourage sustainable forest management, its implementation is not easy because of the economical costs and bureaucracy that certification represent for the forest managers and the manufacturers. These costs can be passed on to the consumer or absorbed into profits.

The United States and the United Kingdom are the most influential and largest export partners for Bolivian certified wood products, because the markets in those countries are willing to pay a premium price for certified products (Ozanne and Vlosky, 2003). One of Bolivia's goals is to increase the market for its certified forest products in European countries. Unfortunately, the domestic market is not a suitable for certified wood and wood products since people will not and often cannot pay a premium price; so the challenge is to capitalize on the value gained by identifying export customers who want to purchase certified wood products. However, consumers in developed countries are not as informed about certified wood products as needed to dramatically increase demand. Once consumers are educated about certification, Bolivian market opportunities should improve.

CADEFOR (2004) suggested that forest certification represents a competitive advantage for tropical countries. But certification alone does not guarantee competitiveness in the world market; it needs to be accompanied by maintaining and/or improving quality, productivity, efficiency, and services. Efficiency and competitiveness in the international arena may be improved through vertical integration and by developing strong relationships with supply chain partners.

Bolivia has developed unique, albeit small, export markets for products made from hardwood tropical species. This has showed that certification can be a win-win opportunity for Bolivia because it expands their international wood markets and positions the country as a large supplier of sustainable wood products. Since Bolivia has the largest area of FSC-certified tropical forest in the world, it is important for the country to develop industry structures and markets that value certified wood products.

2.5. Trade of Forest Products

2.5.1. Domestic Use of Forest Products

Forest products coming mainly from the states of Santa Cruz, Beni, north of La Paz and Pando are processed in the main cities from where they are distributed as finished products to local markets and exporting ports.

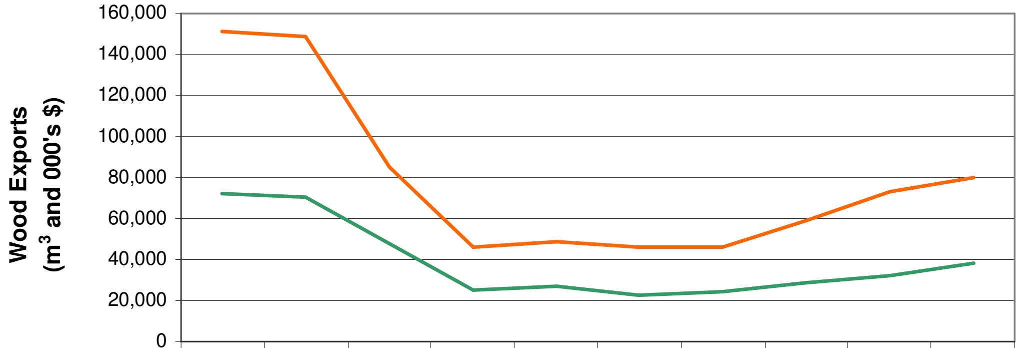
Compared to the total national forest resources, the Bolivian timber activity is quite small in terms of volume and value, represented by limited number of non-specialized products. In 2005 total wood production was 810 thousand m^3 with a conversion rate from stump to sawn wood of 50% approximately. Comparing the consumption in relation to the production, the domestic market consumes around 80% and 90% of the primary forest product production and, almost 50% of the value-added products (FAO, 2006).

The main domestic products are sawn wood, plywood, and other value-added products such as doors, moldings, windows, and furniture (UDAPE, 2005).

2.5.2. Export of Wood and Non-wood Products

Figure 2.6 shows the increase in wood exports from Bolivia and the money received from sales for the period 1996 to 2005. Bolivia exports wood as round wood and wood products (e.g., sawn wood, doors, windows, moldings, flooring and furniture) to 45 countries. In the year 2005, wood exports accounted for 80,144 m^3 (FAO, 2007), an amount that has been increasing since 2002 after a marked depression.

Exports of value-added products have had a significant expansion in the last 15 years, but they still represent a small percentage of the commercialized amounts. Currently, the main markets for Bolivian wood products are the United States, where (44.5%) of the total wood volume is exported, the United Kingdom (19.2%) and, to a lesser extent Chile (5.2%), Argentina (3.7%), Germany (3.3%) and the Netherlands (3%) (UDAPE, 2005).



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Amount (m3)	151,000	149,100	85,200	46,500	48,400	46,000	46,000	59,217	72,617	80,144
Value (000's $)	71,930	70,278	47,409	24,827	27,178	23,030	24,187	28,462	32,184	37,870

Year

Figure 2.6. Amount and value of wood exported from Bolivia

Source: (FAO, 2006)

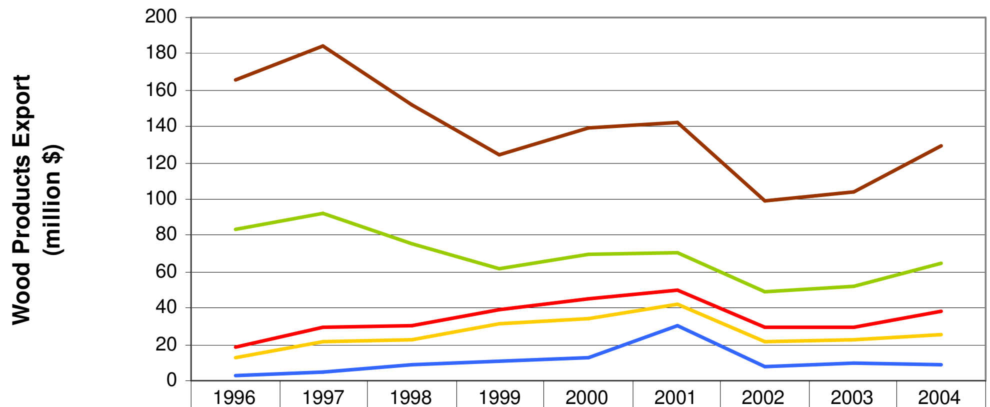
In 1996, Bolivian forest exports reached their highest level of all time at $71.9 million. Afterwards there was a downtrend that was not reversed until the year 2001, when there was an increase. Forest product exports in 2005 equaled 53% of the forest exports of 1996 in quantity and in value.

Manufactured goods occupy also an important portion of the total wood exported as observed in Figure 2.7. There was a significant rise from 1996 to 2001 in exports of products with added value, such as doors, windows, frames and furniture. Semi processed products (wood-based panels) exports have increased since 2001.

All in all, after 1997 the value-added forest product exports received greater attention than the primary ones. The change in the composition of the exports can be observed in Figure 2.7.

According to a report from UDAPE (2005), there is the hope that in the next 10 years the value of the Bolivian forest exports will surpass $1.1 billion. This perspective is based on an estimate that world-wide commerce for wood will be in the range of $140 billion per year, with a 2.7% annual increase world-wide.

Exports of certified products (also called "green label" products) allowed to Bolivia gain access to markets where the country had very limited access before (CFB, 2007).

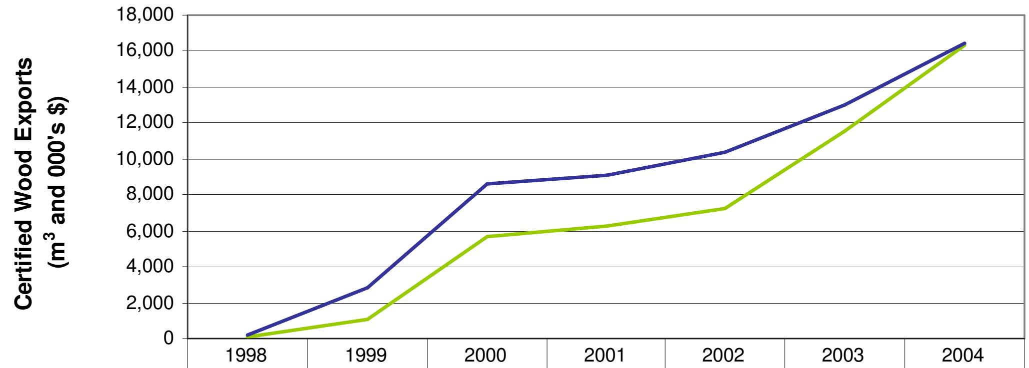


	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total	82.89	92.26	75.90	62.18	69.73	70.94	49.37	51.94	64.91
Saw n w ood	64.63	62.88	45.11	22.70	24.44	20.93	19.75	22.88	26.60
Semi-processed	5.51	8.26	7.92	7.77	10.74	7.98	7.79	6.52	13.27
Doors & w indow s	9.54	16.44	14.18	20.84	22.09	12.10	13.58	13.05	16.05
Furniture	3.21	4.68	8.69	10.87	12.45	29.93	8.25	9.49	8.99

Figure 2.7. Wood products exported from Bolivia
Source: (Gutiérrez *et al.*, 2005)

Bolivia exported certified wood to more than 20 countries as of 2005. Most markets are located in developed countries such as the United Kingdom, the United States, France, Spain, Switzerland, the Netherlands and Germany. About 30 species are exported (e.g., male mahogany, white yesquero, possum wood, fig tree, spanish cedar, and mahogany).

Although the international certified wood markets have responded slowly, in terms of volume and prices, there has been a growing market for certified products from Bolivia (Figure 2.8) with more growth expected (UDAPE, 2005).



	1998	1999	2000	2001	2002	2003	2004
Amount (m3)	106	1,071	5,685	6,245	7,219	11,579	16,339
Value (000's $)	181	2,846	8,632	9,121	10,402	12,962	16,458

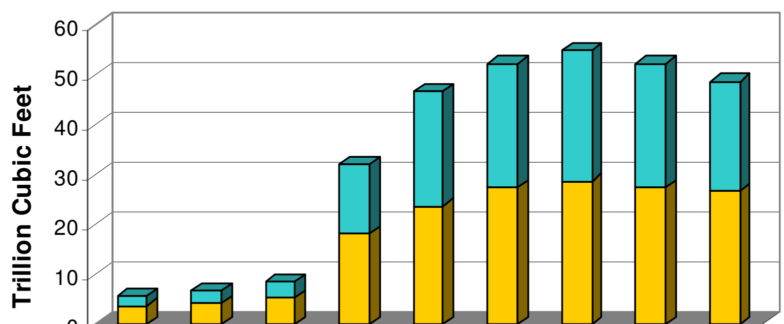
Figure 2.8. Amount and value of certified wood exported from Bolivia
Source: (CFV, 2006)

2.6. Bolivia's Non-forest Resources

Even though most of the country was (and still is) covered by forests, Bolivia's economy was based on mineral resources. Metals' extraction dominated the national economic activity for many decades and presently, the country's largest export is natural gas. In fact, exploitation of non-renewable natural resources dominated the Bolivian economy from colonial times until a few decades ago. After the 1985's crash of the international tin market, natural gas replaced this and other minerals as the leading export and was the focus of future development strategies (Andersen and Faris, 2002).

Bolivia's proven reserves of natural gas jumped 700 percent from 3.8 trillion cubic feet (tcf) in 1997 to 26.7 tcf in 2005 (Figure 2.9). If valued at today's wellhead price of approximately $6.5 per thousand cubic feet (EIA, 2007), the reserves would be worth more than $125 billion. In a country with an annual GDP of $25.82 billion and the second lowest per capita GDP in the Western Hemisphere, this offers a tremendous opportunity for spurring economic development that could be sustainable if integrated with investment in social, educational and technological institutions.

If natural gas could be used domestically to support a developed wood-products industry, then the well-being of the population could be increased. The opportunity is so great that it has the power to change the structure of the Bolivian economy for years to come, offering the country the opportunity to support its own development.



	1997	1998	1999	2000	2001	2002	2003	2004	2005
Probable	1.9	2.5	3.3	13.9	23	24.9	26.2	24.7	22
Proven	3.8	4.2	5.3	18.3	23.8	27.4	28.7	27.6	26.7

Year

Figure 2.9. Natural gas production in Bolivia
Source: (YPFB, 2005)

The natural gas sector in Bolivia has been controlled by foreign companies, such as the trans-national Repsol-YPF that held the largest quantity of reserves through its subsidiary called Andina; while the Brazilian state-owned oil and gas company called

Petrobras was the largest natural gas producer in the country. However, President Morales and his administration reclaimed the nation's control of the gas and re-nationalized the resource. Development of Bolivia's natural gas reserves has been a divisive question in the country due mainly to two issues:

First, Repsol-YPF's plan to develop the Pacific LNG pipeline project, which included building a natural gas pipeline from Bolivia to an LNG export terminal in Chile, sparked strikes and social protests that lead to the resignation of President Sanchez (EIA, 2004). A major problem stemmed for the land dispute between Bolivia and Chile that dated back to their war in 1879. The Bolivian government has since endorsed a plan to export LNG via a terminal in Peru, but international investors have balked at the idea, due to its higher cost compared to the Chilean plan.

Second, in 2004 Bolivia overwhelmingly approved a referendum that called for the re-nationalization of the formerly state-owned Andina and Chaco which are in charge of oil and natural gas operations. The referendum also called for a sizable increase in taxes on foreign hydrocarbon producers. Additional protests in 2005 forced the resignation of President Mesa, after he opposed implementing the referendum. Following this unrest, foreign investment in Bolivia's natural gas sector plummeted. The country's Chamber of Hydrocarbons, a trade group, reported that investment during the first half of 2005 fell by 80 percent compared to the same period in 2004.

In May 2005, Bolivia's Congress approved a new Hydrocarbons Law that codified the results of the 2004 referendum. The law imposed an additional 32 percent tax on oil and gas production at the wellhead, on top of the existing 18 percent royalty. The law called for the compulsory conversion of existing contracts to the terms of the new law, a provision that international companies have protested and threatened to appeal before international arbitration panels.

2.7. U.S. Companies Purchasing Wood Products from Bolivia: a case study

At the time of dissertation submission, this section has been submitted to the Global Forest & Trade Network (GFTN - a WWF's initiative to eliminate illegal logging and improve the management of valuable and threatened forests) to be published as a country profile document: "A Brief for US Companies Purchasing Wood Products from Bolivia" by Izursa and Tararan, (2006 - unpublished).

2.7.1. Introduction

Bolivia is a landlocked country, centrally located in South America about the size of Texas and California combined. Almost half of the Bolivian territory is covered by forests (53 million ha) and just over half of this area (30 million ha) is dedicated to timber extraction. In 2003, almost nine million ha were under some sort of forest management, of which, 2.2 million ha were certified under FSC's standards, positioning Bolivia as a world leader in FSC certification of natural tropical forests. However, that situation was then and it is now totally different with the country's forest mismanagement history, leading an annual deforestation rate of 150,000 ha over the past 20 years (Bojanic, 2001).

Despite the great potential for wood production in the country, only 1.4% of the total Bolivian income comes from the export of wood and wood products. The United States was the largest trading partner. In 2003 the United States bought around 36% of all Bolivian wood exports (in volume), which represented $55 million or 48% of total value of wood exports (CFB, 2004).

For this situation we might assume that most of the wood market could be dominated by some importer countries and that the sustainability of Bolivian forests is closely related to decisions made by the U.S. importers. Hence, to have a better knowledge about wood and wood products acquired from certified forests will assist to design operations towards sustainability of forests, biodiversity and improve local livelihoods.

2.7.2. Sustainable Logging in Bolivia

Predatory logging in Bolivia represents a clear threat to the environment, economy and human communities. For the past 20 years, 150,000 ha/year of forests were lost in Bolivia because of mismanagement. Predatory logging was a result of:

- Forest land conversion into crop lands/grass lands,
- Short term vision of wood extraction,
- Lack of knowledge at a community level,
- Lack of knowledge on the part of the forest industry,
- Problems of corruption and/or inadequate transparency,
- Lack of capacity within the local governments to administer natural resources adequately,
- Lack of institutional and/or processing capacity.

Things became more promising for Bolivia's natural resources. During the last decade, the country has experienced significant institutional and legislative progress in promoting sustainable land/forest management, forest certification and strengthening of their protected areas system. Figure 2.10 shows a map with the geographical distribution of protected areas.

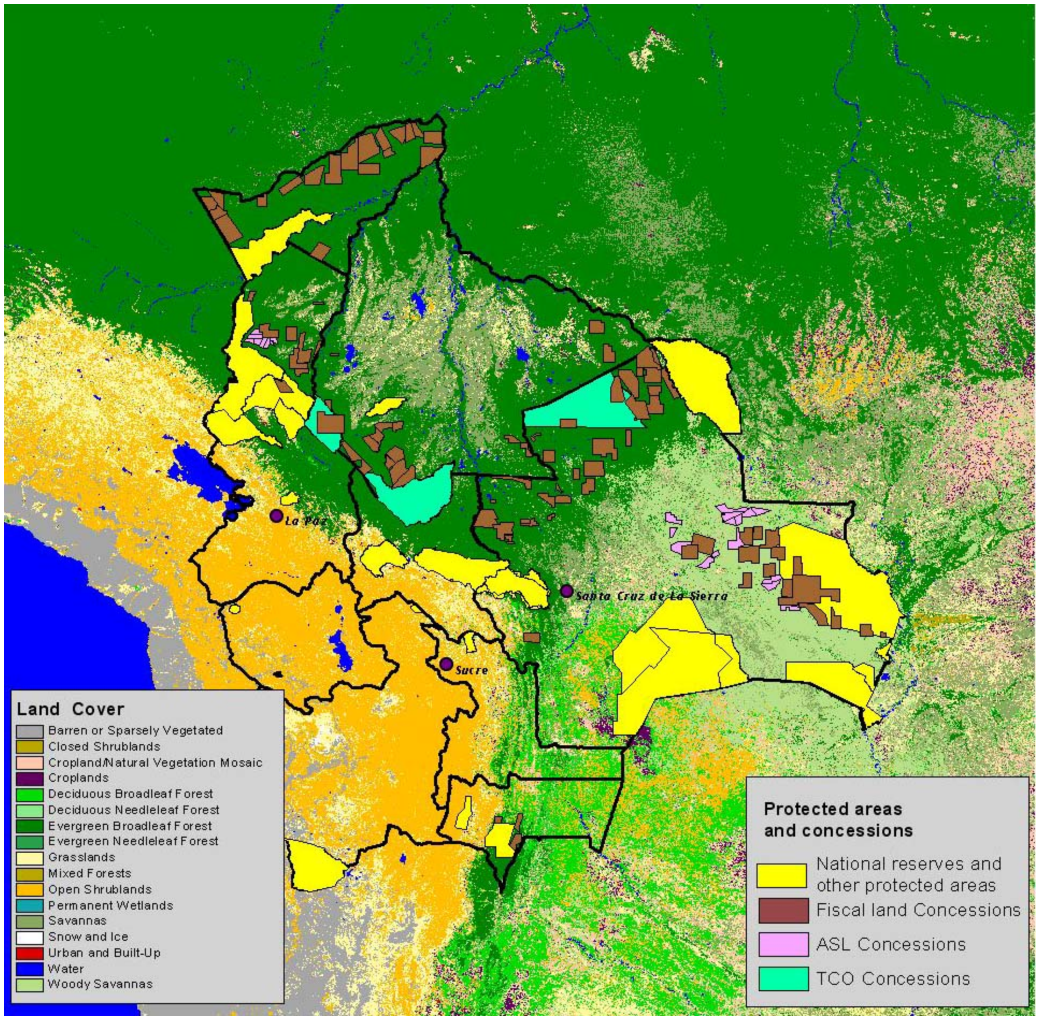


Figure 2.10. Protected areas and concessions in Bolivia

2.7.3. Wood and Wood Products from Bolivia to the U.S.

In 2003, Bolivia exported 77,523 m^3 of wood and wood products worldwide, 36% of the total exports (27,377 m^3) went to the U.S., which was the largest consumer of tropical wood from Bolivia (Figure 2.11) (CFB, 2004).

The most important products imported from Bolivia are sawnwood and doors. In 2003, around 14,000 m^3 of sawnwood hardwood were imported to the U.S. This represents more than 40% of Bolivian total sawnwood exports. When comparing the total sawnwood bought by the U.S. with all the other products, sawnwood accounts for more than 50% of Bolivian exports (Figure 2.12). The end-use of sawnwood by hardwood importers was mainly to manufacture fine furniture, cabinetry, and doors. A small proportion of sawnwood exports were used in the musical instruments industry (Gutiérrez *et al.*, 2005).

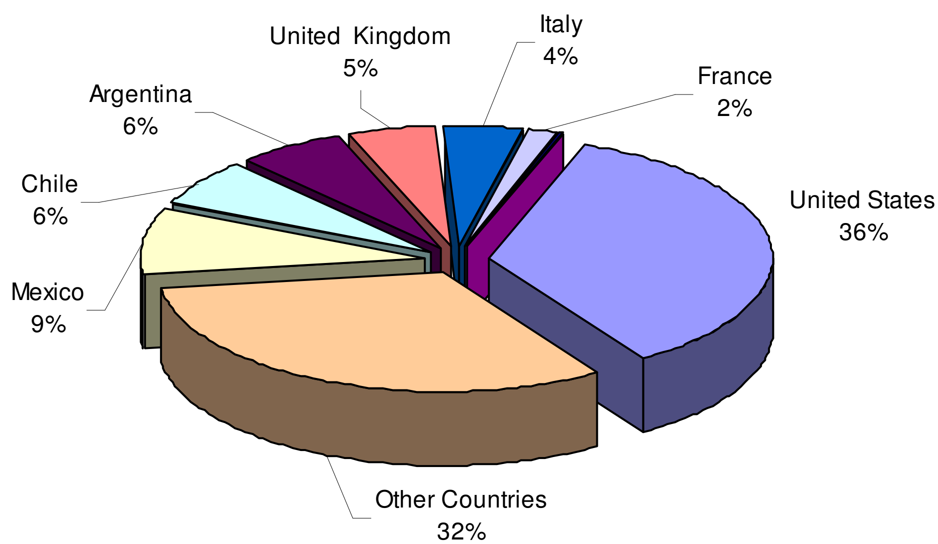


Figure 2.11. Bolivian wood and wood products exports to the world, 2003
Source: (CFB, 2004).

Doors are the second most important product exported from Bolivia. In 2003, Bolivia exported 7,896 m^3 of doors to the U.S. This represented 29% of all Bolivian wood products exported (CFB, 2004). Sawnwood and doors accounted for more than 80% of all Bolivian exports, which indicated that despite its potential, the country does not have a diversified wood product industry.

The dependency on these two products is not the only setback for the country. Another conflict is that sawnwood and doors trade is monopolized by just a few companies is also. The top 4 exporters from Bolivia and their respective importers in the U.S. control over 60% of the market. Furthermore, the top companies exporting and importing these products monopolize approximately 40% of the total volume traded (PIERS, 2005).

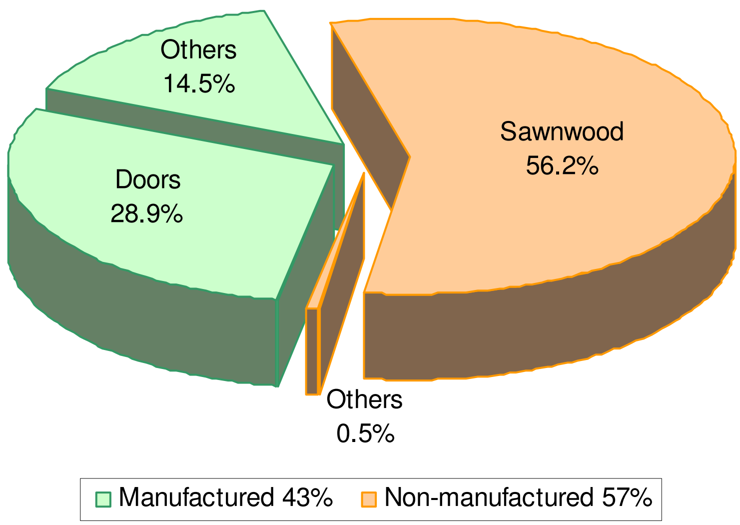
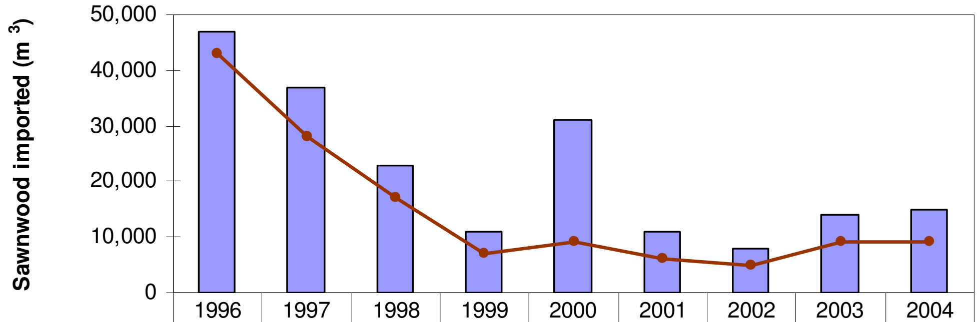


Figure 2.12. U.S. wood and wood products imports from Bolivia, 2003
Source: (CFB, 2004).

Traditionally, Mahogany *(Swietenia macrophylla)* was the primary species exported from Bolivia and from other Latin American countries as sawnwood. Overexploitation during this period considerably affected mahogany population in all the South American countries (Gutiérrez *et al.*, 2005). Since 1996, mahogany exports from Bolivia have been constantly declining, contributing to the decrease of sawnwood exports from 47,000 m^3 in 1996 to 15,000 m^3 in 2004 (68%) (Figure 2.13).

In 2002, due to its overexploitation, mahogany was included in the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES -

appendix II). As a result, mahogany exports now require CITES documents attesting that the timber was extracted according to the countries' regulations and that it does not present a threat to preserving the wild population (CITES, 2002).



	1996	1997	1998	1999	2000	2001	2002	2003	2004
Hardwood	47,000	37,000	23,000	11,000	31,000	11,000	8,000	14,000	15,000
Mahogany	43,000	28,000	17,000	7,000	9,000	6,000	5,000	9,000	9,000

Years

Figure 2.13. U.S. sawnwood and mahogany imports from Bolivia, 1996-2004
Source: (USITC, 2005)

2.7.4. Improvements in the Logging Industry in Bolivia

Quevedo (1998) cited a series of reasons why forests should be certified, including: to have better market access and prices, to improve the public image, to gain more political prestige, to obtain access to funding sources, and to improve community livelihoods. Also, certification of wood products in Bolivia could guarantee the sustainability of its ecosystems hence preserving valuable timber species, such as mahogany, for future use. Under these circumstances, Bolivia became a world leader in FSC certification of tropical forests. In 2005, the country had 64% of the total certified area of natural forests in Latin America that totaled 3.46 million ha (FRA, 2005).

U.S. importers, manufacturers and retailers are important stakeholders to prevent irresponsible logging in Bolivia by purchasing certified wood and wood products. Many of these companies are trading certified products in order to avoid the bad image they have when trading illegal forest products (Metafore, 2004).

At the same time, the FSC certification and CITES regulations are improving the control of wood products traded on the international market to prevent predatory logging in producer countries and organization such as the World Wildlife Fund are committed to support companies that are willing to incorporate environmental policies and trade certified products with producer countries.

The Global Forest & Trade Network (GFTN) is the WWF's division providing the necessary technical support and guidance to companies to achieve certification and manage the risks of trading illegal forest products.

Chapter 3: Emergy and the Issue of Forestry and Wood Production

Humans have been using natural resources (e.g., food, hydrocarbons, minerals, timber, etc.) from the environment generally in a non-sustainable way, which caused increasing concern, as this situation ultimately threatens humanity's well-being.

According to Odum and Odum (1981), one possible way to deal with our future depends on how humanity may be able to combine energy, economics, and the environment into one system. This way, understanding that energy causes and maintains the array of nature (human beings part of it), it will be possible to make better economic and political decisions, and individuals can choose how to live in a world they understand. A key for understanding so much complexity is to realize how energy affects and maintains dynamic systems.

One of the reasons why ecosystems of the world are threatened is because market-based valuations do represent their importance to human life-support. Both, people and ecosystems provide services but only one of them gets compensated; meaning that money is only paid to people for their contributions, and not to ecosystems for their service (Odum and Odum, 2000b). Properly accounting for these "free services" from ecosystems has been difficult, mainly because ecosystems are not fully represented in market-drive economies.

In order to conduct ecological accounting, a biophysical method based on the analysis of the embodied energy has been proposed. Over five decades of work on ecological and general systems theory by H.T. Odum culminated in his notion that embodied energy (or emergy) could be used to compare the work of nature with that of humans on a fair and equal basis. This chapter reviews the fundamental concepts of emergy analysis as given by H.T. Odum starting with his seminal work, "Environment, Power and Society" (Odum, 1971). The concepts are demonstrated by depicting the relationship between forests and people.

3.1. Energy Systems

As universally stated, energy "is the ability to cause work, and work is defined as any useful energy transformation" (Odum, 1996). And energy may be classified as whether it is potential or kinetic. Potential energy is stored energy that has the capacity to drive a process that transforms energy from one form to another. Kinetic energy is the energy of movement. Each body possesses certain amount of kinetic energy, which depends on the speed of its motion and mass.

3.2. Laws of Thermodynamics

- First law of thermodynamics: Energy can neither be created nor destroyed.

Energy is conserved during transformations. Energy that goes into a system must either come out or stay inside. For example in Figure 3.1 energy flows into the forest from several sources (i.e., sunlight, water, nutrients) and energy is converted into biomass and degraded energy (plants respiration).

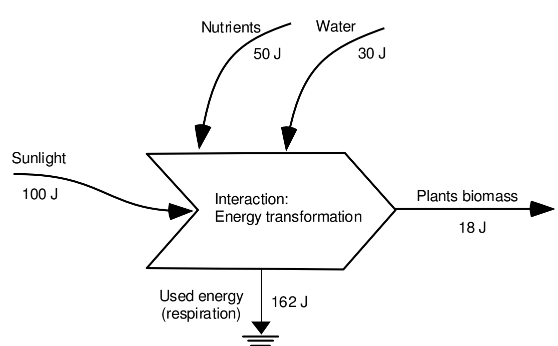


Figure 3.1. Example of a simple energy budget in the forest

• Second law of thermodynamics: All transformations of energy from one form to another leads to a loss in the ability of that energy to do work. Due to the second law, the ability of energy to work is lost, but according to the first law no energy is lost. This loss of ability results in an increase in entropy. The second law of thermodynamics tells us that the quality of energy is degraded every time energy is used in any process. This 'energy quality' has been named exergy.

For example, the work of a tree in the forest results on most of its potential energy going into the soil when it is decomposed after dying. Some of its energy is retained as high quality genetic material (seeds) that were produced when it was alive and now they are young trees (Figure 3.2).

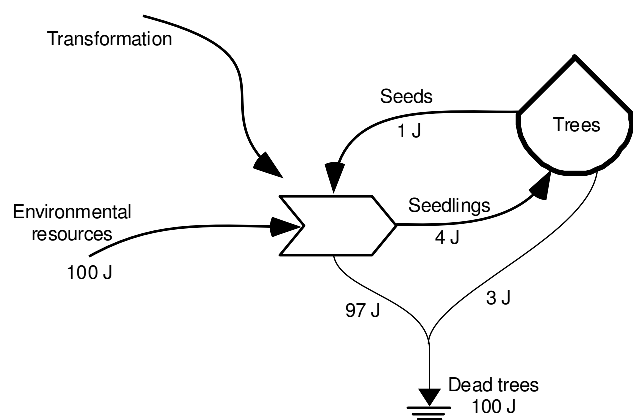


Figure 3.2. Example of a simple degradation of energy in the forest

• Third law of thermodynamics: Absolute zero exists. Entropy at absolute zero is zero. As heat content approaches absolute zero (-273^{o}C) molecules are in crystalline states, and the entropy of the state is defined as zero.

Energy comes to our planet from the sun as ultra-violet radiation, visible light and near-infrared radiation, where it heats the seas, produces plant food, and indirectly generates winds, waves, and geologic uplift. It also made the ancient biomass that is today's coal and petroleum. Processing information from books, newspapers, television, and internet requires that energy be used.

Some activities, like education seem like small energy consumers because they apparently involve only people and not many fuel-using machines, but the energy involved in all the educational activities is large. Maybe because we are used to thinking of energy as physical work, we do not realize that the thinking process uses energy too. Much energy goes into educating the mind and maintaining the body to support the mind.

Different kinds of energy can be associated and/or compared using conversion factors which show how much of one kind of energy is equivalent to how much of another kind of energy (Odum and Odum, 1981). Connecting different kinds of energy, we can associate many parts and visualize complexity in a simple way. This is called the "systems" approach. In this approach, diagrams are used to visualize the systems, and from the diagrams calculations are made about flows and storages (Odum, 1996).

3.3. Energy Hierarchy

The concept of energy hierarchy refers to the fact that it takes more energy of one kind to generate another, higher quality form of energy. Sunlight, for example, is considered a dilute form of energy while others, like gasoline, and firewood, are concentrated forms of energy. In other words, many joules of available energy of a certain kind are required in a transformation process to produce a unit of energy of a higher quality form.

Odum utilized an analogy to explain energy transformation hierarchy: "*A hierarchy, such as a military organization, has many units of one kind (privates) that contribute to and are controlled by a unit at a higher level (corporals). Similarly, many corporals contribute to and are controlled by a unit at the next level (sergeant), and so on*" (Odum, 1996 pp. 18). Hence, one unit of dilute energy cannot be used in the same way as one unit of concentrated energy, and since it takes energy to concentrate energy, we must degrade some energy to concentrate what is left. Many units of dilute energy are needed to form one unit of concentrated energy. For example, four joules of coal are required for one joule of household electricity and 1,000 joules of sunlight maybe required to make one joule of wood.

According to Odum and Odum (1981), the total energy required for a product is the embodied energy in that product, which was the starting point for the development of emergy (spelled with an M) analysis as a new field of study.

3.4. What is Emergy?

The word emergy is a contraction of the term "embodied energy". The term was introduced in 1987 by D.M. Scienceman who also used emergy to refer to the concept of "energy memory" (Scienceman, 1987). As a systems concept, emergy was defined as "***the sum of all energy of one form needed to develop a flow of energy of another form, over a period of time***".

The emergy synthesis method was introduced by H.T. Odum in the 1980s with the aim of taking into account energy from different sources that participate in a process and allowing their comparison on a common basis. The problem of multi-quality inputs is solved by transforming them to an equivalent of energy of a single quality, which is usually solar energy (Tilley, 1999; Tilley and Brown, 2006). In other words, emergy expresses the cost of a process or a product in solar energy equivalents. The basic idea is that solar energy is our ultimate energy source and by expressing the value of products in emergy units, it becomes possible to compare different kinds of energy (Jorgensen *et al.*, 1995; Laganis and Debeljakb, 2006) using transformity.

Howard T. Odum, based on the "Principle of Maximum Energy Flux" developed by Lotka (1922), proposed the "Fourth law of thermodynamics" as the Maximum Empower Principle (Odum, 1971). It states that self-organizing systems tend towards the maximization of useful power. This sometimes has been interpreted as increasing efficiency, but this may be the selection criteria of choice when new energy sources are scarce.

3.5. What is Transformity?

Like with emergy, the concept of transformity was first introduced by D.M. Scienceman in collaboration with Howard T. Odum. Scienceman (1987) proposed that the phrases, "energy quality", "energy quality factor", and "energy transformation ratio", all used by H.T.Odum, be replaced by the word "transformity".

Transformity is defined as "***the emergy of one kind required to make a unit of energy of another kind***". For convenience, all types of contributing energy are expressed in units of solar energy that would be required to generate all the inputs (Odum, 1996). For example, if 3 solar emjoules (sej) of sunlight and 1solar emjoule (sej) of nutrients are required to produce 1 joule (J) of wood, the transformity of wood is 4 sej/J.

3.6. What is Empower?

Empower is "***the flow rate of emergy***". According to Scienceman (1987), the time rate of change of emergy is empower, analogous to power that is the time rate of change of energy. Maximum empower therefore is the maximum flow rate of emergy.

Maximum empower has been proposed by Odum as a corollary of the maximum power principle suggested by Lotka in 1922 when he described the maximum power principle as an organizational law of evolution (Lotka, 1922; Odum, 1971).

3.7. Definition of a System

The word system refers to entity/objects, real or abstract, that function as a whole by the interaction of each and every component/element into organized parts. Thus, a subsystem is a set of elements which is a system itself and a part of a whole system.

Some examples of systems are: A house, which is a system of water pipes, electrical wires, rooms, building materials, and so on. A forest is an ecological system consisting of trees, soils, chemical cycles, wildlife, and microorganisms interacting so that the forest as a whole is sustained, and each of the major divisions of the forest constitutes a subsystem. Looking with greater detail, a tree has component cells and tissues which are also systems since they too have parts, the microscopic components of living cells. There are systems within systems within systems. Since we cannot consider everything at once, we must decide at what scale we are going to work. A convenient way to clarify the simplifications that humans need in their window of attention is the use of systems diagrams (Odum, 1998).

3.7.1. Systems Diagrams and Energy Flows

Systems diagrams can be used to represent the main inflows and outflows of energy. Figure 3.3 is a simple system diagram showing how the energy for wood production comes in with sunlight, rain, nutrients, the work of the logging company, the machinery, etc.; and how most of this incoming energy leaves the system as timber and dispersed heat which spreads out into the surroundings. The timber that goes out of this system has a higher grade of energy than the standing tree and in this form is useful to man.

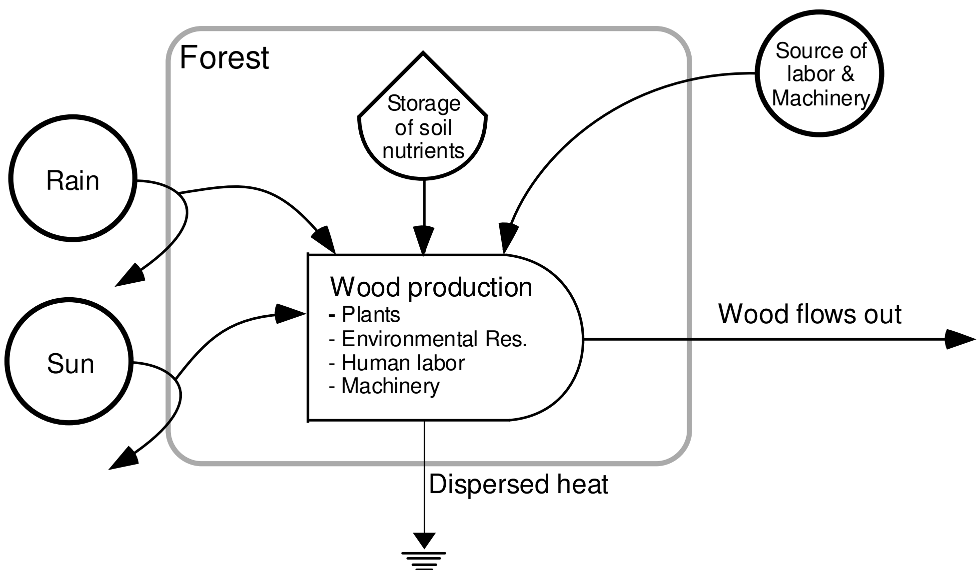


Figure 3.3. Energy flows necessary for a forest to produce wood
Redrawn from Odum and Odum, 1981

Energy systems diagrams may be helpful for a better understanding of the laws of thermodynamics.

In order to accomplish a complex work, many kinds of high-quality energy are required. And currently, we tend to think of the energy requirements in terms of fuel use, ignoring the contribution from nature and human beings, without realizing that the energy used in services and in obtaining the material may be larger than that of the fuels in many processes. Let's consider for example the energy required to make a piece of wooden furniture (a chair for example); which will include the energy involved in growing the tree, operating and maintaining the equipment for timber process, the energy used in manufacturing, operating and maintaining the machinery (Figure 3.4).

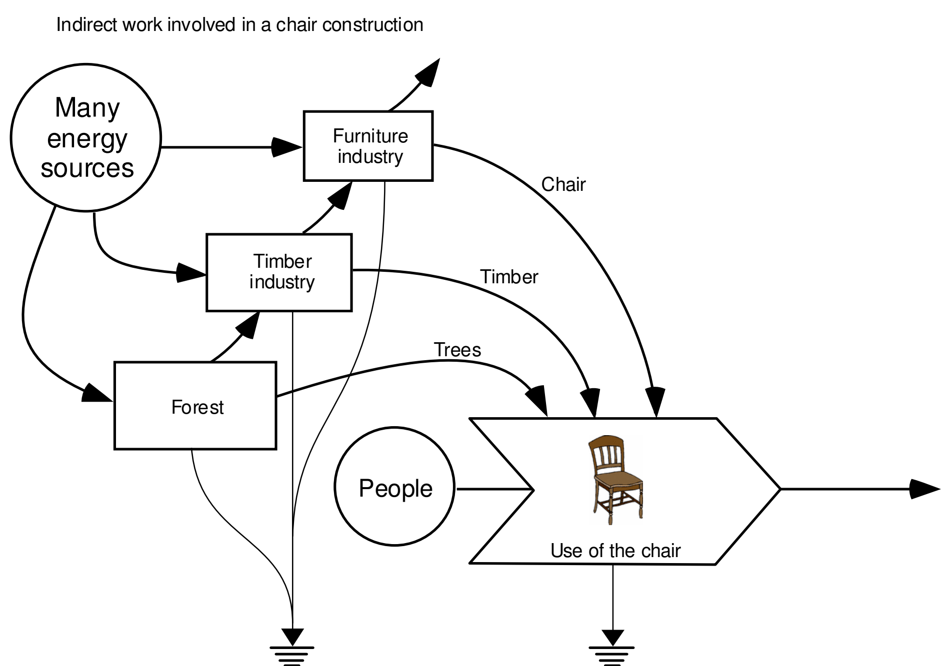


Figure 3.4. Energy flows required to manufacture a wooded chair
Redrawn from Odum and Odum, 1981

If we consider energy as a universal measure for all kinds of work performed by humans and nature, and agree that everything that happens is an expression of the flow of energy in one of its forms, then we can apply the basic laws of energy to all processes of nature and human beings, including economics, culture, and aesthetics.

According to Odum and Odum (1981) all the different sources of energy constitute the real basis of the economic system and are commonly named as externalities because these inflows come from outside the money circle.

3.7.2. Energy Flows without Money Flows

Figure 3.5 is an energy system showing a forest that supports people selling wood. Money is exchanged between people as a medium for keeping track of the exchange of wood and the services related to the provision of it. However, money is not exchanged between the parts of a natural ecosystem.

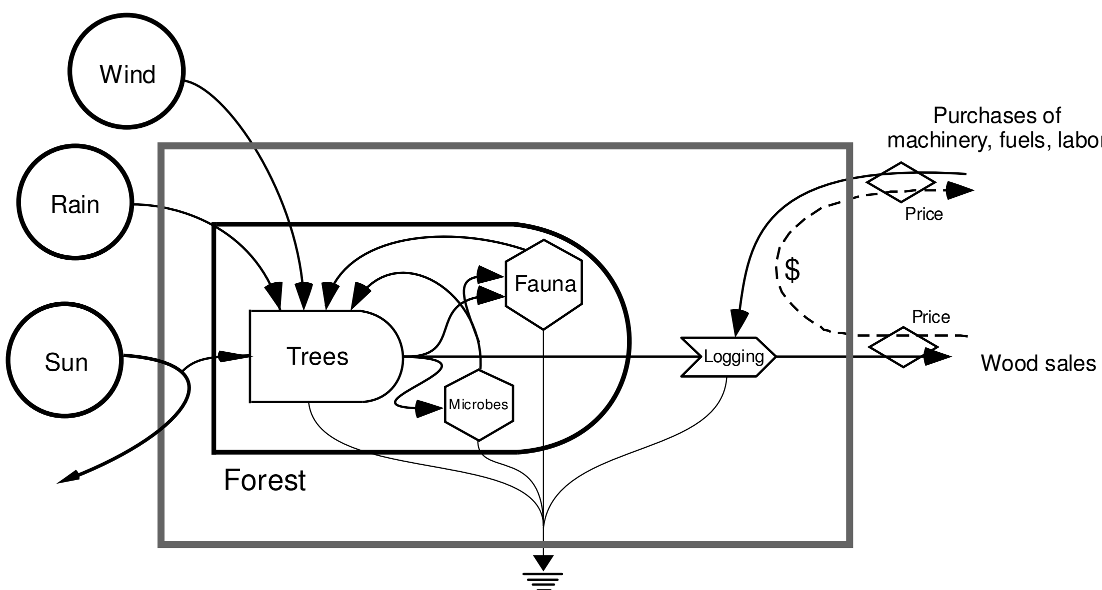


Figure 3.5. Work of a forest that supplies wood

3.8. Economics

Most of the energy involved in developing the wood is in organic matter production based on the solar energy, the soil nutrients system, and the weather. Money is involved only in the last stages of the wood harvest and sale. Money in this case, like in most of the cases related with natural resources use, measures only the work of people, not the work of the forest. There should be a means to include energy as a measure of value of the wood that accounts for all contributions to the product, including those of forest, the loggers, people providing services, and those of nature.

3.8.1. Prices

Price is the ratio of money flow to goods flow. Money always flows in opposite direction to the flow of goods and the price can be set based on the costs of goods, costs of operations and the expected profit. Often the price is determined by markets. In order to make a profit, the amount of money the company pays for its costs must be lower than the money the company receives for its sales. Market prices are also regulated by demand or supply. In the case of wood, for instance, the amount of wood that people want to buy is called the demand and the amount of wood the logging company has to sell is called the supply. When there is more supply than demand, prices go down but if there is more demand than supply, prices go up (Odum and Odum, 1981).

Figure 3.5 shows also the relationship between the contribution from the environment and the economy. For wood production, the environment contributes with fuels, soil, air, water, sunlight, wind, etc., and the economic system contributes by feeding back goods, services, equipment, and fuels.

The price of wood does not recognize how valuable the environmental input is to the economy because it does not indicate how much of the main economy's money flow comes from the external inflow (from the forest). That is why the only way that the real value of an external input to the economy can be calculated is through the emergy evaluation.

3.9. Why Use Emergy?

Most people use money to judge the values of products for sale so money is everywhere to acquire goods and services. Money flows in circles while energy flows through a system generating work and ultimately it degrades to a form that is no longer capable of driving work. The flow of energy makes possible the circulation of money, and the manipulation of money can control the flow of energy. According to Odum, we must understand something about money and energy and their relationship in order to understand the economic system and the way energy affects it.

By now, it is clear that both energy and money are used to measure value and that energy and money flow in opposite directions (Figure 3.5). As wood produced on a forest goes to a town, people pay the logging company money that goes back to the extraction of wood. The logging company uses money to buy machinery and fuels from the town, sending the money back to town to pay for it.

This relationship forms a loop, where money circulates around and around and energy flows in as high grade potential energy and is used to maintain the structures of the wood-producing forest and town; however, as described before in the thermodynamic laws, most of the energy necessarily goes out as low-grade dispersed heat (Odum, 1971).

Human economic systems can produce materials and fuels to support populations and cultures. However, human beings are only a small part of the great biosphere (including: forests, oceans, mountains, valleys, land, rivers, and the atmosphere).

Ultimately, it is not just human beings and their money that determine what is important; it is the world's energy. It would make, therefore, more sense to measure everything by the flow of energy, since only in this way nature can account for its contribution. In our example about logging, the money received by the timber company for its products pays only for the human work and the cost of using machinery but not for the work of sun, rain, soil, and wind.

3.9.1. Ratio of Energy to Money

Money can go around only if energy flows through the system to support the work that the money buys. The more work is done for each dollar that circulates, the more truly valuable the dollar is. Accounts for production systems based on natural resources cannot be kept in dollars alone, because environmental systems are based on the work of both humanity, which is paid for by a counter flow of dollars, and the work of ecosystems, for which no money is paid but energy can be used as a common denominator for quantifying all these flows.

Converting flows of energy and money into emergy puts the work done by humans and the environment on the same scale, so that economic and environmental flows are directly comparable. As stated by Brown and Ulgiati, emergy analysis is an accounting of social, economic and environmental flows in common terms on an objective basis (Brown and Ulgiati, 1999).

Emergy accounting may provide to environmental managers tools similar to those used by financial analysts to make business decisions. The development of emergy analysis will make possible for decision makers to examine and commensurate economic and environmental accounting data before making policy decisions about environmental systems.

Chapter 4: Methods

This dissertation uses systems diagramming, emergy synthesis, and simulation modeling to understand the relationships among Bolivia's forests, gas reserves and economic assets to explore the potential of the country achieving an ecologically-based industrialization. This chapter describes each method and defines key terms used.

4.1. Systems Diagrams and Energy Flow

Diagramming was done using Odum's energy systems language. The explicitly defined symbols were connected by pathways representing energy, material or money (names and definitions of symbols can be seen in Appendix 2). Energy systems diagrams help to understand systems, especially to understand the environment and society as a system, thinking about their parts, processes, and connections (Odum and Odum, 2000a). The symbols included in the diagrams represent scale units and the pathways may indicate causal interactions, show material cycles, or depict flows of information, but always with some energy. The systems diagrams developed in this study served two purposes: to assist in the generation of tables for emergy evaluation and to help in defining the equations used to develop the simulation model.

The following steps were taken to develop each energy systems diagram:

1. Spatial and temporal boundaries were defined.
2. Exogenous energy sources crossing system boundary were itemized
3. State variables representing all the internal units that vary over time were identified.

4. Driving energy sources and internal components were arranged according to their position in energy hierarchy.
5. All driving energy sources and components were connected using appropriate pathways.

4.2. Emergy Systems Evaluations

Emergy evaluation consisted of two basic steps. The first step was to conduct an inventory of all energy, material and money that was entering a system. The second step was to analyze these flows with standard emergy indices that describe such attributes as proportion of emergy derived from renewable resources, the ratio of purchased to renewable emergy, and the balance between environmental load and yield.

In order to evaluate the energy of flows and storages of all the systems considered in this study, energy, mass and money contained or transferred by each unit was evaluated and converted into emergy. To perform emergy evaluation, a system diagram was constructed, following the steps in section 4.1 and then the emergy evaluation table was built, based on the diagram. Each energy or material crossing the system boundary was represented as a line item in the emergy table, which inventoried the inputs and contained the calculations for transforming the raw units into solar emergy. Data on inputs, outputs and solar transformities was obtained from official databases and published literature. Typically the values of inputs were expressed as energy (joules), mass (grams) or money ($) and converted to solar emergy by multiplying them by the respective transformation ratio as given in Equations 4.1, 4.2 and 4.3.

$$\text{Energy Transformation Ratio (ETR)} = \frac{\text{Solar Emergy (sej)}}{\text{energy (J)}} \quad (4.1)$$

$$\text{Mass Transformation Ratio (MTR)} = \frac{\text{Solar Emergy (sej)}}{\text{mass (g)}} \quad (4.2)$$

$$\text{Dollar Transformation Ratio (DTR)} = \frac{\text{Solar Emergy (sej)}}{\text{Money (\$)}} \quad (4.3)$$

Tables similar to the one described on Table 4.1 were developed for all the systems that were part of this research. Emergy tables show how energy and mass flows are converted to solar emjoules by multiplying them by solar transformity values. The emdollar value for each flow or storage was found by dividing the solar emergy by the mean emergy-to-dollar ratio of the Bolivian economy (BO_{EDR}).

Table 4.1. Emergy evaluation template

1	*2*	*3*	*4*	*5*	*6*	*7*
Note	**Item**	**Data**	**Physical units** (J, g, $, etc)	**Transformity** (sej/unit)	**Solar Emergy** (sej)	**Emdollars** (Em$)
Inputs						
1	Energy	e_i	joules	ETR_i	$S_i = ETR_i \times e_i$	$Em\$_i=S_i/(BO_{EDR})$
2	Mass	m_j	grams	MTR_j	$S_j = MTR_j \times m_j$	$Em\$_j=S_j/(BO_{EDR})$
Outputs						
3	Human Service	d_k	money	DTR_k	$S_k = DTR_k \times d_k$	$Em\$_k=S_k/(BO_{EDR})$
Total Emergy						TE

BO_{EDR} = emergy-to-dollar ratio of Bolivia

To obtain the total solar emergy used by the system, the solar emergy of all items were summed, according to the following mathematical representation:

$$TE = \sum_{i=1}^{n} ETR \times e_i + \sum_{j=1}^{p} MTR \times m_j + \sum_{k=1}^{q} DTR \times d_k \qquad (4.4)$$

Where: e_i = energy of input i

m_j = mass of input j

d_k = dollars of input k

The tables were prepared considering the 7 columns that are normally used, where:

Column 1 is the line item number and also represents the number of the footnote in the table where raw data source is cited and calculations are shown.

Column 2 is the name of the item.

Column 3 contains the raw data expressed in terms of energy, mass or money (joules, grams or dollars) obtained from various sources.

Column 4 shows the unit on what the raw data is expressed.

Column 5 includes transformity values expressed in solar emjoules per unit of energy, mass or money (sej/joule; sej/gram; or sej/$). Unless calculated in this work or otherwise noted, transformities used in this dissertation were taken from different sources making the necessary adjustment from global emergy base of reference from 9.44 E24 sej/yr (for values based on the 1996 solar empower base) to 15.83 E24 sej/yr, multiplying those values (from 1996 or older) by 1.68.

Column 6 is the solar emergy. It is the product of columns three and five.

Column 7 represents the macroeconomic value expressed in macroeconomic dollars for a selected year. To obtain this, it emergy value in column six was divided by the emergy-to-dollar ratio of Bolivia (BO_{edr}) for the year 2005. BO_{edr} was found by dividing the gross national product by the total contributing emergy use by the combined economy of man and nature in Bolivia in the year 2005.

4.2.1. Emergy Indices

Emergy indices were used to draw inferences from emergy analyses, as well as to evaluate and compare alternatives for energy sources, environmental impacts, and emergy exchange between Bolivia and its international counterparts.

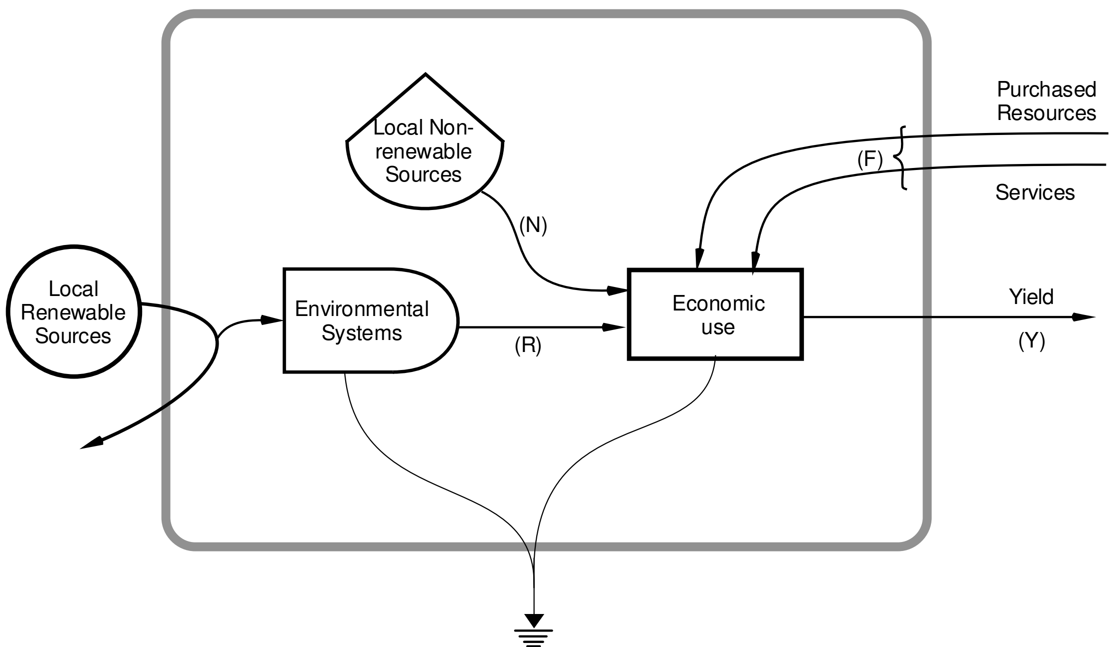


Figure 4.1. Analysis of flows with standard emergy indices

The main indices used in this study were calculated based on the systems diagram showed in Figure 4.1., where: N are the non-renewable environmental contributions (as an emergy storage of materials), R are the renewable environmental inputs, and F are the inputs from the economy as purchased goods and services. The indices or ratios used to evaluate the performance of Bolivia and the different processes studied were:

Transformities, used to evaluate the quality of the energy flows. Transformities were calculated and compared with other energy forms.

Emergy yield ratio (EYR) is the emergy of an output (Y) divided by the emergy of those inputs to the process that are feedback from the economy (F) and it was used for interpretation of the net benefit. This ratio indicates whether the process can compete in supplying a primary energy source for an economy.

Environmental loading ratio (ELR) is the ratio of nonrenewable and imported emergy use (F+N) to renewable emergy use (R). It is and indicator of the pressure of a transformation process on the environment and can be considered a measure of ecosystem stress due to a production (transformation activity.

Emergy investment ratio (EIR) was used to anticipate whether an investment is well matched by free resources. The emergy investment ratio is the ratio of the emergy fed back from the economy (F) to the free emergy inputs from the environment (R+N). This ratio indicates if the process is economically practical to be used in comparison to other alternatives.

4.3. Computer Simulation Model

A model to simulate the "Ecologically-based Development for the Bolivian Industrial Forestry" (DEBBIF) was developed based on energy systems diagrams and simulated using standard spreadsheet software (MS Excel®). The process to develop the model followed the steps recommended by Odum and Odum (2000a):

1. An energy systems diagram was drawn to shown the sources and flows participating in the process. Figure 7.1 shows the complete diagram, but for the purpose of this chapter a portion of that diagram is shown as an example in Figure 4.2.

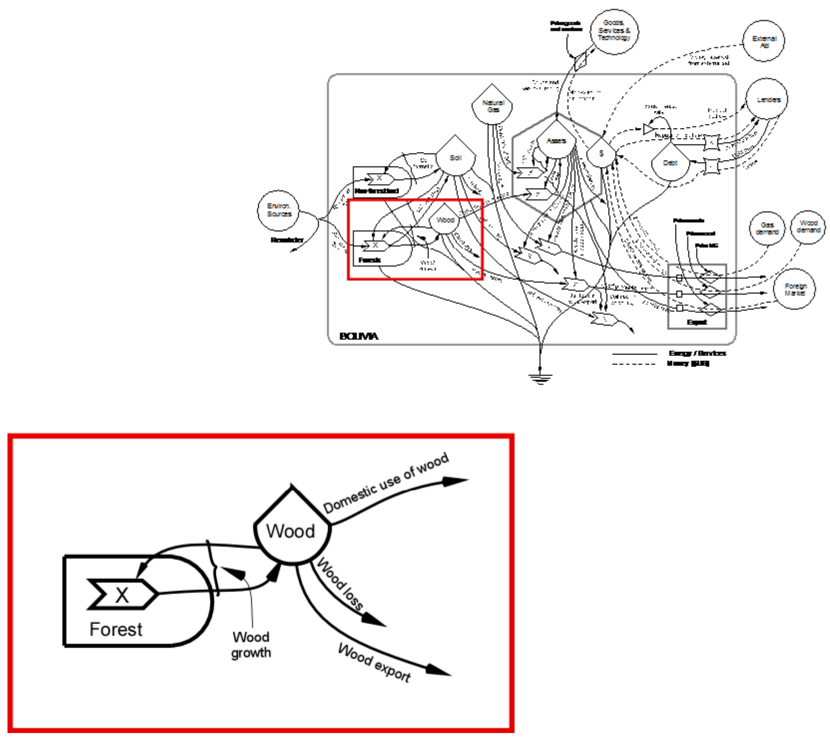
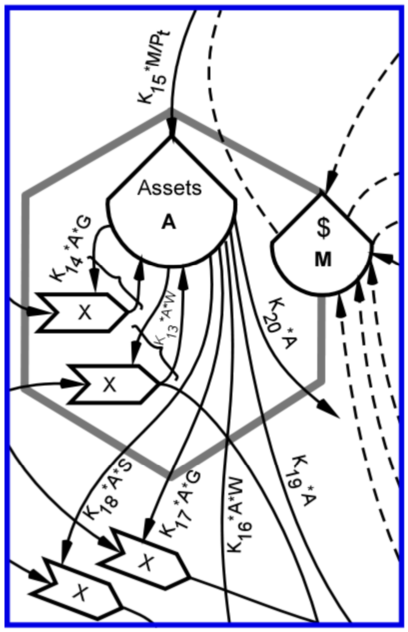
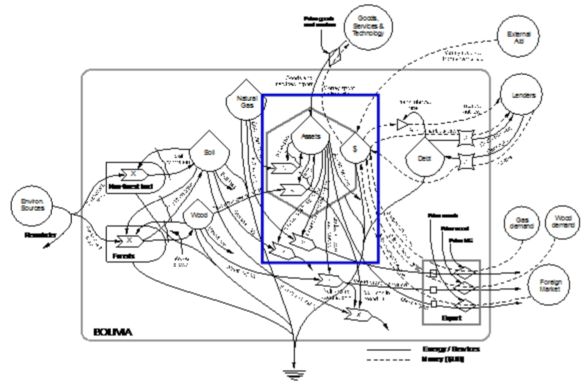


Figure 4.2. Example of energy systems diagram construction process

2. Based on an energy systems diagram, difference equations from the systems diagrams and calibrate pathways coefficients were written. Figure 4.3 shows a portion of the energy systems diagram of the model DEBBIF where all the flows that participate in the difference equation for the Bolivian assets are shown.





$$dA/dt = (k_{13}*A*W)+(k_{14}*A*G)+ (k_{15}*M/P_t)-(k_{16}*A*W)- (k_{17}*A*G)-(k_{18}*A*S)- (k_{19}*A)-(k_{20}*A)$$

Figure 4.3. Portion of the model DEBBIF showing flows and difference equation

3. Using spreadsheet, all the initial conditions and the calibrated storages and flows were listed and organized.
4. The main simulation table was set up by entering the terms of the model equations in a row as headings for the columns including sources, storages, equations for pathways flows, and differential equations for storages (Figure 4.4.).

	A	B	C	D	E	F	G	
2								
3	Item	Description	Variable	Equation	Calibration			
4					Value	Unit	*k* - Value	
5	Inputs							
6	1	Environmental sources	J		1.5E+12	m^3/yr		Average a
7	2	Remainder	R		2.7E+11	m^3/yr		18% of en
8	3	External aid	U		3.8E+10	$US/yr		Global ext
9	4	External demand for wood	E_w		2.7E+07	MT/yr		Potential e
10	5	External demand for natural gas	E_g		4.9E+09	m^3/yr		Potential e
11	6	External demand for assets	E_a		1.5E+06	MT/yr		Potential e
12								
13	Flows							
14	7	Resources flowing into non-forestal land	J_a	k_a*R*S	7.3E+11	m^3/yr	2.33E-10	Non-fores
15	8	Resources flowing into forestal land	J_b	k_b*R*S*W	9.5E+11	m^3/yr	3.87E-20	Forest lan
16	9	Soil formation (rate of C increase) non-forest land	J_{1a}	k_{1a}*R*S	1.9E+07	MT/yr	6.23E-15	0.38 MT C
17	10	Soil formation (rate of C increase) forest land	J_{1b}	k_{1b}*R*S*W	7.8E+08	MT/yr	3.20E-23	Above + E
46								
47	Storages							
48	39	Soil - Total national carbon storage	S		1.2E+10	MT		162 TOC/h
49	40	National land area	S_{a+b}		1.1E+12	m^2		Total natio
50	41	Non-forest land area	S_a		5.1E+11	m^2		National la
51	42	Forest land area	S_b		5.9E+11	m^2		Area cove

Figure 4.4. Use of spreadsheet to calibrate coefficients

BD6 =(AA6+AB6-AC6-AD6-AF6)*B86

	K	L	M	N	O	Y	Z	AA	BD	BE	BF
2		*Inputs*		*Storages*		*Flows*			*Increments*		
3						J_a	J_b	J_{1a}			
4	Time	J	R	S	W	k_a*R*S	k_b*R*S*W	k_{1a}*R*S	ds/dt	dw/dt	dg/dt
5	Time	Env. sources	Remainder (m^3)	Soil (MT)	Wood (MT)	Flows into non-forest	Flows into forest	Soil formation	ds/dt	dw/dt	dg/dt
6	2005.0	1.5E+12	2.7E+11	1.2E+10	7.8E+09	7.3E+11	9.5E+11	1.9E+07	-2.6E+07	4.3E+07	-1.2E+09
7	2005.1	1.5E+12	2.1E+11	1.2E+10	7.9E+09	7.3E+11	9.5E+11	1.9E+07	-2.6E+07	4.3E+07	-1.2E+09
8	2005.2	1.5E+12	2.1E+11	1.2E+10	7.9E+09	5.5E+11	7.2E+11	1.5E+07	-4.5E+07	3.3E+07	-1.2E+09
9	2005.3	1.5E+12	2.1E+11	1.1E+10	7.9E+09	5.5E+11	7.3E+11	1.5E+07	-4.5E+07	3.3E+07	-1.2E+09
10	2005.4	1.5E+12	2.1E+11	1.1E+10	8.0E+09	5.5E+11	7.3E+11	1.5E+07	-4.4E+07	3.3E+07	-1.1E+09
11	2005.5	1.5E+12	2.1E+11	1.1E+10	8.0E+09	5.5E+11	7.3E+11	1.5E+07	-4.4E+07	3.3E+07	-1.1E+09
12	2005.6	1.5E+12	2.1E+11	1.1E+10	8.0E+09	5.5E+11	7.3E+11	1.5E+07	-4.3E+07	3.3E+07	-1.1E+09
13	2005.7	1.5E+12	2.1E+11	1.1E+10	8.1E+09	5.5E+11	7.3E+11	1.5E+07	-4.3E+07	3.3E+07	-1.1E+09
14	2005.8	1.5E+12	2.1E+11	1.1E+10	8.1E+09	5.4E+11	7.3E+11	1.5E+07	-4.2E+07	3.3E+07	-1.1E+09
15	2005.9	1.5E+12	2.1E+11	1.1E+10	8.1E+09	5.4E+11	7.3E+11	1.5E+07	-4.2E+07	3.3E+07	-1.1E+09
16	2006.0	1.5E+12	2.1E+11	1.1E+10	8.2E+09	5.4E+11	7.3E+11	1.4E+07	-4.1E+07	3.3E+07	-1.1E+09
17	2006.1	1.5E+12	2.1E+11	1.1E+10	8.2E+09	5.4E+11	7.3E+11	1.4E+07	-4.1E+07	3.3E+07	-1.1E+09
18	2006.2	1.5E+12	2.1E+11	1.1E+10	8.2E+09	5.4E+11	7.4E+11	1.4E+07	-4.0E+07	3.3E+07	-1.1E+09
19	2006.3	1.5E+12	2.1E+11	1.1E+10	8.3E+09	5.4E+11	7.4E+11	1.4E+07	-4.0E+07	3.3E+07	-1.1E+09
20	2006.4	1.5E+12	2.1E+11	1.1E+10	8.3E+09	5.4E+11	7.4E+11	1.4E+07	-3.9E+07	3.3E+07	-1.1E+09
21	2006.5	1.5E+12	2.1E+11	1.1E+10	8.3E+09	5.3E+11	7.4E+11	1.4E+07	-3.9E+07	3.3E+07	-1.1E+09

Figure 4.5. Use of spreadsheet to calculate increments

5. Based on the set up table, storage values for a time frame were found following the Equation 4.5.

$$Q_{new} = Q_{old} + (dQ \times dt) \quad (4.5)$$

See Figure 4.5.

Finally, the formulas for the second line and beyond (each line represents a step in time) were duplicated in a way that every calculation was repeated on the next line, and so on until the last line. The final result was a simulation graph (Figure 4.6) for each one of the variables we monitored.

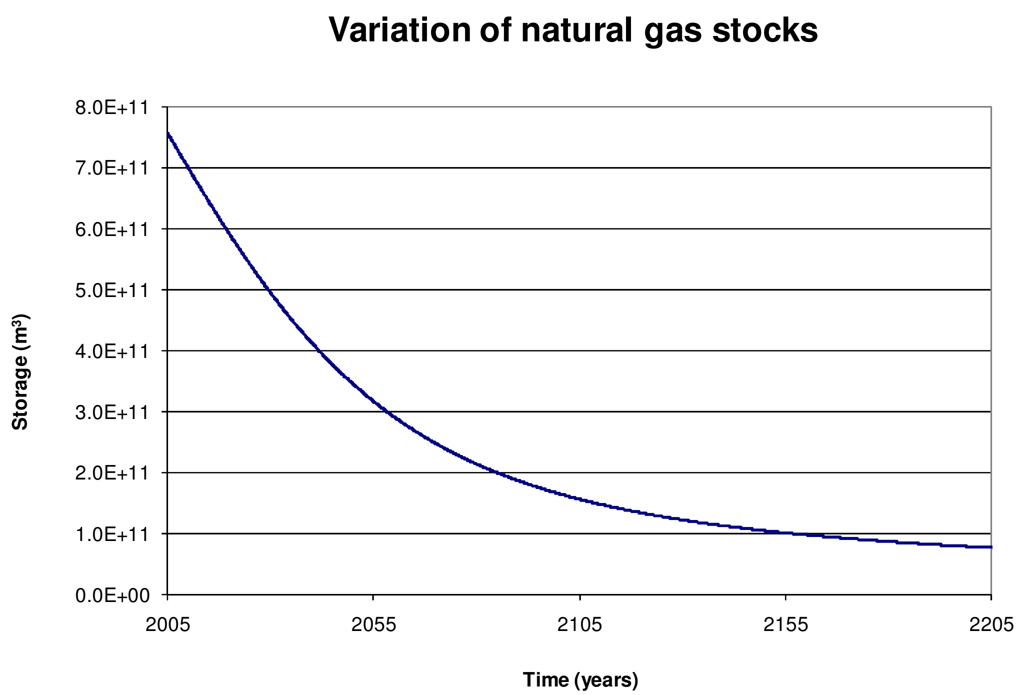


Figure 4.6. Example of a simulation graph using the model DEBBIF.

4.3.1. Model Application

Once the simulation model was completed, the next step was to use it to explore how various changes in Bolivia's use of forest resources for domestic and export markets and biological preservation would alter the state of the forest and the population's economic well-being.

Specifically four different scenarios were analyzed:

Reference Scenario represented the "Business-as-usual" case whereby national use of the forest and natural gas reflected historical attitudes, which meant that model parameters were kept at levels calibrated for year 2005.

Increased Exports Scenario assumed that exports of unprocessed wood and natural gas were increased while other parameters remained unchanged.

Increased Domestic Use Scenario assumed more wood and natural gas were used domestically to expand national industrial capacity, but that parameters controlling exports of wood and gas were not changed.

National Industrialization Scenario simulated an ideal situation, where natural gas is intensively used within the country as part of the forestry industry development and instead of exporting unprocessed wood and natural gas (Increased Export Scenario), value-added products are exported.

Chapter 5: Emergy Analyses of Bolivia, its Forestry and its Natural Gas

This chapter is organized into three main sections. The first section presents the emergy evaluation of Bolivia, including evaluations of major internal systems and storages as well as summaries of major trading sectors. The second section concentrates on the emergy analysis of the national forestry system. The third section shows the emergy analysis of Bolivia's natural gas sector.

5.1. Emergy Analysis of Bolivia

The emergy analysis of Bolivia included an energy systems diagram, annual emergy analysis and indices of the national economy for the year 2005.

5.1.1. Energy Systems Diagrams

The systems diagram in Figure 5.1 shows the external environmental and economic energies interconnecting prominent features in the Bolivian national system. Starting at the left of the diagram, major ecosystems like the tropical forests, the mountains with its lakes and river system and agriculture capture the ample range of environmental energies (e.g., sun, wind, chemical and geo-potential rain, and geologic uplift). Large mineral deposits, forests, natural gas reserves and agriculture provide the basis for industries that transform national resources into goods and services. The processes for the transformation are depicted rightward in the diagram, showed as logging industry, agriculture and coca leaf production, minerals and natural gas exploitation, which along with electricity generation, the social services, and the import of goods and services support the Bolivian population.

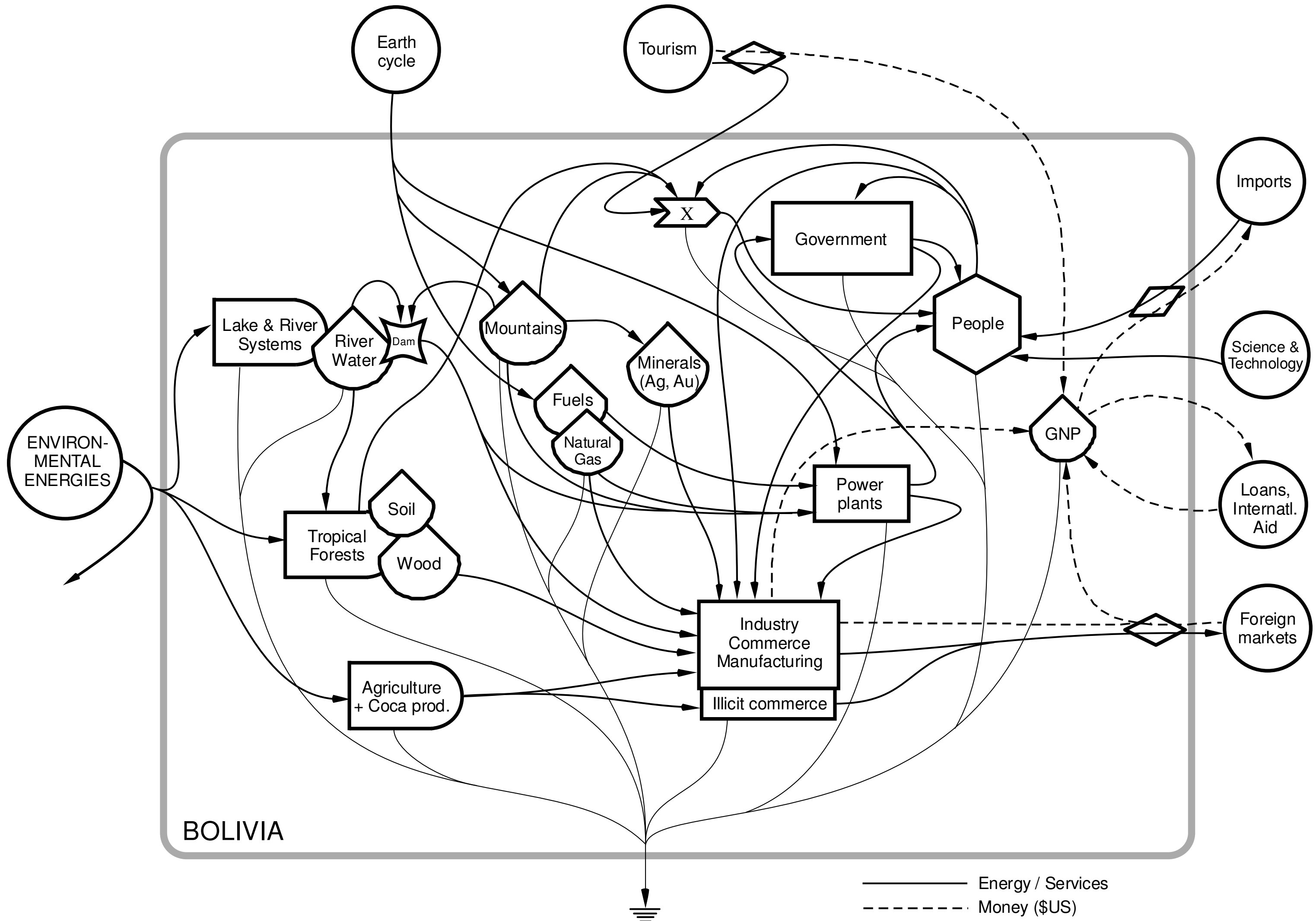


Figure 5.1. Energy systems diagram of the Bolivian national system, 2005

Furthest to the right of the diagram is the connection of Bolivia with the outside world, including trade of goods and services, exchange of money with outside markets, donors, lenders and the provision of services to tourists.

The interaction of these interconnected features and the external energy sources play an important role defining the character of the country.

5.1.2. Emergy Analysis of Annual Flow

Annual flows of emergy were evaluated using the energy values listed in Table 5.1 which included renewable sources, indigenous renewable energy, non-renewable sources from within the system, imports and outside sources, and economic exports for the year 2005. Details of the calculations performed to estimate the energy, material and money flows in Table 5.1 are shown in footnotes in Appendix 3. Bolivia's total emergy use is shown in Table 5.2 and Figure 5.2. All the indices of the national economy are summarized in Table 5.3.

5.1.2.1. Renewable Resources of Bolivia

Annual rain chemical with 4,205E+20 sej/yr and rain geopotential inputs with 3,818E+20 sej/yr are the largest annual environmental contributions, and added together represent almost 68% of the national renewable resources (Table 5.1). The country's total annual input of renewable solar emergy (considering rain chemical and mountain deep heat) is 5,815E+20 sej/yr (Table 5.3). The other renewable resources like earth heat cycle, wind kinetic and evapotranspiration provided 1,610E+20 sej/yr; 1,103E+20 sej/yr; and 1,070E+20 sej/yr, respectively. Sunlight provided the least empower with only 41E+20 sej/yr.

Table 5.1. Emergy evaluation of resource basis for Bolivia, 2005

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value (E6 2005 $)
RENEWABLE RESOURCES:						
1	Sunlight	4.09E+21	J	1	41	123.46
2	Rain, chemical	1.62E+19	J	2.59E+04	4,206	12,700.73
3	Rain, geopotential	2.56E+19	J	1.49E+04	3,818	11,531.05
4	Wind, kinetic	4.38E+19	J	2.52E+03	1,103	3,331.23
5	Evapotranspiration	4.13E+18	J	2.59E+04	1,070	3,230.82
6	Earth heat cycle	2.82E+18	J	5.71E+04	1,610	4,862.74
INDIGENOUS RENEWABLE ENERGY:						
7	Agriculture production	3.27E+17	J	4.00E+05	1,310	3,955.01
8	Livestock production	6.52E+16	J	8.60E+05	561	1,694.65
9	Coca leaf production	3.69E+10	g	5.48E+10	20	61.01
10	Coca leaf consumption	2.09E+10	g	5.48E+10	11	34.60
11	Hydroelectricity	7.68E+15	J	2.77E+05	21	64.28
12	Forest growth	8.28E+18	J	2.76E+04	2,286	6,903.24
13	Wood extraction	2.94E+16	J	6.89E+04	20	61.13
14	Fuelwood use	2.16E+16	J	6.89E+04	15	44.96
15	Wood consumption	2.05E+15	J	6.89E+04	1	4.26
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:						
16	Natural gas production	4.87E+17	J	8.06E+04	393	1,185.80
17	Natural gas consumption	4.28E+16	J	8.06E+04	34	104.11
18	Oil	9.53E+16	J	8.90E+04	85	256.34
19	Cement	1.42E+12	g	3.31E+09	47	141.50
20	Electricity	1.21E+16	J	2.77E+05	34	101.31
21	Metals	3.05E+13	g	2.82E+09	862	2,603.20
22	Soil losses	1.97E+13	g	2.82E+09	556	1,679.74
23	Topsoil losses	4.01E+16	J	1.24E+05	50	150.52
IMPORTS AND OUTSIDE SOURCES:						
24	Petroleum products	1.27E+16	J	1.11E+05	14	42.52
25	Fertilizers (N, P and K)	2.57E+10	g	2.87E+09	1	2.23
26	Machinery & equipment	9.07E+10	g	1.13E+10	10	30.82
27	Pulp, paper, wood	1.51E+15	J	1.01E+05	2	4.59
28	Capital goods	6.07E+08	$	3.31E+13	201	606.84
29	Imported services	5.78E+08	$	3.31E+13	191	578.00
30	Foreign aid	7.67E+08	$	3.31E+13	254	767.00

Table 5.1. Emergy evaluation of resource basis for Bolivia, 2005 (Continued)

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value (E6 2005 $)
EXPORTS:						
31	Natural gas	4.04E+17	J	9.88E+04	399	1,205.97
32	Oil	3.43E+16	J	1.11E+05	38	114.99
33	Wood and wood products	7.38E+14	J	6.89E+04	1	1.53
34	Agriculture products	2.47E+16	J	4.00E+05	99	298.15
35	Livestock	4.40E+13	J	8.60E+05	0.4	1.14
36	Metals	2.57E+11	g	1.36E+09	4	10.60
37	Coca leaf	1.60E+10	g	5.48E+10	9	26.41
38	Service in exports	2.53E+09	$	1.50E+12	38	114.47
39	Turism services	2.65E+08	$	1.50E+12	4	12.00
40	External debt	5.13E+08	$	1.50E+12	8	23.24

Footnotes to Table 5.1 appear in Appendix 3

5.1.2.2. Indigenous Renewable Energy

Forest growth, which accounts for 2,285E+20 sej/yr represented almost 54% of all the indigenous energy. Since this value is important for the whole country, the emergy analysis of the forest growth has been performed (Table 5.5) and the calculated solar transformity value was used as the solar transformity for the Bolivian forest growth. Adding agriculture (1,309E+20 sej/yr) and livestock production (561E+20 sej/yr) to the national forest production, the percentage raises to 98%, with the remaining 2% the inputs from hydroelectricity, wood extraction, coca leaf production, fuelwood use, coca leaf consumption, and wood consumption (Table 5.1).

5.1.2.3. Nonrenewable Sources from Within the System

Similar to the indigenous renewable energy sources, three items accounted for almost 90% of the nonrenewable energy: extraction of metals (e.g., gold, silver, tin, cooper, lead, and zinc) occurred at rate of 861E+20 sej/yr; the rate of erosion was valued at 556E+20 sej/yr and natural gas exploitation depleted the non-renewable stock at a rate of 392E+20 sej/yr (Table 5.1).

5.1.2.4. Imports and Outside Sources

The emergy for goods and services imported by Bolivia are unevenly distributed. Since Bolivia is not an industrialized country, imports of capital goods are important to the country and they represented around 30% (201E+20 sej/yr). Imported services which represented 28% of the imports, accounted for 191E+20 sej/yr. The amount of emergy imported in the form of foreign aid (254E+20 sej/yr) was the highest item in this group with 38% and represents the amount of money coming into the country as donations and development projects, which are generally managed by international social-environmental organizations. According to the World Bank, in 2005 Bolivia received $767 million from different countries. Other imports like petroleum products (i.e., highly refined hydrocarbons and diesel fuel) (14E+20 sej/yr), machinery and equipment (10E+20 sej/yr), fertilizers (in the form of N, P and K), and pulp, paper and wood products, combined represented only 4% of the imported sources.

5.1.2.5. Exports

Natural gas has become Bolivia's most important exported good in 2005. The 399E+20 sej/yr exported by the country as natural gas represented 69% of the total emergy exported in 2005. Far behind from natural gas was agricultural products, which represented 18% of the total emergy exported, and was exported at a rate of 99E+20 sej/yr. Figure 5.2 shows all the flows described above.

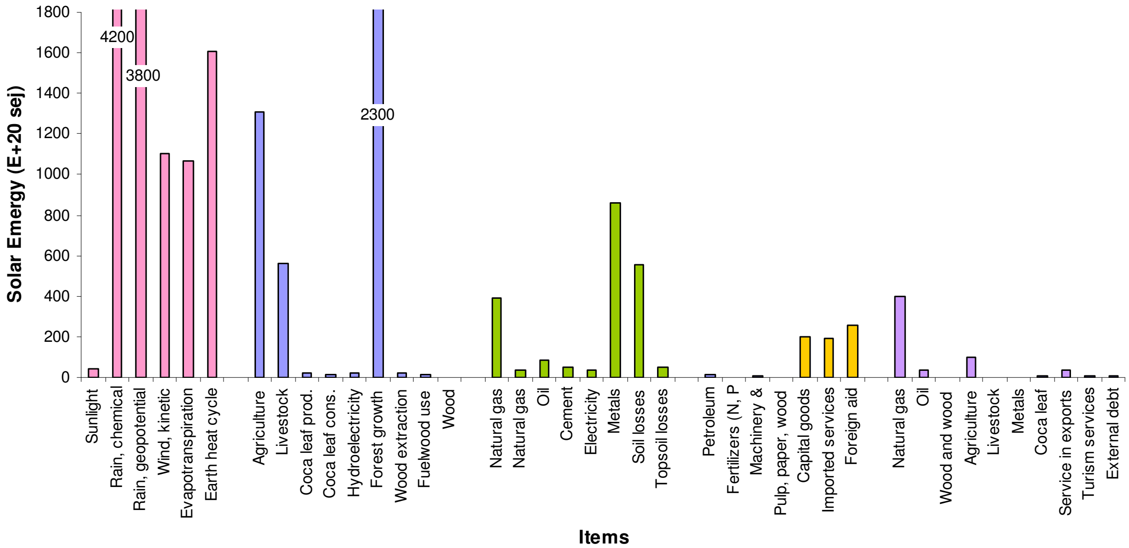


Figure 5.2 Solar emergy of main flows for Bolivia in 2005.

5.1.3. Summary of Emergy Use in Bolivia

Tables 5.2 and 5.3 summarize the emergy flows and show emergy rates of Bolivia during the year 2005. This was obtained by combining items from Table 5.1 into categories that had the same energy source. Figure 5.3 shows a systems diagram defining the letters used in Table 5.2.

For the year 2005 the total emergy-to-dollar ratio of Bolivia was 3.31E+13 sej/$ (P_1 in Table 5.2). By comparison the United States had an emergy-to-dollar ratio of 1.94E+12 sej/$ in 2000, which was 17 times smaller than Bolivia. This meant that for every dollar of economic product generated in Bolivia, 3.31E+13 sej were used.

Much of Bolivia's economy is hidden from money flows and its GDP as shown by the fact that 85% of total emergy comes from free sources, provided by the environment (Item 13). Total emergy free for the U.S. in 2000 was around 41%. The emergy investment ratio of Bolivia was only 1/21st of U.S., meaning that the match between the money economy and the free economy of nature was low. This also indicated that small money investments can return high rewards. Although, when counted by money, Bolivia is poorer than the U.S., by measuring emergy/person (total emergy available per person) Bolivians were doing better than Americans (8.07E+16 versus 6.63E+16 sej/person).

According to the "fraction of electricity used ratio", electricity use of only 0.0039 sej-electric (a measure of development), Bolivia was doing poorly. However, less than 0.5% of its vast geopotential energy was being used to produce electricity. The country could expand sustainable hydroelectric power dams to 10% of geo-stream power and greatly increase its standard of living. The same trend is observed in the per capita fuel use in Bolivia which is 33% of U.S. rate.

Although Bolivia is a heavily forested nation (39% of its renewable emergy was 'funneled' through its natural forest - Item 27 in Table 5.3), the amount of forest harvest emergy used in the country was less than 0.5% (Item 26 in Table 5.3).

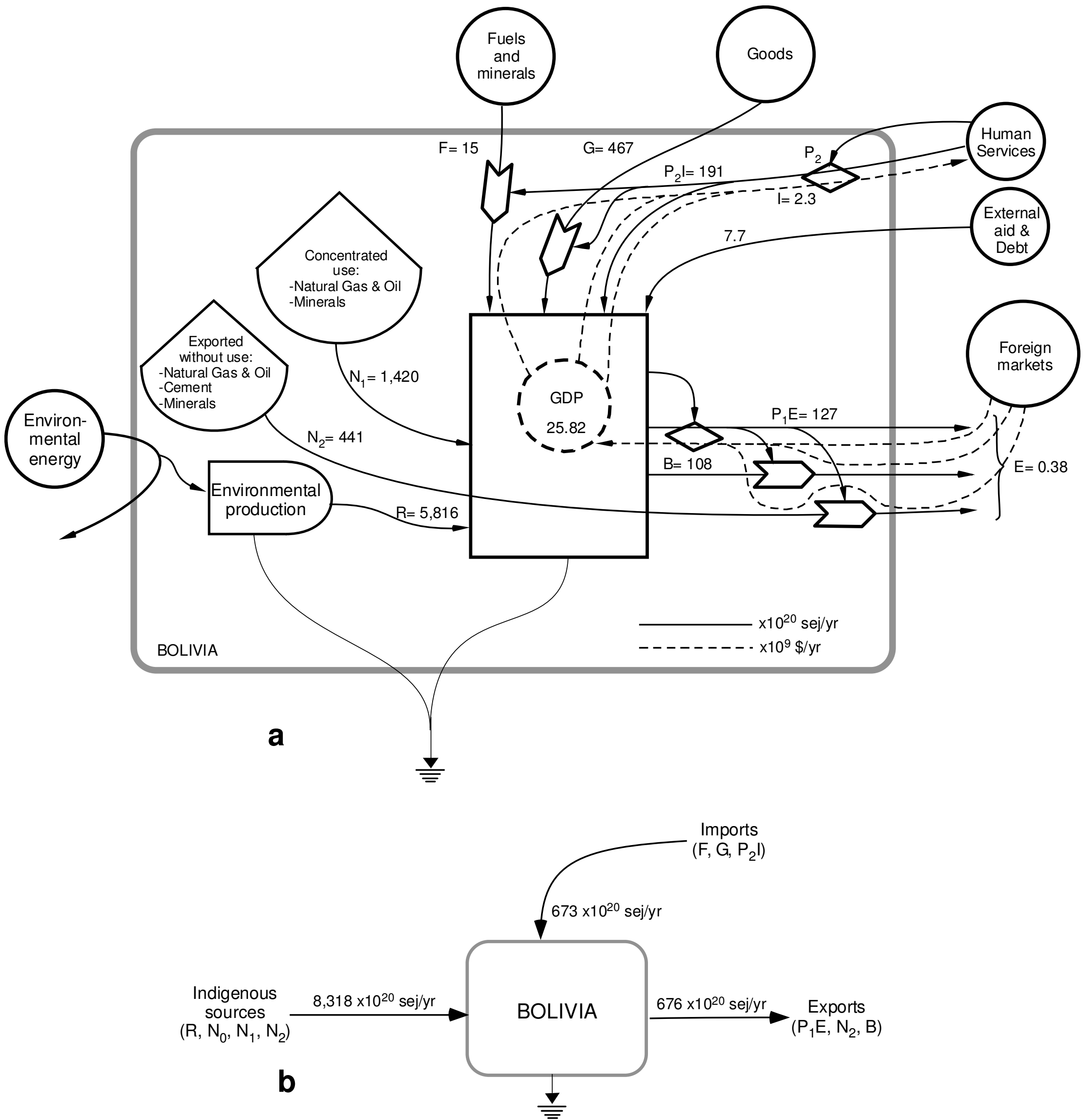


Figure 5.3. a) Aggregated summary diagram of Bolivia national system and b) Summary

Table 5.2. Summary of flows in Bolivia, 2005

Letter	Item	Solar Emergy (E20sej/yr)	Dollars	Comparison to U.S. 2000* (E20sej/yr)
R	Renewable sources (Rain chemical, mountain deep heat)	5,816		22,800
N	Nonrenewable sources flow within Bolivia, (N0+N1+N2)	2,502		57,700
N_0	Dispersed rural source (forestry, soil loss, accelerated sediment loss)	641		1,560
N_1	Concentrated use (natural gas, oil, cement, electricity, minerals)	1,420		53,900
N_2	Exported without use (natural gas, oil, minerals)	441		2,160
F	Imported fuels and minerals (petroleum products)	15		47,600
G	Imported goods (Meat, agricultural products, metals, wood, foreign aid)	467		29,900
I	Dollars paid for imports		2.34E+09	
P_2I	Emergy value of goods and service imports	191		33,100
B	Exported goods (forest products, agricultural products, livestock, coca leaf)	108		
E	Dollars received for exports		2.53E+09	7.74E+11
P_1E	Emergy value of goods and service exports	127		15,000
X	Gross Domestic Product (GDP - $)		2.58E+10	9.76E+12
P_2	U.S. emergy/$ ratio, used in imports	1.50E+12		
P_1	Bolivia Emergy/$ ratio	3.31E+13		1.94E+12
Z	Population	9.83E+06		2.85E+08
	Area (m^2)	1.10E+12		9.16E+12

* (Cohen and Brown, 2007)

Table 5.3. Indices using emergy for overview of Bolivia, 2005

Item	Name of Index	Expression	Quantity (sej/yr)	Comparison to U.S. 2000* (sej/yr)
1	Renewable emergy flow	R	5.82E+23	2.28E+24
2	Flow from indigenous non-renewable reserves	N	2.50E+23	5.77E+24
3	Flow of imported emergy	$F+G+P_2I$	6.73E+22	1.11E+25
4	Total emergy inflows	$R+N+F+G+P_2I$	8.99E+23	1.91E+25
5	Total emergy used, U	$N_0+N_1+R+F+G+P_2I$	8.55E+23	1.89E+25
6	Total exported emergy	P_1E	1.27E+22	1.50E+24
7	Fraction emergy use derived from home sources	$(N_0+N_1+R)/U$	0.92	0.41
8	Imports minus exports	$(F+G+P_2I) - (N_2+B+P_1E)$	1.05E+22	9.34E+24
9	Export to imports	$(N_2+P_1E)/(F+G+P_2I)$	0.84	0.16
10	Fraction used, locally renewable	R/U	0.68	0.12
11	Fraction of use purchased	$(F+G+P_2I)/U$	0.08	0.59
12	Fraction imported service	P_2I/U	0.02	0.18
13	Fraction of use that is free	$(R+N_0)/U$	0.85	0.41
14	Ratio of concentrated to rural	$(F+G+P_2I+N_1)/(R+N_0)$	0.32	6.75
15	Use per m^2	U/(area)	7.78E+11	2.06E+12
16	Use per person	U/population	8.70E+16	6.63E+16
17	Carrying capacity: use renewables only to remain at present living standard	(R/U) (population)	6.68E+06	3.44E+07
18	Standard of living if current population supported with only renewables	R/population	5.92E+16	8.00E+15
19	Ratio of use to Gross Domestic Product empower per dollar flow	$P_1=U/GDP$	3.31E+13	1.94E+12

* (Cohen and Brown, 2007)

Table 5.3. Indices using emergy for overview of Bolivia, 2005 (Continued)

Item	Name of Index	Expression	Quantity (sej/yr)	Comparison to U.S. 2000* (sej/yr)
20	Ratio of electricity to use	(el)/U	0.0039	0.17
21	Fuel use per person	fuel/population	5.00E+15	1.5E+16
22	Environmental Loading Ratio (ELR)	$(N_0+N_1+F+G+P_2I)/R$	0.47	7.28
23	Use to Import Ratio (UIR)	$U/(F+G+P_2I)$	12.71	1.71
24	Emergy Sustainability Index (ESI)	(UIR/ELR)	27.03	0.23
25	Purchased to indigenous renewable	$(F+G+P_2I)/R$	0.13	4.86
26	Fraction of use from forest	(forest extraction/U)	0.0041	
27	Fraction of R captured by forest	(forest growth/R)	0.39	

* (Cohen and Brown, 2007)

5.2. Emergy Analysis of Bolivian Forestry

Figure 2.1 shows the distribution of forest land in Bolivia which, according to the latest assessment made by the Food and Agriculture Organization of the United Nations, covers approximately 58.74 million ha, nearly half of the national territory.

The emergy analysis of Bolivian forestry included emergy analysis of the national forestry system, as well as evaluation of five (5) individual sectors: forest growth, logging industry, certified logging industry, wood-based panel industry, and coca leaf production. Emergy evaluations are shown in tables and summarized in energy systems diagrams.

5.2.1 Emergy Analysis of the National Forestry System

Figure 5.4 shows the energy system diagram for the emergy evaluation of Bolivian national forestry system. The major environmental energies driving Bolivia's forests' production comprise solar insolation, winds, rainfall, earth cycle, nutrient inputs from rock weathering and atmospheric sources. Trees and understory plants from the forests are used for wood or as a source for non-timber forest products (NTFP). In its raw form those can be used in the country, exported or can go through a manufacturing process and be used in the domestic market. In order to obtain and trade forest products, Bolivia needs to import goods, mainly machinery to carry out the different phases in the forestry processes. Services from outside the country are also imported, mainly as technical assistance for machinery repairing, specialized forestry technicians and forest management planners.

The largest amount of emergy coming from renewable sources to the forestry system is from rain as chemical and geopotential energy contributing 3,433E+20 sej/yr. Evapotranspiration, the source of forest formation provided an empower of 1,210E+20 sej/yr (Table 5.4). The money paid for imported services for non-timber forest products (NTFPs) was higher than the money paid for services to harvest timber products (213E+20 sej/yr and 44E+20 sej/yr respectively) due to the fact that NTFPs' harvesting and processing is a labor intensive process.

Inputs for internal processes come to the forestry emergy budget from the net primary production. Biomass accumulating at the rate of 7.34 MT/ha/yr (Jordan, 1983) provides with an empower of 2,286E+20 sej/yr. Other sources that participate (in a minimal percentage) in the internal processes are soil erosion with 0.19E+20 sej/yr and wood loss with 2.25E+20 sej/yr; both adding less than 0.5%.

Emergy use from forest products was calculated according to the final market: domestic and international. Observing these results separately, can be seen that timber without service sold at domestic markets shows the higher empower with 12.61E+20 sej/yr which represents 53% of the total forest products use in Bolivia. This figure represents fuelwood consumption and wood used in construction without previous treatment or value added. The second place goes to the consumption of non-timber products with 9.65E+20 sej/yr (40%) and finally the use of timber with service, representing only 7%.

Non-timber forest products (NTFP) are the most important goods exported from the Bolivian forests. The 0.87E+20 sej/yr that the country exported in NTFPs represented almost 68% of the total emergy exported from its forests in 2005. Manufactured wooden products (timber with service) represented 31% of the total emergy exported in the forestry sector (0.39E+20 sej/yr) and, exports of timber without service represented only 0.9% of the total exports with 0.01E+20 sej/yr.

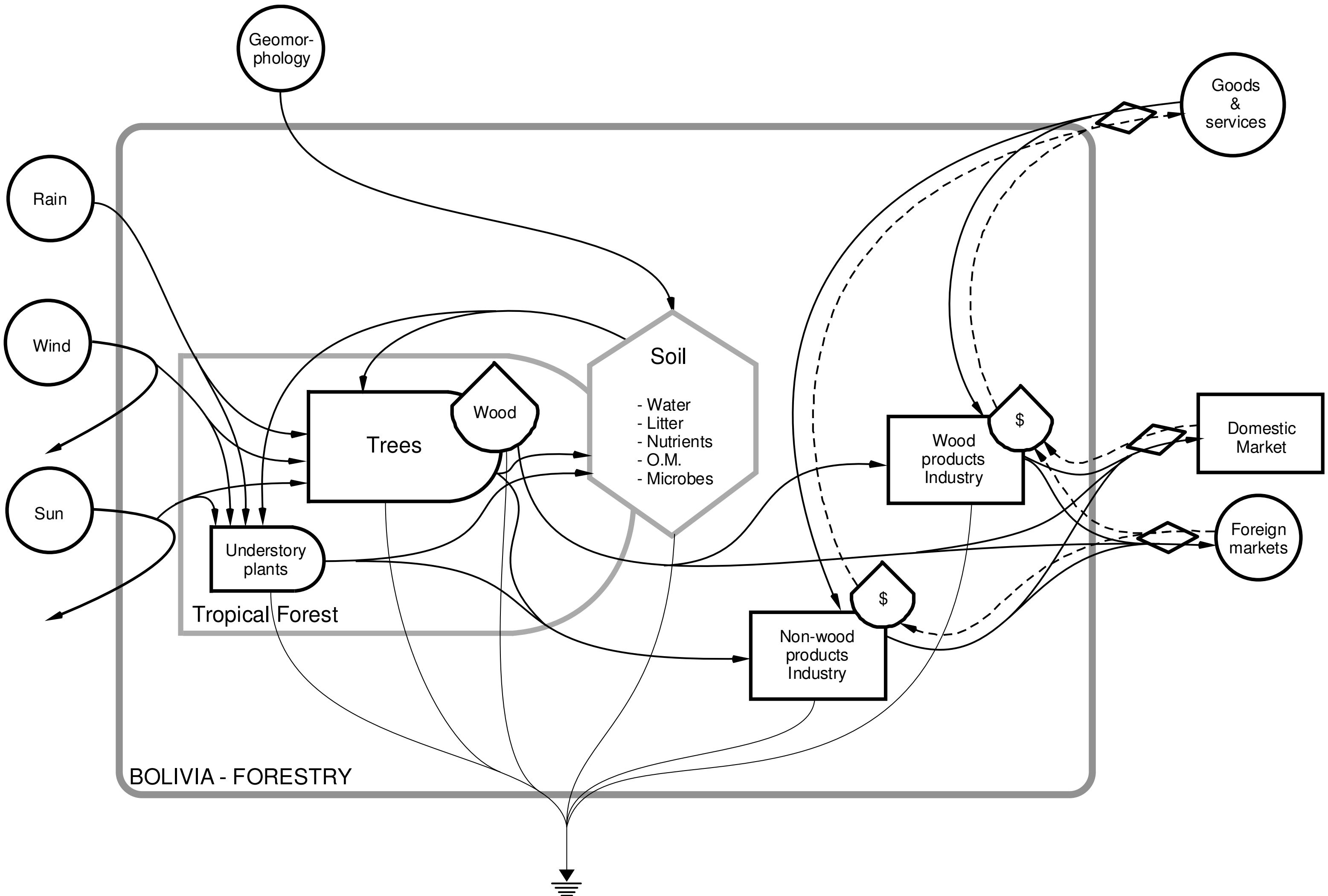


Figure 5.4. Emergy diagram for the Bolivian forestry system

Table 5.4. Emergy evaluation of the Bolivian forestry system, 2005

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value (E6 2005 $)
RENEWABLE RESOURCES:						
1	Sunlight	2.19E+21	J	1	22	66
2	Rain, chemical	1.13E+19	J	3.05E+04	3,433	10,368
3	Rain, geopotential	6.98E+18	J	8.89E+03	620	1,873
4	Wind, kinetic	2.34E+19	J	2.52E+03	589	1,779
5	Evapotranspiration	4.67E+18	J	3.05E+04	1,425	4,303
6	Earth Cycle	1.51E+18	J	3.40E+04	512	1,548
IMORTED ENERGY SOURCES						
7	Timbering, services	1.32E+08	$	3.31E+13	44	132
8	Timbering, fuels	1.21E+14	J	4.80E+04	0.06	0.18
9	Non-timber forest products services	6.44E+08	$	3.31E+13	213	644
INTERNAL PROCESSES						
10	NPP - aboveground coarse wood	8.28E+18	J	2.76E+04	2,286	6,903
11	Soil erosion	2.50E+14	J	7.40E+04	0.19	1
12	Wood lost	3.83E+15	J	5.88E+04	2	7
DOMESTIC USE						
13	Timber without service	2.14E+16	J	5.88E+04	13	38
14	Timber with service	3.12E+15	J	5.30E+04	2	5
15	Non-timber forest products	2.91E+07	$	3.31E+13	10	29
EXPORTS						
16	Timber without service	1.90E+13	J	5.88E+04	0.01	0.03
17	Timber with service	7.44E+14	J	5.30E+04	0.39	1
18	Non-timber forest products	5.81E+07	$	1.50E+12	1	3

Footnotes to Table 5.4 appear in Appendix 4

Figure 5.5 illustrates all the emergy flows in the forestry system in Bolivia for the year 2005

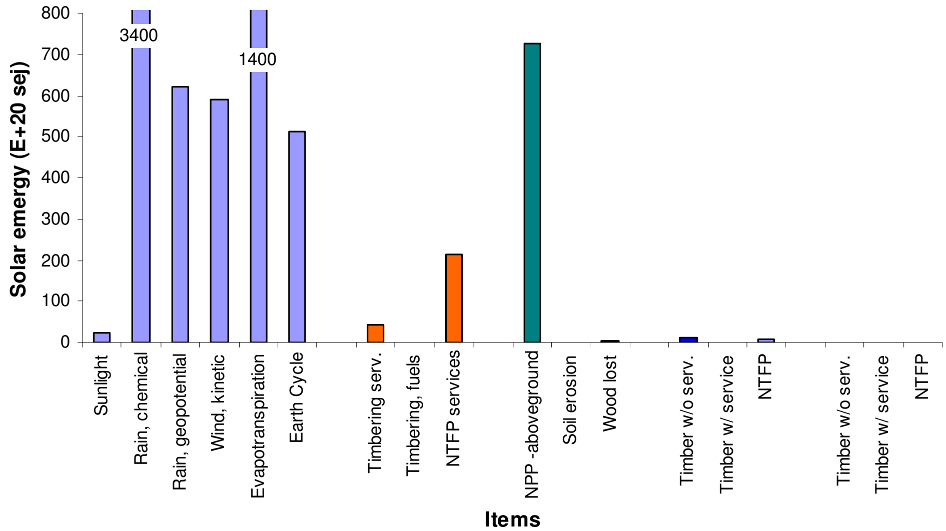


Figure 5.5. Solar emergy of main emergy flows in the Bolivian forestry system, 2005

5.2.2. Emergy Analysis of Forest Growth

Table 5.5 and Figure 5.6 show the emergy evaluation of forest growth in Bolivia for the year 2005. Forest growth was a function of evapotranspiration, and geologic weathering. Evapotranspiration (entering the system as rainfall), represented 2/3 of the total emergy input.

Both sources gave the value of the transformity of the Bolivian forest growth (2.7E+4 sej/J), which was used as the transformity of wood biomass in emergy evaluations of Bolivia's forestry system, non-certified timber, certified timber and wood-based panels. All the calculations preformed during this analysis can be seen in the Appendix 5 (footnotes of Table 5.5).

Table 5.5. Emergy evaluation of forest growth in Bolivia, 2005

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value (E6 2005 $)
FOREST GROWTH						
1	Sunlight	2.19E+21	J	1	22	66
2	Evapotranspiration	4.67E+18	J	30,500	1,425	4,303
3	Earth heat cycle	1.51E+18	J	57,120	861	2,600
4	Soil erosion	2.50E+14	J	74,000	0.19	1
	Sum of 2 and 3				2,286	6,904
5	Forest growth	8.28E+18	J			
6	Forest growth, transformity			27,615		

Footnotes to Table 5.5 appear in Appendix 5

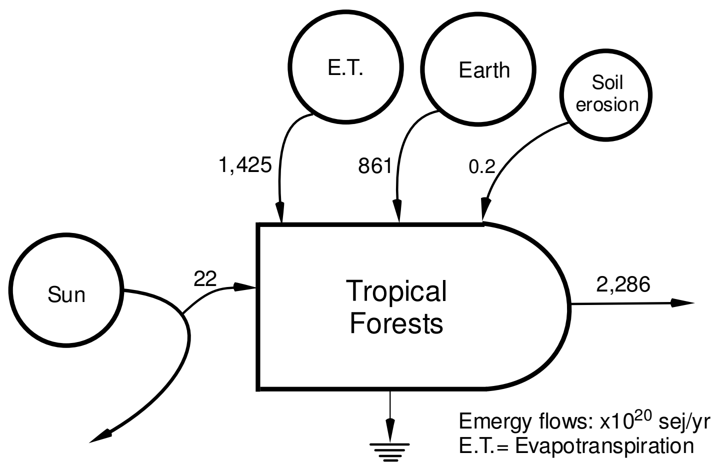


Figure 5.6. Systems diagram of emergy inputs for the Bolivian forest growth, 2005

5.2.3. Emergy Analysis of Bolivian Logging Industry

The emergy evaluation of the Bolivian logging industry is shown in Table 5.6, its footnotes in Appendix 6 and Figure 5.7.

Table 5.6. Emergy evaluation of logging industry in Bolivia, 2005

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value (2005 $)
Logging						
1	Services	1.32E+08	$	3.31E+13	43.79	1,322.5
2	Biomass	2.94E+16	J	2.76E+04	8.12	245.1
3	Fuels	1.21E+14	J	4.80E+04	0.06	1.8
4	Electricity	7.69E+13	J	1.60E+05	0.12	3.7
	Sum of 1-4				52.09	1,573.0
5	Timber output	1.38E+06	J			
6	Timber output transformity			8.49E+15		
7	Emergy/$ ratio for logs	3.94E+13	sej/$			

Footnotes to Table 5.6 appear in Appendix 6

The energy of human services is by far the most important input to this system with 84% of the total. Wood biomass contribution was about 16% and the other two items: fuels and electricity contributed less than 1%. Total transformity for harvested and transported logs was 3.78E+15 sej/J.

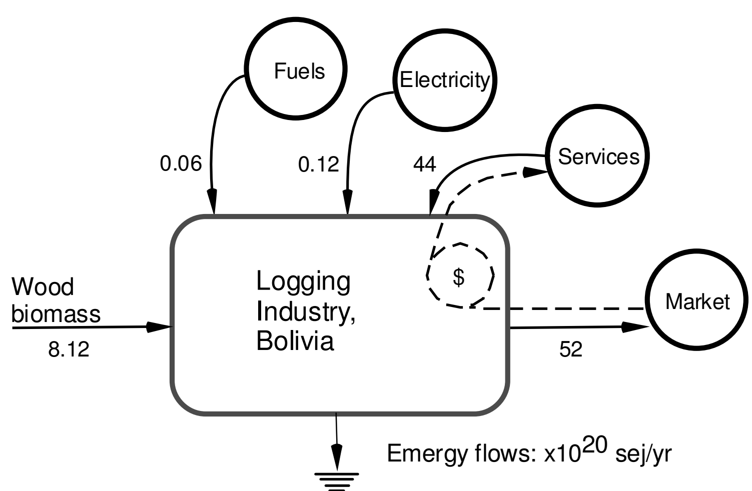


Figure 5.7. Systems diagram of emergy inputs for the logging industry, 2005

5.2.4. Emergy Analysis of the Wood-based Panel Industry in Bolivia

Wooden panels' production shown in Table 5.7 and Figure 5.8, involved 79E+20sej/yr of services, which was more than any other input including logs biomass (1.08E+20 sej/yr). The solar transformity of wood-based panels was 4.41E+16 sej/J.

Table 5.7. Emergy evaluation of wood-based panel industry in Bolivia, 2005

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value (E6 2005 $)
Logging						
1	Services	2.40E+08	$	3.31E+13	79.52	240
2	Biomass	3.92E+15	J	2.76E+04	1.08	3.27
3	Fuels	1.21E+14	J	4.80E+04	0.06	0.18
4	Electricity	1.54E+14	J	1.60E+05	0.25	0.74
	Sum of 1-4				80.90	244
5	Timber output	1.84E+05	J			
6	Timber output transformity			4.41E+16		
7	Emergy/$ ratio for logs	3.37E+13	sej/$			

Footnotes to Table 5.7 appear in Appendix 7

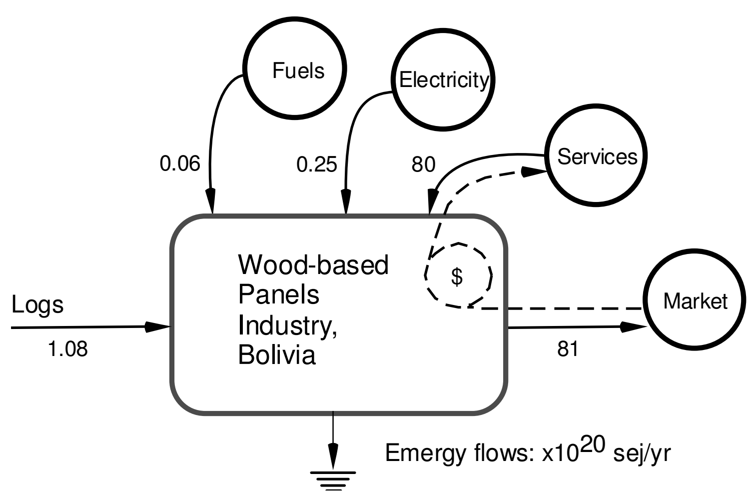


Figure 5.8. Systems diagram of emergy inputs for the wood-based panel industry, 2005

5.2.5. Emergy Analysis of Coca Leaf Production in Bolivia

Emergy requirements for production of coca leaf in Bolivia are shown in Table 5.8 and Figure 5.9.

Table 5.8. Emergy evaluation of coca leaf production in Bolivia, 2005

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value (E6 2005 $)
1	Sun	9.45E+17	J	1	0.01	0.03
2	Evapotranspiration	2.02E+15	J	1.54E+04	0.31	0.94
3	Soil used	3.20E+13	J	7.40E+04	0.02	0.07
4	Supplies	1.19E+07	$	3.31E+13	3.94	11.89
5	Tools	1.52E+05	$	3.31E+13	0.05	0.15
6	Labor	7.86E+13	J	2.11E+07	16.62	50.19
	Sum of 2 to 6				21	63.24
7	Coca leaf output	7.18E+14	J			
8	Coca leaf output	4.90E+10	g			
9	Transformity of coca leaf (sej/J)			2.92E+06		
10	Coca leaf output (sej/g)			4.27E+10		

Footnotes to Table 5.8 appear in Appendix 8

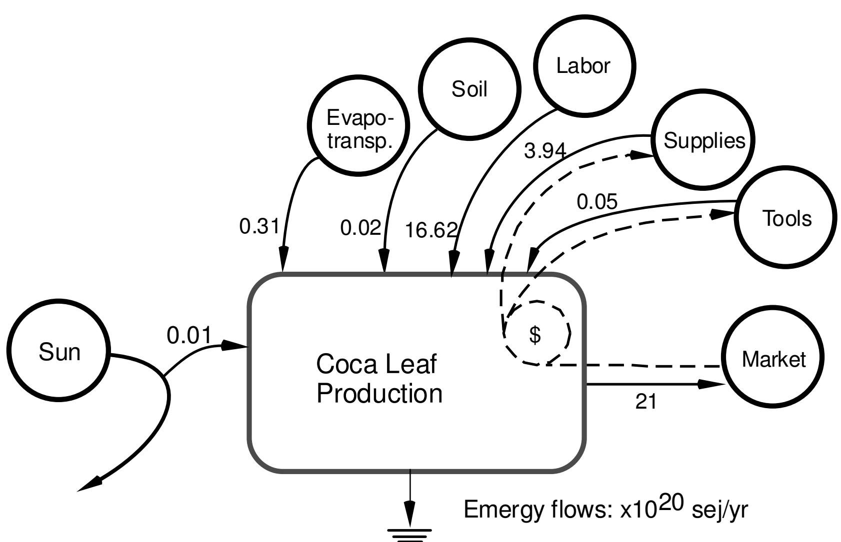


Figure 5.9. Systems diagram of emergy inputs for the coca leaf production, 2005

Labor was the greatest source of emergy with almost 79% of the total (16.62E+20 sej/yr) followed by supplies (e.g., fertilizers and pesticides) with 3.94E+20 sej/yr representing 19% of the total. The remaining 2% was almost evenly distributed among evapotranspiration, soil used and tools imported. The solar transformity of coca leaf production was 2.92E+06 sej/J.

5.3. Emergy Analysis of Bolivian Natural Gas

At the time of dissertation submission, this section has been published in Emergy Synthesis 3: Theory and Applications of the Emergy Methodology, titled “Emergy Analysis of Bolivia’s Natural Gas” (Izursa and Tilley, 2005).

Bolivia has traditionally been a mining country that produced antimony, bismuth, copper, gold, lead, silver, tin, tungsten, and zinc. It has large reserves of gold, lithium and iron ore. In 2000, Bolivia exported $429 million worth of minerals, one third of total exports (Vice Ministerio de Minería y Metalurgia, 2000). Mining of non-fuel minerals remains important to date and provides a considerable income to the country. Agriculture, forestry, fishing, oil and gas provided one-fourth of the country’s legitimate gross domestic product (GDP) (Fox, 2000).

Bolivia’s proven reserves of natural gas jumped 730% from 3.75 trillion cubic feet (tcf) to 27.4 tcf from 1997 to 2002 (Table 5.9). If valued at 2002’s well-head price of approximately $5 per thousand cubic feet (mcf), the reserves for that year would be worth $137 billion. In a country with an annual GDP of $25.82 billion and the second lowest per capita GDP in the Western Hemisphere, this offers a tremendous opportunity for spurring economic development that could be sustainable if integrated with investment in social, educational and technological institutions. The opportunity is so great that it has the power to change the structure of the Bolivian economy for decades to come, offering the country the opportunity to support its own development.

However, not all of the structural economic changes would be positive. Evidence from around the world generally indicates that countries like Bolivia, rich in natural resources but undeveloped economically, tend not to do economically as well as countries poor in natural resources (Sachs and Warner, 1997). Auty (1997; 1998) shows that between 1960 and 1990 per capita incomes of resource deficient countries grew two to three times faster than those of resource rich countries. Natural resource rich countries also tend to have stunted manufacturing sectors (Auty and Mikesell, 1998); have less product diversification (Duncan, 1993); be more prone to political problems; experience slower accumulation of technical skills (Wood and Berge, 1997) mainly due to deficient training programs; develop less social and institutional capital; suffer higher levels of corruption and unproductive rent (Karl, 1997); and have a higher degree of economic inequality (Leamer *et al.*, 1998).

Emergy evaluations of nations and their trading policies often have shown that countries rich in natural resources lose when they trade with developed economies (Odum and Arding, 1991; Scatena, 2002). Emergy (with an “m”) represents an energy-based measure of the contribution and potential influence a given input has on a productive process and is defined as the energy of one type (in this case solar) required to produce a flow or storage of another type (Odum, 1996). Calculations of emergy production and storage provide a basis for making choices about environment and economy following the general public policy of maximizing real wealth, production and use of non-renewable resources.

In our on-going emergy study of Bolivia (Izursa and Tilley, 2003), we found that the country as a whole was losing in international trade at a rate of 12.2 to 1. That is, Bolivia exported 12.2 emdollars of resources and goods for every $1 it received in foreign exchange. Stated another way, Bolivia could improve its long-term economic condition if it developed a greater capacity for transforming its natural resources via domestic production rather than exporting them for cash. Obviously, some foreign capital investment is required because Bolivia is deficient in technical expertise. For example, large inflows ($1.4 billion) of foreign investment were necessary to capitalize the Yacimientos Petrolíferos Fiscales Bolivianos (state petroleum company), which increased oil and gas exploration (Andersen and Faris, 2002). Trade contracts like the one the Bolivian government signed with neighboring Brazil in 1999 to deliver 7.1 tcf of natural gas over the next 20 years may not be in Bolivia's best interest if the hopes of some trade unions are accepted (Chávez, 2004). There have also been efforts by the Bolivian government to export liquefied natural gas (LNG) to Mexico and the United States (EIA, 2004).

The objectives of our analysis were to evaluate whether Bolivia as a country was benefiting from its export of natural gas and to compare Bolivia's stocks and flows of natural gas to its forest resources to estimate the potential for sustainable economic development.

Table 5.9. Historic view of Bolivian reserves of natural gas

	1997	1998	1999	2000	2001	2002
Proved (P1)	3.75	4.16	5.28	18.31	23.84	27.36
Probable (P2)	1.94	2.46	3.3	13.9	22.9	24.93
P1+P2	***5.69***	***6.62***	***8.58***	***32.21***	***46.74***	***52.29***
Possible (P3)	4.13	3.17	5.47	17.61	23.18	24.87
P1+P2+P3	***9.82***	***9.79***	***14.05***	***49.82***	***69.92***	***77.16***

Source: (OLADE, 2003) Units are Trillion Cubic Feet (TCF)

Figure 5.10. Map of Bolivia.
Taken from CIA (2005)

5.3.1. Methods

Bolivia is the fifth largest South American country in terms of surface area and one of only two land-locked nations in the continent (Figure 5.10). Just over eight million people live in an area of approximately 110 million hectares. Population density is the lowest in South America, at 7.1 people per square kilometer.

Urbanization is also lower than the regional average: 67% of the population lives in urban centers, compared to 79% for South America as a whole. Bolivia is the poorest country in South America. The per capita GDP was estimated at $2,534 for the year 2002, representing about one-third of the regional average of $7,154 (CIA, 2005).

5.3.1.1. Emergy modeling

We used the standard emergy methodology given by Odum (1996) to evaluate Bolivia's natural gas system. That is, flows of money and energy were translated to solar emergy by multiplying money flows by Bolivia's mean national emergy-to-dollar ratio and multiplying energy flows by their respective solar transformities (solar emjoules per joule, sej/j). Export and import values were taken from the CIA Factbook (CIA, 2005). The emergy to dollar ratio of Bolivia (5.95 E12 sej/$) was estimated and the solar transformities were taken from Odum (1996), Brown and Bardi (2001) and Romitelli (2000).

5.3.2. Results and discussion

Figure 5.11 emphasizes the important economic role of two of Bolivia's largest natural resources, gas reserves and forest ecosystems. Gas reserves and forest resources offer the potential to support a thriving Bolivian economy, building economic assets that feedback to amplify development.

The current situation relies heavily on foreign loans and investments to build economic assets and requires that Bolivia develop international trade. This has led the country to increase exports of it natural resources. The country's domestic energy infrastructure and market are presently small, but the interaction potential of the gas and forest resources to spur economic development is large. In a globe approaching limited supplies of petroleum and a fear of exceeding the atmosphere's assimilative capacity of carbon, natural gas is an increasingly attractive fuel.

Figure 5.12 summarizes the stocks and flows of the country's main natural resources. Bolivia exports a large amount of its natural capital, not only its natural gas but also precious metals, forest logs, agricultural produce, and crude oil. In Figure 5.12, we can see that many of the abundant natural resources are exported at a rate exceeding domestic consumption. For example, only 32% of natural gas is consumed within the country. Although data on mineral (i.e., gold and silver) production is incomplete, the amount that we could account for was exported. Bolivia does import some refined petroleum products. Tables 5.10 and 5.11 provide details on the emergy values of the flows and storages, respectively, of Bolivia in 2001. Footnotes for these tables are shown in Appendices 9 and 10 respectively.

Figure 5.13 summarizes Bolivia's overall trade and natural gas trade in units of dollars and solar emjoules in 2001. In Figure 5.13a, we see that Bolivia's GDP was $21.2 billion, while it paid $1.72 billion for imports and received $1.29 billion for exports. Along with each flow of money is a counter flow of emergy. Bolivia imported 25.9 E20 sej and exported 337 E20 sej. Figure 5.13b shows that Bolivia exported 76% of its produced natural gas. Bolivia exported $78.3 million of gas which was the equivalent of 43.8 E20 sej.

The overall net emergy exchange ratio between Bolivia and its trading partners was 12.2 to 1, which was found by dividing the total exported emergy [337 E20 sej + ($1.72 E9 x 5.95 E12 sej/$) = 439 E20 sej] by the total imported emergy [25.9 E20 sej + ($1.29 E9 x 0.8 E12 sej/$) = 36.2 E20 sej] (see Figure 5.13a). The net emergy exchange ratio for the natural gas trade was worse than the country's overall position. Using an emergy-to-dollar ratio of 4.82 E12 sej/$ for Brazil (Comar, 1998), we estimated that Bolivia exported 12.53 emdollars of natural gas for each $1 it received.

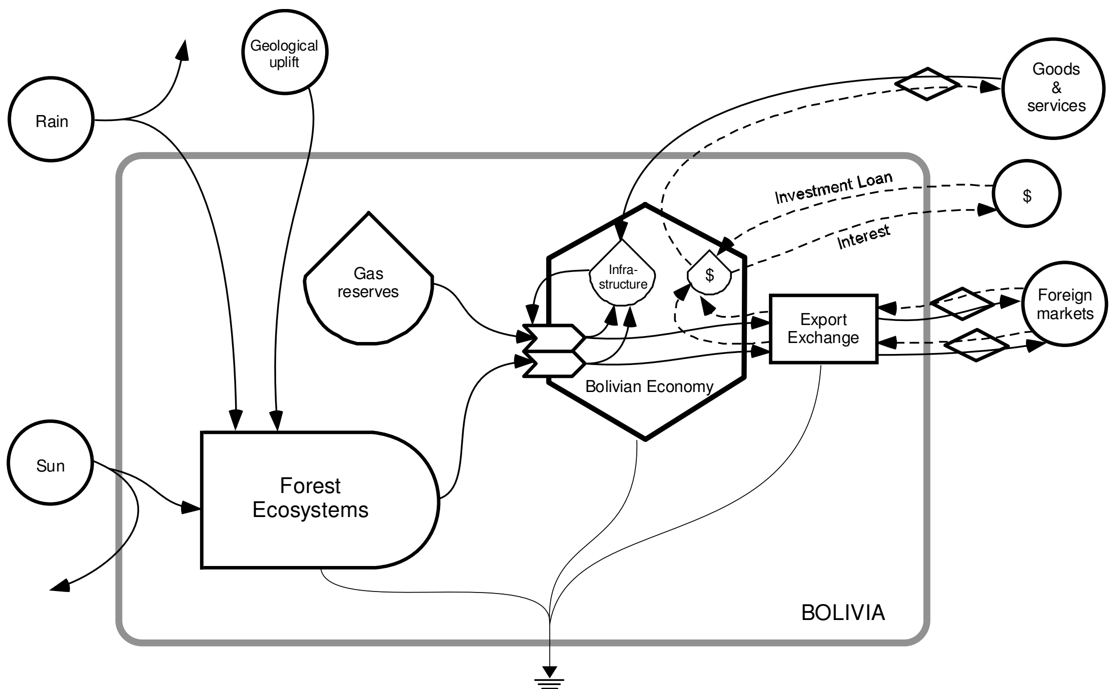


Figure 5.11. Emergy systems diagram for the Bolivian natural resources trade

From Tables 5.10 and 5.11, we can deduce that the natural gas being internally used and exported at current rates, could last about 340 years; but if natural gas exports stop and it is used domestically at Bolivia's current capacity, it could last three times more (about 1040 years).

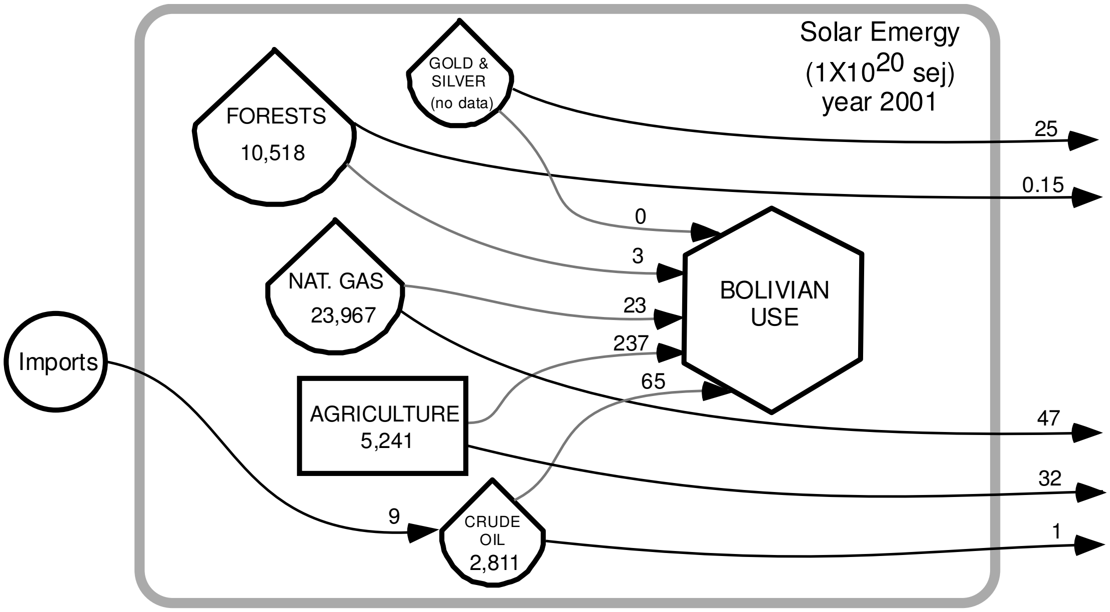


Figure 5.12. Energy systems diagram of the main emergy flows and stocks in Bolivia, 2001

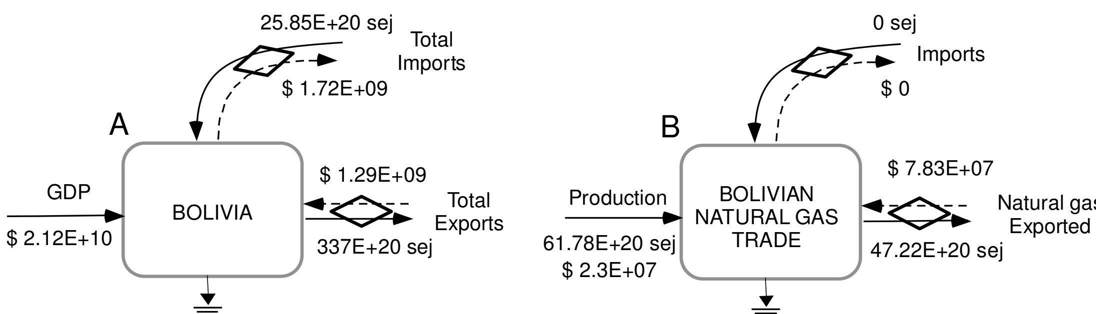


Figure 5.13. A) Energy and economic balance of Bolivian trade. B) Trade in Natural Gas, 2001

Table 5.10. Annual emergy value of important resource flows in Bolivia, 2001

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)
1	NG domestic use	4.84E+16	J	48,000	23.23
2	NG exported	8.03E+16	J	58,800	47.22
3	Oil products domestic use	9.86E+16	J	6.60E+04	65.05
4	Oil exported	1.93E+15	J	5.30E+04	1.02
5	Cash crops domestic use	1.18E+17	J	2.00E+05	236.77
6	Cash crops exported	1.62E+16	J	2.00E+05	32.44
7	Livestock exported	1.54E+14	J	2.00E+06	3.08
8	Forest products domestic use	2.97E+16	J	9.86E+03	2.93
9	Forest products exported	4.29E+14	J	3.50E+04	0.15
10	Gold exported	1.32E+07	g	1.32E+14	17.40
11	Silver exported	2.39E+09	g	3.29E+11	7.85

Footnotes to Table 5.10 appear in Appendix 9

Table 5.11. Emergy value of the main storages of Bolivian natural capital, 2001

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)
1	Soil organic matter	7.08E+18	J	7.40E+04	5,241
2	Forests	1.07E+20	J	9.86E+03	10,518
3	Natural gas	4.99E+19	J	4.80E+04	23,967
4	Crude oil	5.21E+18	J	5.40E+04	2,811
5	Gold and Silver	Unreliable sources for stocks			

Footnotes to Table 5.11 appear in Appendix 10

5.3.3. Conclusion

Clearly there is a substantial potential for increased gas production, consumption and exportation in Bolivia. In South America, natural gas demand is increasing at rates above the world average and this trend is expected to continue in the next decade (Andersen and Faris, 2002). However, rather than consider export the prime use of its natural gas, Bolivia should examine the potential that gas may offer for achieving a prosperous, and perhaps sustainable independence that will minimize the amount of borrowing and consequently the amount of debt. Bolivians could improve their economic condition if they invest in the infrastructure needed to explore, produce, refine, distribute and use the gas. When gas is exported, the nation loses more value than it receives in return as payment. To combine the use of its newly discovered gas with its vast reserves of primary forests, Bolivia must invest in its human and technological capital. It needs to train and retain engineers and scientists that can lead the effort to make Bolivia's economy sustainable and independent. Important questions for Bolivia and Bolivians to address are how do we develop a self-sufficient, sustainable economy, and what is the proper mix of export and import in international trade which can provide a level of capital investment that allows the economy to develop and people to prosper, but does not deplete the country's principle attribute.

5.4 Update on Bolivia's overall trade

Figure 5.14 represents an actualized summary for the stocks and flows of the country's main natural resources as for 2005. Comparing with the results obtained for 2001 (Figure 5.12) it can be observed that Bolivia increased the exports of its natural capital, especially natural gas (by 5 times). But there was a small decrease in the emergy export of precious metals (gold and silver). It can also be seen that export of natural resources exceeds domestic consumption; again, natural gas is an example of this behavior. These values were obtained using the emergy evaluations depicted in

Tables 5.12 for the flows and Table 5.13 for the stocks. Footnotes with their calculations are shown in Appendices 11 and 12 respectively. Figure 5.15 shows how the annual emergy values of important resources in Bolivia changed during the period 2001 -2005. Cash crops account for the largest item in both years with an increment of 13% in the year 2005. Without a doubt, exports of natural gas, increased largely, going from 47E+20 sej in 2001 to 238E+20 sej in 2005.

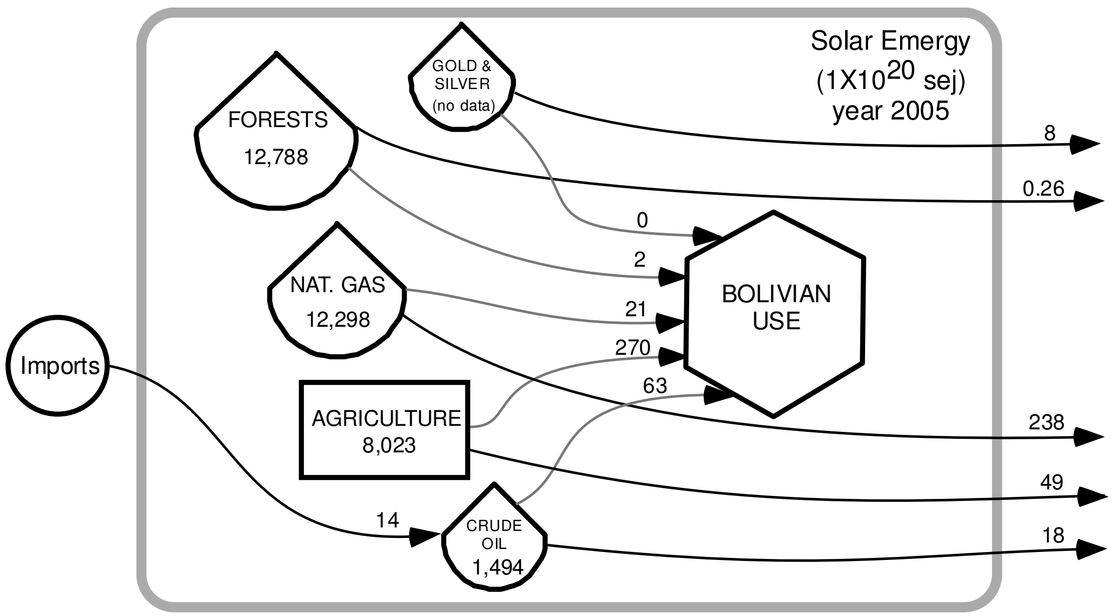


Figure 5.14. Energy systems diagram of the main emergy flows and stocks in Bolivia, 2005

Figure 5.16, is a comparison of Bolivia's overall trade units of dollars and solar emjoules for 2001and 2005. Along with each flow of money is a counter flow of emergy. We see that Bolivia's GDP went from $21.2 billion in 2001 to $25.8 billion in 2005. Total imports also increased, from $1.72 billion in 2001 to $2.34 billion in 2005. Exports also increased, going from $1.29 billion in 2001 to $2.53 billion in

2005. Along with the money received, the emergy accounted for these transactions were 337E+20 sej and 549E+20 sej in 2001 and 2005 respectively.

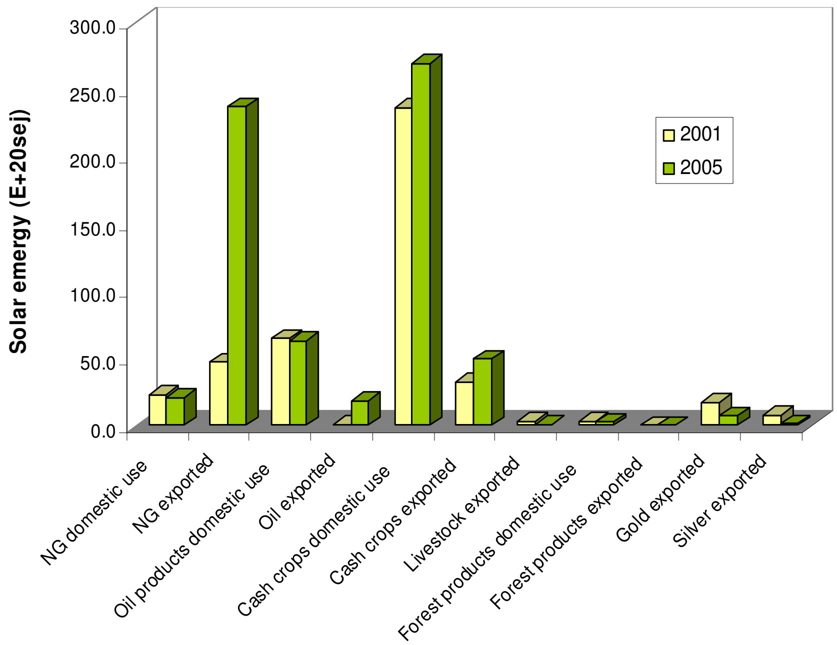


Figure 5.15. Changes in the use and export of major natural resources from 2001 to 2005.

Table 5.12. Annual emergy value of important resource flows in Bolivia, 2005

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)
1	NG domestic use	4.84E+16	J	48,000	20.52
2	NG exported	8.03E+16	J	58,800	237.69
3	Oil products domestic use	9.86E+16	J	6.60E+04	62.92
4	Oil exported	1.93E+15	J	5.30E+04	18.20
5	Cash crops domestic use	1.18E+17	J	2.00E+05	269.86
6	Cash crops exported	1.62E+16	J	2.00E+05	49.36
7	Livestock exported	1.54E+14	J	2.00E+06	0.88
8	Forest products domestic use	2.97E+16	J	9.86E+03	2.33
9	Forest products exported	4.29E+14	J	3.50E+04	0.26
10	Gold exported	1.32E+07	g	1.32E+14	7.07
11	Silver exported	2.39E+09	g	3.29E+11	1.31

Footnotes to Table 5.12 appear in Appendix 11

Table 5.13. Emergy value of the main storages of Bolivian natural capital, 2005

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E20 sej)
1	Soil organic matter	1.08E+19	J	7.40E+04	8,023
2	Forests	1.30E+20	J	9.86E+03	12,788
3	Natural gas	2.56E+19	J	4.80E+04	12,298
4	Crude oil	2.77E+18	J	5.40E+04	1,494
5	Gold and Silver	Unreliable sources for stocks			

Footnotes to Table 5.13 appear in Appendix 12

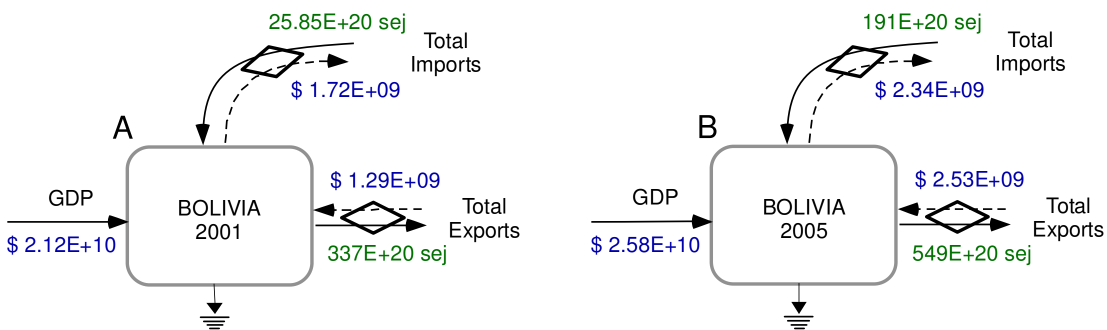


Figure 5.16. Summary of GDP, imports and exports in Bolivia in 2001 and 2005.

Table 5.14. Changes in the annual emergy value of important resource flows in Bolivia, from 2001 to 2005

Item	2001	2005	Variation
NG domestic use	23.2	20.5	-12%
NG exported	47.2	237.7	403%
Oil products domestic use	65.1	62.9	-3%
Oil exported	1.0	18.2	1681%
Cash crops domestic use	236.8	269.9	14%
Cash crops exported	32.4	49.4	52%
Livestock exported	3.1	0.9	-71%
Forest products domestic use	2.9	2.3	-20%
Forest products exported	0.2	0.3	72%
Gold exported	17.4	7.1	-59%
Silver exported	7.9	1.3	-83%

It was found that the overall net emergy exchange ratio between Bolivia and its trading partners was changed from 12.2 to 1 in 2001 to 6.3 to 1 in 2005. For both years, it was found by dividing the total exported emergy by the total imported emergy (Figure 5.16). Table 5.14 summarizes the ratio of change (expressed in percentage) of the annual emergy value of important resource flows in Bolivia from 2001 to 2005. Oil exports are the most changed with an increase of almost 20 fold. Silver and livestock exports had decreased at higher rates than other resources, with 83% and 71% respectively.

Chapter 6: Emergy Analysis of Bolivian Certified Forestry

6.1. Introduction

Forestry in Bolivia have been characterized by lack of planning and management (i.e., excessive and unnecessary construction of forest roads, excessive use of heavy machinery, excessive collateral damage, inefficient milling processes and waste of residues) placing a few valuable species, such as mahogany (Swietenia macrophylla King) at levels of threat of extinction (Bawa and Seidler, 1998; Rice et al., 1997).

As part of an important strategy in response to Bolivian and international concern over the ecological and economic sustainability of harvesting its forests (Bennett, 2001) sustainable forestry production systems, such as certified forestry or sustainable forest management (Pearce et al., 2003; Rice et al., 1997) have been developed.

Certification of forest products is a practice widely adopted in Bolivia as a means to reduce negative impacts to the forest ecosystems and also as a way to find markets for less well-known tree species. According to Elliot and Donovan (1996), the ultimate objective of certification is “to provide an economic incentive to forest managers voluntarily interested in promoting forest management practices that are in accordance with principles of sustainable development”. Forest product certification, allows consumers to identify products that come from well-managed forests (Elliot and Donovan, 1996).

In Bolivia, the Forest Stewardship Council (FSC) standards are used for timber certification. These standards have 10 principles, each with its own guidelines which cover social, economic and environmental aspects (Putz and Romero, 2001).

Several studies have been carried out to assess the damage to the forests (Rockwell et al., 2007; Sun and McNulty, 1998) and to evaluate the environmental impacts of forestry activities under different management methods (Feldpausch et al., 2005). Also, efforts have been made to evaluate the differences between conventional logging activities and improved techniques, such as certified or reduced impact logging forestry (Holmes et al., 2002; Jackson et al., 2002; Krueger, 2004), especially considering the financial benefits (Hanrahan and Grimes, 1997; Holmes et al., 2000).

Emergy evaluation, a method of accounting developed by Odum (1996), is an appropriate tool for this study because it deals with systems at the interface between the natural and the human levels and because it is able to account for all the direct and indirect environmental work involved in generating wood and considers all the inputs on a common basis from its production until it is out in the market as timber (Castellini et al., 2006; Tilley and Swank, 2003). It should be emphasized that all these inputs, coming in different forms of energy, do not have the same quality. To measure such differences, emergy based on solar energy units, defined as the solar (equivalent) energy required to generate that flow or storage, is used. In addition, the inputs are not considered only on the basis of their energy content, but are weighted by the transformities. This way nature's work necessary to obtain forest products can be accounted. The units are solar emjoules (sej). Emergy analysis is also considered as a tool to measure environmental stress.

Economical analysis has been used in order to compare the efficiency and profitability of conventional and improved timber harvesting systems, but cannot provide valuable information on forestry sustainability. Emergy evaluation, on the other hand, has been used to measure environmental sustainability of other natural resource sectors (Martin and Tilley, in press) However, a specific emergy evaluation of certified forestry has not been conducted.

Thus, the aim of this study was to compare the net national benefits of certified forestry to more traditional uncertified forestry in Bolivia.

In order to do that, our purpose is to answer three questions:

- How much better is certified forestry for the forest's ecosystem?
- How does Bolivia benefits from forest certification?
- How much investment is required to implement certification, relative to the extra benefits?

6.2. Material and Methods

6.2.1. System Description

The forest systems analyzed were models of 1 ha of certified forest and 1 ha of uncertified forest in the Bolivian Amazon. The forests were assumed to be identical in age, structure and species composition prior to logging. Emergy inputs were those associated with logging 1 ha of forest. Each was logged according to prescribed practices.

6.2.2. Data Sources

The data used in this study was taken from previous studies performed in the Bolivian and the Brazilian Amazon, where environmental, social and production characteristics are similar to each other (Hanrahan and Grimes, 1997; Holmes *et al.*, 2002; Holmes *et al.*, 2000; Jackson *et al.*, 2002; Krueger, 2004). The productivity parameters considered for each logging activity are reported as the result of averaging typical productivity parameters. According to Holmes *et al.* (2002) the standard harvest volume was 25.4 m^3/ha/yr, which we used as the average harvest volume. The different costs were computed by taking averages of daily parameter values reflecting productive activity of crews (trained workers in the case of certified logging), labor costs were based on the standard monthly wage for each job category, and fixed equipment costs were computed on an hourly basis according to standard parameters provided by equipment manufacturers.

6.2.3. Inventory of Emergy Inputs

The method for inventorying all inputs as solar emergy was given in Chapter 4 of this dissertation. In this Chapter the specific inputs evaluated for certification included the environmental basis of the forestry system and its connection to domestic and foreign markets. An energy systems diagram was drawn to explain the main pathways that were affected by certification (i.e., forest production, silvicultural practices and timber prices).

The emergy input inventory was obtained by calculating the solar emergy of each environmental and human-controlled input, according to the process described in section 4.2 with the exception of the emergy of wood harvested. The emergy of wood harvested considered emergy stored in trees of different ages. Each inventory included environmental inputs, wood harvesting, impacts to soil and non-harvested trees, cost of human inputs and revenue generated from foreign and domestic sales. For the environmental inputs the solar emergy of rain was included, but not the solar emergy of sunlight. This avoided double counting the same global emergy contribution because sunlight and rain are co-products of the same global atmospheric-oceanic system (Odum, 1996). Wood production refers to the total amount of marketable wood extracted from the forest. Soil erosion and tree damage caused during harvesting, and merchantable wood wasted during harvesting were added together as an estimate of environmental stress. Human services consisted of payment for access to the forest (concession rights and certification fees) and the costs for each component of logging.

Since one of the main differences between certified and uncertified forestry is the distribution in the age-classes harvested, age-specific solar transformities were estimated for each age-class. First, the number of trees removed at each DBH was based on Holmes (2002). Second, DBH was used to infer tree-age based on the relationship developed in Figure 6.1 (Baker, 2003; Korning and Balslev, 1994; Lieberman and Lieberman, 1987; Lieberman *et al.*, 1985). Once the estimated age for trees was found, Tilley's (1999) age-specific estimate of the solar transformity of forest trees (Figure 6.2) was applied to each age-class to derive solar emergy for each age-class. Summing the solar emergy across age-classes provided the total solar emergy of the wood harvested. A similar technique was applied to the wood wasted during harvesting. Details on these calculations can be found on Appendix 14.

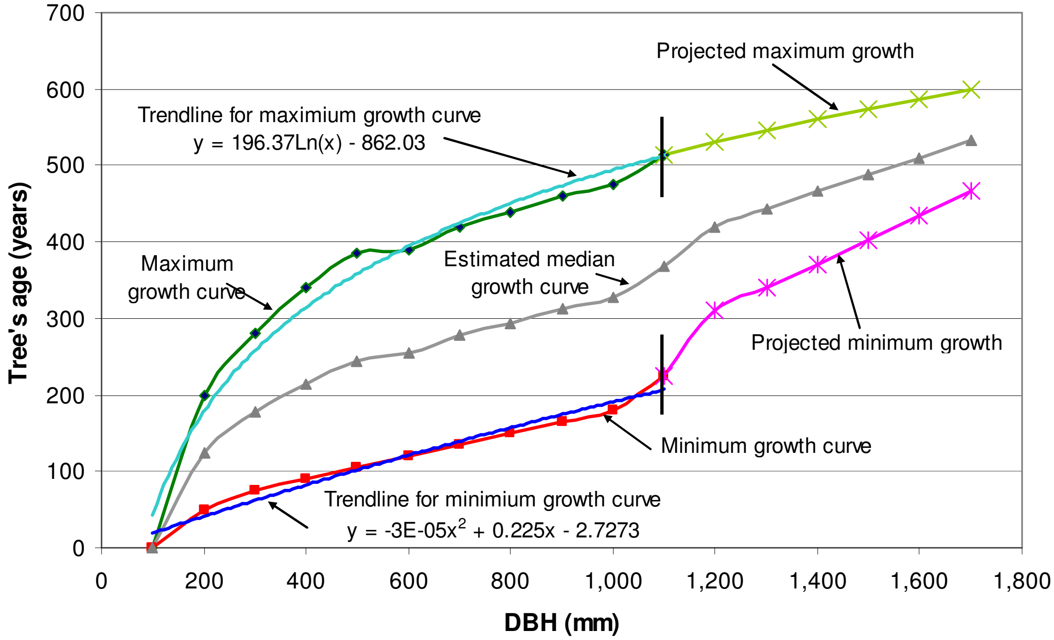


Figure 6.1. Estimated age from measured DBH

Adapted from (Lieberman and Lieberman, 1987)

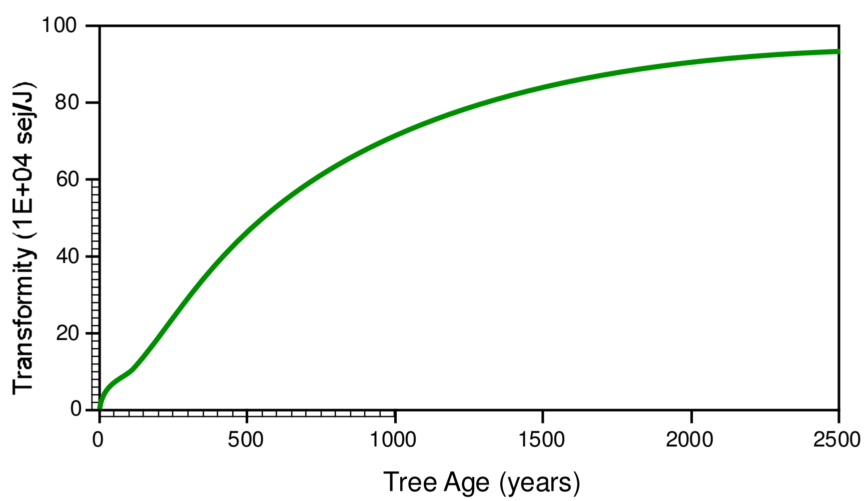


Figure 6.2. Transformity of trees at different ages

Adapted from (Tilley, 1999)

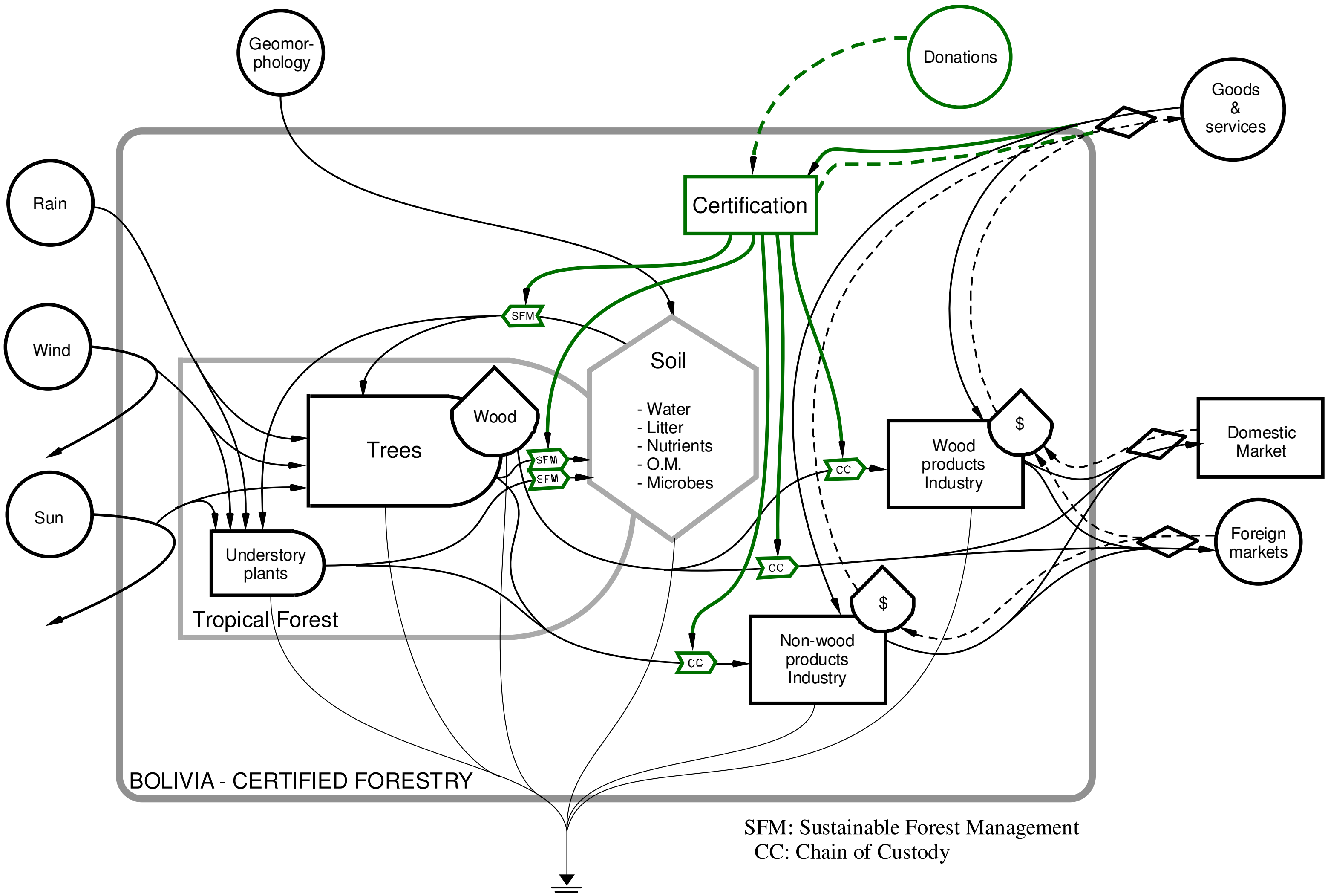
6.2.4. Emergy Indices for Analysis

The various flows of emergy necessary to grow, harvest, certify, and market the timber were combined in ways typically done in emergy analyses to create indicators for comparing the certified with the uncertified forestry. Several emergy-based indicators were used (i.e. solar transformity, environmental loading ratio – ELR and emergy yield ratio – EYR; Bastianoni and Marchettini, 2000). Emergy yield ratio (EYR) is the ratio of total emergy produced (Y) to the emergy purchased from the market (F), including costs of operation, goods, services, payment for concessions, and in this case, payment for certification fees. Environmental loading ratio (ELR) is the ratio of all non-renewable emergy (both from inside and outside the system; N and F) to the renewable emergy (R).

To compare the resource efficiency of each forestry system the solar transformity was used. The harvested timber that had a lower solar transformity was the one that used fewer total resources.

6.3. Results

Figure 6.3 is an energy systems diagram of the Bolivian Certified Forestry system that highlights the important interactions between the forest ecosystem and certified forestry. Goods & services as well as donations from outside the system support the certified operation, which extracts timber and non-timber products for sale to domestic and foreign markets. This diagram also shows that certification is an added sub-system that has two important elements: Sustainable Forest Management (SFM) and Chain of Custody (CC). SFM are the processes that occur in the forest, while CC covers the downstream aspects once timber leaves the forest.



SFM: Sustainable Forest Management
CC: Chain of Custody

Figure 6.3. Systems diagram of energy inputs for the certified forestry system, 2005

Tables 6.1 through 6.3 show differences in area disturbed, wood wasted and costs between uncertified and certified forests. Table 6.1 summarizes Holmes *et al.* (2002) estimate of the forest area disturbed by uncertified and certified forestry. The affected area between uncertified and certified forest production systems can be explained more clearly at a tree's population level. Forestry operations negatively affect the development of trees during the vegetation life cycle, i.e., road and deck construction, cutting, and skidding. Tree harvesting machinery increases the amount of compacted soil, which reduces seed production and germination and hinders juvenile growth. In general uncertified affects twice the area of certified since uncertified requires more roads, more logging decks and more skid trails. Wood harvesting in uncertified forests impacts 1,006 m^2 of forest per each ha harvested, while certified forestry impacts only 518 m^2. Also, the rate of soil erosion between uncertified logging (154 MT/ha/yr) and certified logging (66 MT/ha/yr) is different according to Sun and McNulty (1998).

Table 6.1. Ground area disturbed under uncertified and certified forestry systems

Activity	**Area disturbed (m^2/ha)**	
	Uncertified	**Certified**
Secondary roads	135	65
Log decks	105	63
Skid trails	766	390
Total	**1,006**	**518**

Source: (Holmes *et al.*, 2002)

Table 6.2 illustrates the difference of future crop trees (FCTs) damaged during harvest under uncertified and certified practices. While uncertified logging caused the loss of 13.55 m^3 of marketable wood per ha, only 3.75 m^3 (27.6%) were lost during logging in certified forest. The single process that caused the largest loss, as reported by Krueger (2004) was FCTs killed during felling. FCTs are all the trees measuring ≥20 cm diameter at breast height (DBH) (Rockwell *et al.*, 2007).

Table 6.2. Loss of wood during tree's harvesting

	Source	Wood wasted (m^3/ha)	
		Uncertified	**Certified**
a	High stumps	0.28	0.10
b	Split logs	0.87	0.31
c	Bucking waste	1.97	0.85
d	Logs lost	0.96	0.06
e	Total in forest (a+b+c+d)	4.08	*1.32*
f	Total in log deck	1.97	*0.60*
g	*Subtotal* (e+f)	6.05	1.92
h	FCTs* killed during felling	5.49	1.83
i	FCTs* killed during skid trailing	2.01	0.00
j	*Subtotal* (h+i)	7.50	1.83
	Total (g+j)	**13.55**	**3.75**

* FCTs = Future Crop Trees
Source: a to g (Holmes *et al.*, 2002); h and i (Krueger, 2004)

Table 6.3 compares the costs associated with each component of the timber harvesting in 1 ha of forest under uncertified and certified logging. In total uncertified logging was a bit more costly ($417 versus $407). Costs of forest certification, pre-harvest operations and training are not part of the uncertified process but since uncertified harvest more volume of timber per hectare, costs are almost equal. Production costs per m^3 of wood harvested were $15.66 for uncertified and $13.84 for certified wood (Holmes *et al.*, 2002).

Table 6.3. Typical forestry activities costs

	Item	Costs ($/ha) Uncertified	Certified
a	Forest concession	20.00	20.00
b	Certification cost	0.00	35.67
c	Pre-harvest	0.00	29.92
d	Harvest planning	3.55	4.06
e	Infrastructure	14.46	14.96
f	Felling and bucking	12.43	15.72
g	Skidding	50.47	31.45
h	Log deck operations	50.97	32.46
i	Waste adjustment	10.14	2.28
j	Stumpage cost	230.52	192.99
k	Training	0.00	5.33
l	Overhead/support	24.60	21.81
	Total	**417.14**	**406.65**

Source: a and b (CFV, 2006); c to l (Holmes *et al.*, 2002)

The emergy evaluations of uncertified and certified logging are presented in Tables 6.4 and 6.5, respectively. Both tables (whose footnotes are in Appendices 15 and 16) list the indigenous environmental resources used, the losses of environmental resources, and the services used to extract timber from the forest.

More wood was harvested under uncertified forestry (line item 3 in Tables 6.4 and 6.5) with a greater loss of soil and more wood wasted (line items 4 and 5 in Tables 6.4 and 6.5). The emergy of wood harvested was by far the largest flow of solar emergy for both systems. A large portion of the difference in the amount of solar emergy harvested as wood was due to the removals of more old trees in uncertified forestry (Figure 6.5). In certified forests some old trees are not harvested because they are left as seed sources. Uncertified forestry harvested more solar emergy at nearly every age class, but was especially pronounced in ages greater than 300 years.

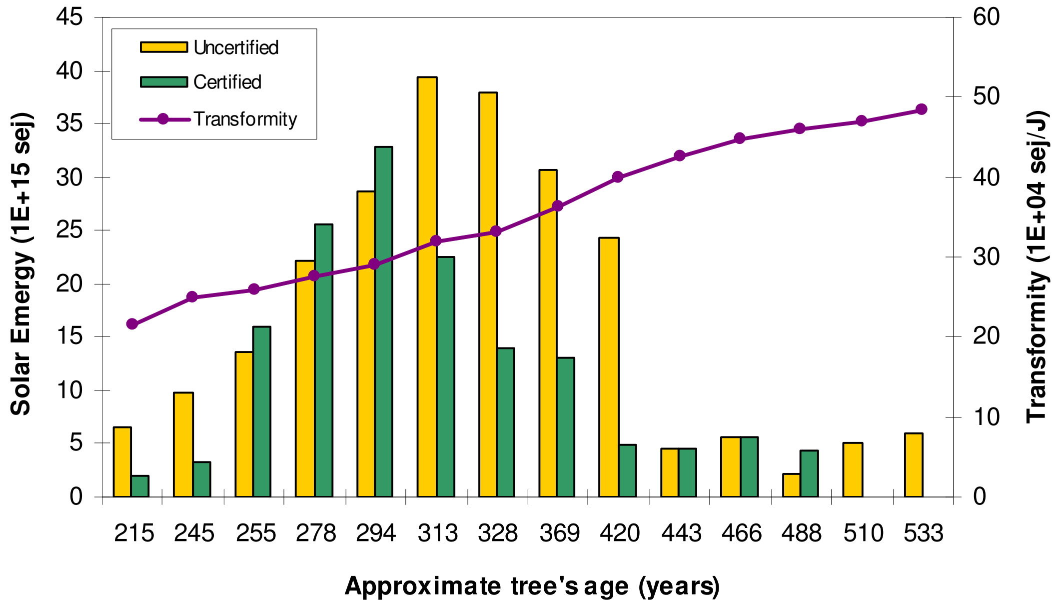


Figure 6.5. Emergy value of wood harvested for each age class

The stress caused to the forest, represented by the emergy of wood removed from forest (W_Y), soil loss (S_L) and wood loss (W_L), was lower when certified logging was practiced. On the contrary, the emergy for the services costs, which includes the payment for forest access fees and the human services, were similar for both systems (Tables 6.4 and 6.5).

Certified logging is characterized for more effort made in terms of training and pre-harvest preparation (resulting in less wood wasted (Tables 6.4 and 6.5). Although certification implies higher cost in goods and services per tree removed, uncertified represents a higher emergy value due to the total amount of wood harvested per ha. All these differences are listed in the Table 6.6, where it can also be seen that the total yield emergy (Y) and the net yield (Y_{net}) for certified logging is lower than uncertified logging system.

Table 6.4. Emergy evaluation of uncertified logging in 1ha per year of tropical forest

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E15 sej)	Macroeconomic Value (2005 $)
Indigenous environmental resources						
1	Sunlight	3.72E+13	J	1	0.04	1.12
2	Rain, chemical (R)	1.92E+11	J	30,500	6	176.50
3	Wood harvested (W_Y)	7.34E+11	J	321,808	236	7,133.32
Loss of environmental resources						
4	Soil erosion (S_L)	3.15E+10	J	74,000	2	70.44
5	Wood loss (W_L)	1.30E+11	J	27,613	4	108.50
Services						
6	Access costs (F)	20.00	$	3.31E+13	1	20.00
7	Services (F)	397.14	$	3.31E+13	13	397.14
	Sum of 2 to 7 (Y)				262	7,905.90
	Sum of 2+3+6+7-4-5 (Y_{net})				250	7,548.03
8	Uncertified timber output	7.28E+11	J			
9	Uncertified timber output	1.74E+08	g			
10	Uncertified timber output transformity (sej/J)			3.43E+05		
11	Uncertified timber output transformity (sej/g)			1.44E+09		

Footnotes to Table 6.4 appear in Appendix 15

Table 6.5. Emergy evaluation of certified logging in 1ha per year of tropical forest

Note	Item	Raw Units		Transformity (sej/unit)	Solar Emergy (E15 sej)	Macroeconomic Value (2005 $)
Indigenous environmental resources						
1	Sunlight	3.72E+13	J	1	0.04	1.12
2	Rain, chemical (R)	1.92E+11	J	30,500	6	176.50
3	Wood harvested (W_Y)	4.83E+11	J	307,435	149	4,487.68
Loss of environmental resources						
4	Soil erosion (S_L)	6.96E+09	J	74,000	1	15.54
5	Wood loss (W_L)	3.60E+10	J	27,613	1	30.02
Services						
6	Access costs (F)	55.67	$	3.31E+13	2	55.67
7	Services (F)	350.98	$	3.31E+13	12	350.98
	Sum of 2 to 7 (Y)				169	5,116.39
	Sum of 2+3+6+7-4-5 (Y_{net})				166	5,025.26
8	Certified timber output	4.79E+11	J			
9	Certified timber output	1.15E+08	g			
10	Certified timber output transformity (sej/J)			3.47E+05		
11	Certified timber output transformity (sej/g)			1.45E+09		

Footnotes to Table 6.5 appear in Appendix 16

Table 6.6. Emergy inputs and outputs for uncertified and certified logging (1 ha).

Item	Symbol	Units	Uncertified	Certified	Uncertified/ certified
Environmental inputs	R	sej/yr	5.84E+15	5.84E+15	1.00
Emergy of Wood harvested	W_Y	sej/yr	2.36E+17	1.49E+17	1.59
Goods and services	F	sej/yr	1.38E+16	1.35E+16	1.03
Emergy exported in timber	Y	sej/yr	2.82E+17	1.89E+17	1.49
Net emergy exported in timber	Y_{net}	sej/yr	2.70E+17	1.86E+17	1.45
Annual wood yield	Q	m^3/yr	76.46	50.35	1.52
Price of timber	P	$/$m^3$	254.24	466.10	0.55
Emergy of Export Revenue	Z	sej/yr	1.60E+18	1.93E+18	0.83
Bolivia Emergy/$ ratio	EDR	$/yr	3.31E+13	3.31E+13	

Annual wood yield (Q) in certified forestry was 50% lower than in uncertified (Table 6.6). However, transformity of certified forestry is around 5% higher.

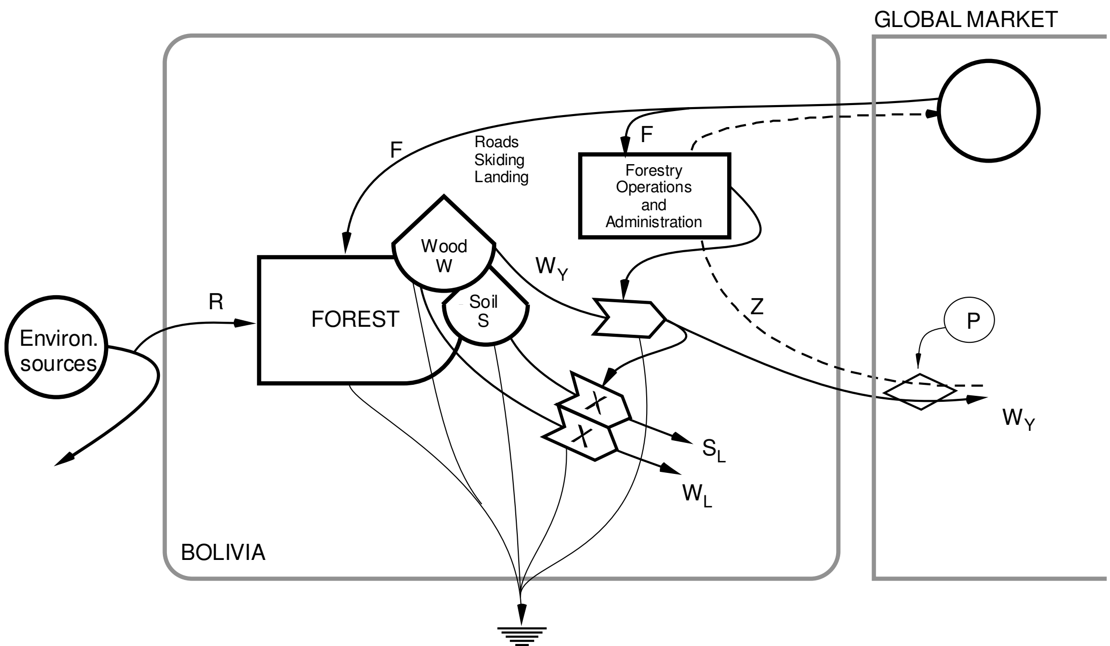


Figure 6.6. Energy systems diagrams of a forest under logging operations

In order to answer the questions proposed for this study, we used the model in Figure 6.6 and the Table 6.7.

To determine how much better certified forestry was for the forest's ecosystem (our ecological question), we used emergy to quantify: 1) total forest emergy removed, 2) wood yield per forest emergy removed and 3) the capacity of the forest to recover from logging, which we estimated using the Environmental Loading Ratio (ELR). First, the sum of total wood harvested (W_Y), soil erosion (S_L) and wood loss (W_L) defined total forest emergy removed. We found that certified removed less (149E+15 sej/ha/yr) than uncertified (236E+15 sej/ha/yr). Second, certified forestry had a better wood yield per forest emergy removed [$Y/(W_Y + S_L + W_L)$] index than uncertified forestry (1.26 versus 1.17; Table 6.7). Thus, certification did a better job of preserving forest while removing wood. Finally, the ELR showed that uncertified forestry had a larger ELR (3.38) than certified (2.56), indicating that certified had less impact per unit of regeneration capacity than uncertified forestry. This meant that certified forests should have a better chance of recovering after logging (Table 6.7).

Table 6.7. Emergy-based indicators of uncertified and certified logging (1 ha)

Indicators	Symbol	Units	Uncertified	Certified
Emergy-based indicators				
Emergy yield ratio	$EYR = Y/F$	Sej/sej	20.43	14.06
Emergy net yield ratio	$EY_{net}R = Y_{net}/F$	Sej/sej	19.58	13.84
Environmental loading ratio	$ELR = (S_L+W_L+F)/R$	Sej/sej	3.38	2.56
Total yield/Forest removal	$Y/(W_Y+S_L+W_L)$	Sej/sej	1.17	1.26
Balance of Trade in Wood	$Z/(F+W_Y+S_L+W_L)$	Sej/sej	6.24	11.78
Money-based indicators				
Money received for exports		$/yr	1.94E+04	2.35E+04
Transformity/Price		sej/J/$	1,461	834
Income	A	$/yr	19,438	23,468
Outflow		$/yr	417	407
Profit		$/yr	19,021	23,061
Indicators at forest boundary				
Emergy of Timber Yield	W_Y	sej/yr	2.36E+17	1.49E+17
Natural Capital wasted (wood lost & soil eroded)	W_L+S_L	sej/yr	5.93E+15	1.51E+15
Natural Capital Removed	$(W_Y+W_L+S_L)$	sej/yr	2.42E+17	1.50E+17
Natural Capital Waste/Timber Yielded	$(W_L+S_L)/W_Y$	sej/sej	2.5%	1.0%

The second question was whether Bolivia as a country benefited from certification. If Bolivia were not to sell wood as certified to foreign markets at higher price, then the extra investment for forest certification would not be wise, because the net emergy yield (Y_{net}) per investment was higher for uncertified i.e., the lower yield and extra cost of certification decreased net emergy yield ratio (19.58 versus 13.84). However, given that a higher price is garnered for certified wood in international markets, the emergy value of Bolivia's Balance of Trade in Wood (emergy received as foreign payments per emergy exported) favored certification (11.78 versus 6.24) (Table 6.7).

This last statement answers question number three (how much investment is required to implement certification, relative to the extra benefits?) and it is interesting because it says that certification is only beneficial to Bolivia's economy if it exports the wood to developed countries at a premium price. When they do that, they receive 11.78 times as much benefit as they lose. When they export uncertified wood they achieve a positive benefit, but one that is below using uncertified wood domestically (EYR= 20.43). In other words the worst thing they could do is certify wood for their domestic market and sell uncertified wood abroad.

6.3.1. Comparison at Forest Boundary

At the smallest scale of analysis, which was the forest, we compared the two forestry systems based on 1) how much total natural capital was removed, 2) how much natural capital was wasted, and 3) the percentage that natural capital waste was of total timber yield. By each of these indicators, certified forestry had less impact on the forest than uncertified forest. Certified forestry removed less (149E15 sej/ha) natural capital compared to uncertified forestry (236E15 sej/ha) (Table 6.7). In absolute terms, certified forestry wasted less (1.5E15 sej/ha) natural capital than uncertified forestry (5.9E15 sej/ha) (Table 6.7). Also, certified forestry wasted less natural capital per timber harvested (1%) than uncertified forestry (2.5%) (Table 6.7).

6.3.2. Comparison at National Boundary

At the larger scale of analysis of the country, we compared the two forestry systems based on 1) Gross Emergy Yield Ratio, 2) Net Emergy Yield Ratio, 3) Net Trade Balance in Wood and 4) Environmental Loading Ratio (Table 6.7). We found that the national benefit of implementing an international forestry certification program was sensitive to how much export revenue was generated due to the certification. The Gross Emergy Yield Ratio and Net Emergy Yield Ratio, which did not consider export revenue, were greater for the uncertified forestry because the emergy imported to implement certification (F in Table 6.6) was more than the m value of the wood yield relative to how much emergy was imported from outside to administer and operate the forestry system. Absent an international export market for certified wood, this meant that Bolivian forestry could provide more total benefit to the nation without implementing an international certification program. However, since certified timber commanded a price nearly double that of uncertified wood (P in Table 6.6), Bolivian forestry could attain more benefit for the nation by implementing an international forest certification program.

ELR, on the other hand, shows that the non-renewable part of the emergy is 2.56 and 3.38 times higher than the renewable part for uncertified and certified logging respectively.

6.4. Discussion

Uncertified forestry placed a larger load on the forest environment than certified because it 1) removed more forest emergy, 2) yielded less wood per forest emergy removed and 3) had a higher Environmental Loading Ratio (ELR) (Table 6.7). Uncertified forestry wasted more wood, harvested more wood and eroded more soil than certified practices. However, both certified and uncertified forestry had large ELR as compared to other types of agricultural activities. For example, Ulgiati *et al.,* (1994) estimated an ERL of 2.5 for Italian agriculture (Martin and Tilley, in review).

Although certified forestry represented a lower environmental impact, the ratio of net emergy yield (Y_{net}) per ha was higher for uncertified. The reason why certified forestry costs more per ha is because of the less trees are harvested and extra fees paid for certification which decrease net emergy yield ratio (Table 6.7).

In order to compare how much timber is obtained with a given quantity of emergy with both forest harvesting techniques (uncertified and certified), we used transformity values. Although certified forestry or other improved forest management systems are considered more beneficial to the local economies and the environment, in terms of emergy, the uncertified logging system requires less emergy in the process (Tables 6.4 and 6.5). This can be explained because certified forests employ qualified labor and training during the harvest planning phase and requires the payment of certification fees. Considering that the total emergy is the sum of all local and external emergy inputs, the higher the ratio, the higher is the relative contribution of the local (renewable and non-renewable) sources of emergy to the system.

The ratios calculated in our study, showing that certification remove and waste less natural capital compared to uncertified forestry (Table 6.7) corroborate studies i.e., Holmes (2002) which confirm that certification cost less and it is a more profitable practice.

Consideration of age and growth rates of potential timber trees was essential for this study, as it is for the planning of sustainable forestry in tropical forests. Despite the vastness and high species richness of Bolivia's Amazonian rainforest, little is known about the age of the trees there. Extrapolated data from short-term growth trend studies such as (Baker, 2003) were considered, using the Macaranduba tree (*Manilkara huberi* - Ducke) which belongs to the Sapotaceae family as the average tree for its closeness in phenotype and environmental requirements to most of the species harvested in the Bolivian Amazon.

Although the indices calculated in this study, as part of emergy analysis, allowed us to answer the proposed questions, there is one aspect that remains unsolved and it is the measurement of stress on biodiversity. It is the law that rare species and wildlife are better protected and hunting is not allowed on certified forestlands, except in justified cases in relation to indigenous people. However, results on how much the certification diminishes the damage to the biodiversity against the uncertified forestry, has not been measured yet.

6.5. Conclusion

The emergy evaluation of certified tropical forestry demonstrated that the forest ecology was better off under certification, mainly due to reductions in total timber removed, timber wasted and soil lost as erosion. However, the national economic benefit was dependent on the international price for certified wood.

The comparison of one hectare of tropical forest under uncertified logging practices and one hectare under certified ones showed that:

Certified forestry removed less emergy than uncertified forestry and had a better wood yield per forest emergy removed index than uncertified forestry.

Certified forest had less impact per unit of regeneration capacity than uncertified forestry offering to certified forests a better chance of recovering after logging.

Certified practices showed a lower emergy yield ratio because the lower yield and extra cost of certification.

The higher price for certified wood in international markets favored certification.

In order to evaluate the benefits of each system towards the environmental sustainability, additional research is required to measure the effect of forest certification over the biodiversity.

Chapter 7: Simulation Model

7.1. Justification

In Bolivia as in the most rich-in-resources countries, forests are very important for progress because of the wide range of products they offer and because they generate strong linkages within the forestry sector, the national economy (Westoby, 1962) and the local communities. According to King, "*forests and forest industries are capable of contributing significantly to the attack on economic underdevelopment*" (King, 1980 pp. 518). Also, these linkages have a multiplier effect on the rest of the economy (Westoby, 1987) since, the contribution of forestry to the national economy can be reflected in the Gross Domestic Product (GDP) (Bojanic, 2001).

With the election of a president that genuinely represents indigenous people in Bolivia, the country is switching from the tendency to use the forests as a source of wood for industry, towards the idea that forests should play a role in improving the well-being of people, especially the poor people living in rural communities. This certainly represents a holistic view and implies a broader range of inputs, which may include environmental services (e.g. carbon sequestration) and more sustainable use of the resources through practices like eco-tourism. (Davis *et al.*, 2001). All in all, the Bolivian population encompasses now new viewpoints that give larger importance to ecological issues and improve the understanding of multiple roles of forests in the country's economical and ecological life (Wiersum, 1989).

In order to achieve the new social and environmental goals for a most sustainable Bolivian development, forests play an important role and it is important they are managed sustainably.

ITTO defines sustainable forest management (SFM) as the "*process of managing the forests to achieve one or more objectives with regard to the production of a continuous flow of desired forest products and services, without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment*" (ITTO, 2005 pp. 34)

In order to reach ecosystem and economic sustainability, forestry practices must achieve three different goals: (1) be economically profitable and perpetuate forest cover, (2) preserve ecosystem structure (e.g., for biodiversity values) and (3) preserve ecosystem function (e.g., carbon storage) (Sverdrup, 2002; Zavala, 1995). Lack of SFM reduces stand biomass, nutrient contents, and litterfall (Harrington and Edwards, 1999; Klemmedson *et al.*, 1990), which can alter decomposition rates (Pérez-Batallón *et al.*, 1998) and ultimately decrease biodiversity.

Continuous long-term studies on the effect of sustainable forest management practices can be expensive and time consuming. For this reason, simulation models are useful tools that allow us to extrapolate observed short-term changes in SFM practices to longer time scales (Landsberg, 2003) as a compliment to long-term observations and data collections. Computer simulation models can assist advocates, researchers and policymakers in exploring consequences of new proposed initiatives, so they can make informed selections of alternatives, with the knowledge that consequences have been investigated (Vanclay *et al.*, 2003) considering a management context that can identify essential mechanisms that allow controlling short and long-term processes critical for maintaining ecosystem structure and function (Grigal, 2000; Kirschbaum, 1999) which can be essential to support local or national economies.

By encouraging people to explore scenarios, models give the possibility to be more innovative and less dependent on technocrats. Models also enable planners to experiment with policy without risks to people or to the environment. Nowadays, modeling processes are less difficult thanks to emerging software that helps to solve many technical limitations. However, the real issue is not software, but rather the provision of a supportive framework within which people can communicate and experiment with ideas (Vanclay *et al.*, 2003) that evaluate whether forest management is sustainable.

While steady state emergy accounting, which integrates multiple system forcing factors (e.g., sun, rain, geomorphology and use of goods and services) into one metric (i.e., solar emergy), has been evolving for several decades, the process of accounting for how system stocks accumulate solar emergy during a certain period of time is a newer approach (Odum, 1996; Odum and Odum, 2000a; Odum and Peterson, 1996) and is now a research frontier in emergy evaluation (Tilley and Brown, 2006).

The “Ecologically-based Development for the Bolivian Industrial Forestry System” model (DEBBIF) was developed with the aim to (1) illustrate the dynamics of timber production and commercialization in Bolivia, (2) demonstrate how dynamic emergy accounting principles could be used in the simulation modeling of the forest sector (Bolivian assets were assessed based on dynamic emergy accounting) and (3) demonstrate the temporal variability of soil carbon content in various scenarios of domestic use and export of the major Bolivian natural resources.

The model that used H.T. Odum's energy systems language to be developed, represents a spatially aggregated simulation of Bolivia as a nation powered by natural forests, natural gas, imports and exports. The model included forested and non-forested natural lands, the domestic forestry sector, forest export sector, manufacturing/construction sector powered by natural gas, natural gas export sector, and general goods export sector. It also accounted for imports of goods and services, financial aid, international development loans with repayment. With certain detail, the forestry sector was analyzed combining life cycle assessment of timber (from the forest to the market) and the economical dynamics implied by the timber trade.

The energy systems model was simulated using Excel® software and the process described by Odum and Odum (2000a).

7.1.1. Description of a Country with Sustainable Forest Management (SFM) Practices

The simulation model (DEBBIF) was developed, calibrated and simulated using data from Bolivia. It is a landlocked South American nation that sits atop the Andes at the headwaters of the Amazon basin. With an area of 110 million hectares, the country is about the size of Texas and California combined, or twice the size of Spain. Bolivia has 6,083 kilometers of land boundaries, and it is surrounded by five countries: by Brazil to the north and east, Paraguay to the southeast, Argentina to the south, Chile to the southwest, and Peru to the northwest. Bolivia's topography has dramatic elevation changes.

Stretching in a broad arc across western Bolivia, the Andes define the country's three geographic zones: the Andes and arid highlands of the west, the semi-tropical valleys in the middle third of the country, and the tropical lowlands of the east. Bolivia’s high plateau, or altiplano (in Spanish), is located between the two major Andean mountain ranges: the Cordillera Occidental and the Cordillera Oriental. The altiplano is arid in the south but not as arid in the north because it is served by Lake Titicaca. The lower, eastern slopes of the Cordillera Oriental, known as the Yungas, compose the semi-tropical region of the country. Rivers are plentiful in this region and drain into the Amazon Basin. In the east, the Bolivian lowlands which include the Chaco region, have semiarid conditions (Library of Congress, 2006). Although forests cover nearly half of the country, the ample plains are used for cattle grazing and, in less inhabited regions, for coca cultivation.

A land-use survey conducted in 2001 (Cochrane *et al.*, 2003) revealed that 6% of primary forest was lost over the previous two decades. However, forests still cover around 50% of Bolivian territory even after this accelerated deforestation rate. Bolivia’s history of slash-and-burn agriculture, overgrazing, and industrial pollution is the cause of significant concern. Soil erosion, made worse by seasonal flooding, and contaminated water supplies are some of Bolivia’s most pressing environmental problems.

Devastation of precious natural resources like timber from mahogany, oak, and cedar encouraged the Bolivian government and international agencies to initiate programs on sustainable forest management. In 1993 it officially launched BOLFOR (Bolivia Sustainable Forest Management Project), whose main goals were to protect

Bolivian biological diversity and keep the country's forests, soils and water healthy by promoting sustainable forestry. By now the project is its second phase (BOLFOR II) and still works on strengthening the Bolivian forestry sector, providing technical and financial support to communities, private business and government.

7.2. Model Development

A national model of Bolivia was developed to assess the effects of various trade and forest-use policies on national wealth given that the country enacted strong Sustainable Forest Management laws.

To develop the national ecological-economic model, the following steps were followed:

1. Conceptualization of the national model was accomplished by using Energy Systems Diagrams. It started drawing complex diagrams of the system, but aggregating and eliminating details to a manageable level for simulation. (Figure 7.2).
2. Model equations were derived from the aggregated energy systems diagram and programmed into spreadsheet software (Microsoft Excel®) (Odum and Odum, 2000a).
3. Calibration of pathway coefficients were derived from published literature values (Table 7.1).
4. Four different scenarios were simulated using the model constructed in Excel® software.

7.2.1. Model Description

7.2.1.1. System Boundary

The simulation model was developed as a model of Bolivia. It represents the whole country and all the components that defined its forestry system, including: natural forests, forest-products sector, domestic markets where the wood and wood-based products were consumed, and the wood export sector. In addition, it included natural gas reserves, domestic economic production based on use of natural gas, and export of natural gas.

External sources driving the model included environmental sources (J_0) and its unused portion (R); goods, services and technology imported (T); development aid money (U); international loans (L) and money paid for Bolivian exports of natural gas (E_g), wood (E_w), and manufactured goods (J_{19}).

Environmental source was a function of water (in the form of rain) coming into the system. Two different figures of rainfall were considered distinctively for land covered by forest and land non-covered by forests. To simulate the existing conditions, actual rainfall data reported in m^3/yr at a national level (INE, 2006; SENAMHI, 2006) was multiplied by non-forest land area (J_a) and forest land area (J_b) to obtain volume of rainfall (m^3/yr) flowing into the country.

The two more representative outflows of the Bolivian money in 2005 were the money spent on imports of goods and services (J_{25}) and the money paid as interest for the loans in that year, being represented by the pathway (J_{26}). This flow is a function of the amount of money owed by the country represented by the stock D (Figures 7.1 and 7.2).

Figure 7.1. Sources of money coming to Bolivia in 2005

Figure 7.1 shows the money inflow coming from different sources. Money coming to the country as loans is represented by two events complementary to each other. One is the money (J_{27}*Z) that goes to the Bolivian money stock but remains a part of the debt due to the other event which is the loan contract (J_i). Both flows are controlled by a switch (Z) representing every agreement for a new loan. Repayment of the loan represents the outflow from the debt stock and is also illustrated by two flows: J_{28} which is the money paid to the creditors as part of the loan's principal and the flow "d" that runs in the opposite way of J_i as a part of the loan agreement. These two actions are also controlled by a switch representing every re-payment event (Figure 7.2).

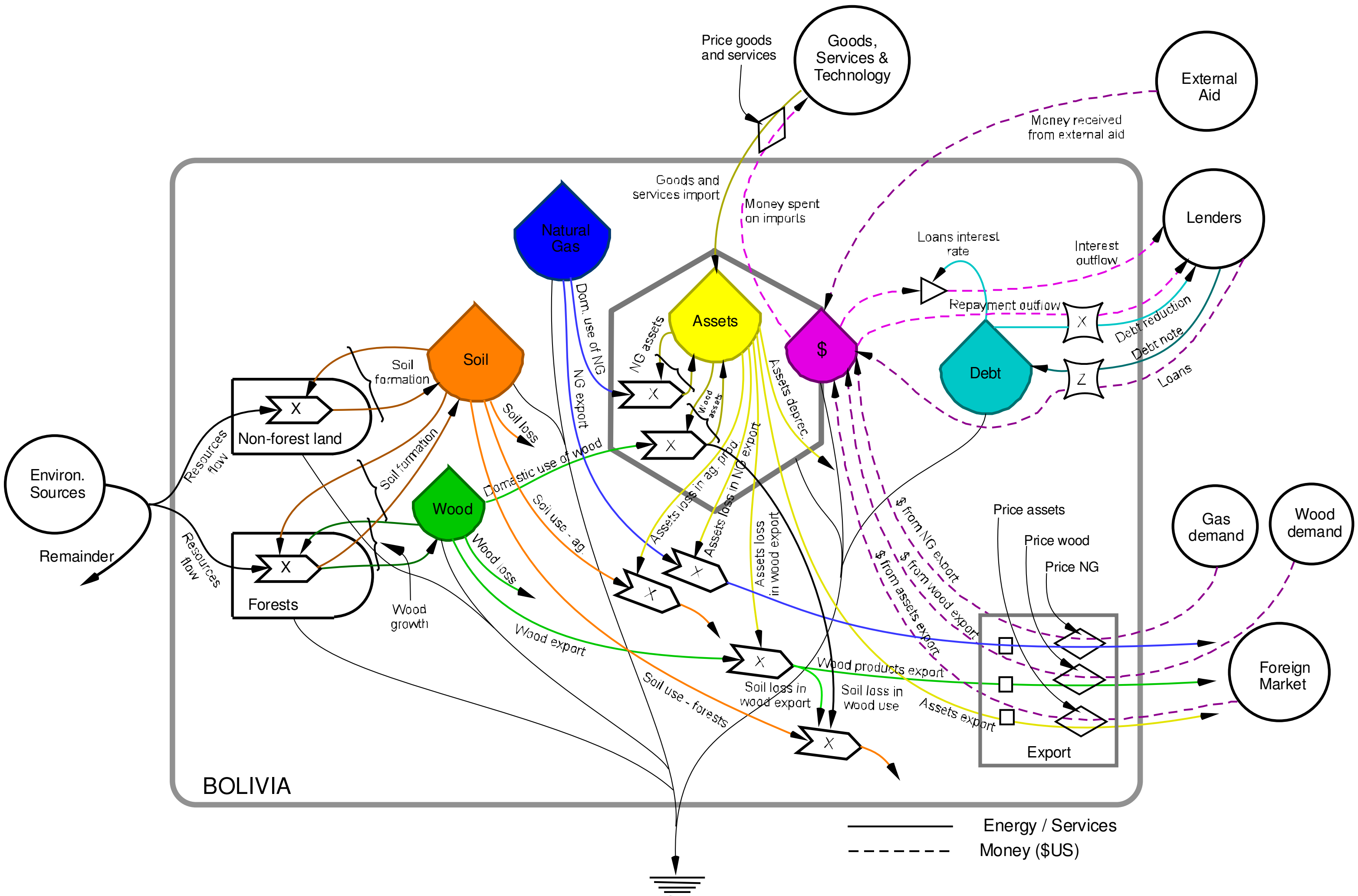


Figure 7.2. Energy systems diagram of simulation model with names and descriptions

7.2.1.2. State Variables

The state variables included within the system were soil (S), wood (W), natural gas (G), assets (A), money (M) and debt (D) (Figures 7.2 and 7.3).

The soil was the total carbon contained in the entire country (1.1E+12 m^2), which consisted of forested (5.9E+11 m^2) and non-forested lands (5.1E+11 m^2) (FAO, 2005). To obtain the value for the total carbon content in Bolivia (1.2E+10 MT), calculations made by Malhi and Grace (2000), Tian *et al*. (2000) and Amado *et al.* (2006) were followed. Wood corresponded to the stock of biomass stored in forests and other wooded land of the country (FAO, 2006; Saatchi *et al.*, 2007).

The natural gas stock represented the proven reserves of the country for the year 2005 (7.6E+11 m^3) (INE, 2006; YPFB, 2005) (Table 5.9). There were three common categories of reserves: proven, probable and possible, which represented the certainty that a reserve exists based on the geologic and engineering data and interpretation for a given location (SPE, 2007).

The money storage corresponded to the money supply for the country which for the year 2005 was $2.9E+11. This stock represented one of the broadest measures of money (M4) (Astley and Haldane, 1995).

The debt storage is the value borrowed from all lenders. By 2005 the amount money owed by Bolivia to its payees was $4.9 billion (Table 7.1).

Table 7.1. Structure of Bolivian external debt for 2005

Creditors (*)	Debt Million $	Participation On the Group	Participation on the Balance
IMF	**243.8**	**100.0%**	**4.9%**
Multilateral	**4,275.1**	**100.0%**	**86.6%**
WB	1,666.6	39.0%	33.8%
IADB	1,622.8	38.0%	32.9%
CAF	871.3	20.4%	17.7%
IFAD	40.8	1.0%	0.8%
FONPLATA	32.4	0.8%	0.7%
NDF	23.8	0.6%	0.5%
OPEC	16.8	0.4%	0.3%
BIAPE	0.6	0.0%	0.0%
Bilateral	**416.4**	**100.0%**	**8.4%**
Spain	139.3	33.5%	2.8%
Brazil	121.5	29.2%	2.5%
Japan	63.0	15.1%	1.3%
Germany	34.0	8.2%	0.7%
China	29.4	7.1%	0.6%
France	13.3	3.2%	0.3%
Italy	9.8	2.4%	0.2%
Venezuela	5.0	1.2%	0.1%
Korea	1.1	0.3%	0.0%
Private	**0.2**	**100.0%**	**0.0%**
TOTAL	**4,935.5**		**100.0%**

Source: (BCB, 2006a)
(*) Complete names of the acronyms can be found in Appendix 17

7.2.1.3. Environmental Production

Ecological production of biomass and soil in non-forested (J_a) and forested systems (J_b) was driven by evapo-transpiration, which was a function of available water (R) and the stocks of wood and soil in their respective storages. Water availability was taken as the amount of rainfall not already used in ecological production (University of Oregon, 2004).

The input considered for the soil stock was soil formation as a result of accumulation of carbon coming from both the forests and non-forests biomass. The flows (J_{1a} for non forest land and J_{1b} for forest land) were a function of the annual rate of carbon increase and the land area. Soil (and carbon with it) was lost from the stock through domestic use of wood (J_3), wood extraction for export (J_2) and due to natural loss of soil (J_5) which was in function of the soil respiration rate and the area (Malhi and Grace, 2000; Malhi and Wright, 2004; Schlesinger, 1984; Schlesinger and Andrews, 2000).

The volume of biomass accumulated in the forests as wood, came from the annual net wood growth rate (7.34 MT/ha/yr) times the forested area (J_6) (Jordan, 1983; Malhi *et al.*, 2004). The main cause for subtraction of wood from the stock was either internal use in Bolivia (J_9) or the export as round wood (J_7) or wood products (J_8) in amounts that were in function of the international market demand (E_w). Figure 2.9 shows the proportion of wood and wood products going to different countries. The wood extraction process was also an increasing factor for depletion of soil, as depicted on the pathways J_{4a} and J_{4b}. Another portion of biomass lost is represented by lost of wood in the way of wood residues (J_{10}), which accounts for almost 45% of the total wood extracted. Although the importance of re-planting trees has been documented widely (Fredericksen *et al.*, 2003), this is a process that very slowly is taking place in the country with no important data to be show at the moment this study was conducted.

Due to the extremely slow process of natural gas formation, the amount of natural gas storage will be increased only by locating new reservoirs. For the purpose of this model, no additions to the proven reserve of natural gas were considered. Bolivia gets the natural gas out of the ground mainly for export. In 2005, only 10% of the total natural gas produced was used internally and almost 90% was exported, according to the market's demand (E_g). Those flows are represented in the Figure 7.2 by the pathways J_{12} and J_{11} respectively.

The stock of Bolivian assets represented in the model, come from various and very diverse sources. In order to provide a dynamic valuation of these assets solar emergy was used as the comparison unit. Three different inputs were considered, and each was the result of adding similar sources: Emergy of wood and wood products (J_{13}), emergy of natural gas, oil and petroleum products (J_{14}) and emergy of goods and services imported i.e., petroleum products, technical assistance, etc. (J_{15}). The emergy going out of the assets stock was represented by five flows; three of these five flows represented the lost of assets in the process of producing and exporting goods i.e., assets loss in natural gas export (J_{17}) which corresponded to almost 79%; assets loss in agricultural production (J_{18}) that was around 20% and assets loss in wood export (J_{16}) with less than 1%. One of the other two outflows from the stock represented the emergy of goods (excluding wood and wood products) exported (J_{19}) and finally, the flow J_{20} stands for the depreciation of assets.

Bolivia's money came from five different sources in 2005 four of them are considered a direct input for the stock money and the fifth one is taken into account as part of the stock debt. Money received for natural gas exports (J_{22}) accounted for almost half of the total money received in 2005. On the other hand, the amount of money received for wood export (J_{23}) was only \$37.8 million or less than the 2% of the total (FAO, 2006). Money received for export of assets (J_{24}) represented the money received for the emergy exported on the flow J_{19}. The fourth input was the money received from external aid (J_{21}) and correspond to the donations from international agencies received in 2005 (Figure 7.1).

7.2 Model Equations

The algebraic expressions, in addition to the difference equations listed below provide the value of inputs, storages and flows used in model calibration.

$$R = \frac{J_0}{K_a * S + K_b * S * W} + 1 \tag{7.1}$$

$$\frac{dS}{dt} = (K_{1a} * R * S) + (K_{1b} * R * S * W) - (K_2 * S(A * W)) - (K_3 * A * S) - (K_5 * S) \tag{7.2}$$

$$\frac{dW}{dt} = (K_6 * R * S * W) - (K_7 * A * W) - (K_9 * A * W) - (K_{10} * W) \tag{7.3}$$

$$\frac{dG}{dt} = -(K_{11} * A * G) - (K_{12} * A * G) \tag{7.4}$$

$$\frac{dA}{dt} = (K_{13} * A * W) + (K_{14} * A * G) + (K_{15} * \frac{M}{P_t}) - (K_{16} * A * W) - (K_{17} * A * G) - (K_{18} * A * S) - (K_{19} * A) - (K_{20} * A) \tag{7.5}$$

$$\frac{dM}{dt} = (K_{21} * U) + ((K_{19} * A)P_a) + (J_8 * P_w) + (J_{11} * P_g) + (J_{27} * Z) - (I_t * D) - (J_{15} * P_t) - (K_{28} * M) \tag{7.6}$$

$$\frac{dD}{dt} = (J_{27} * Z) - (K_{28} * M) \tag{7.7}$$

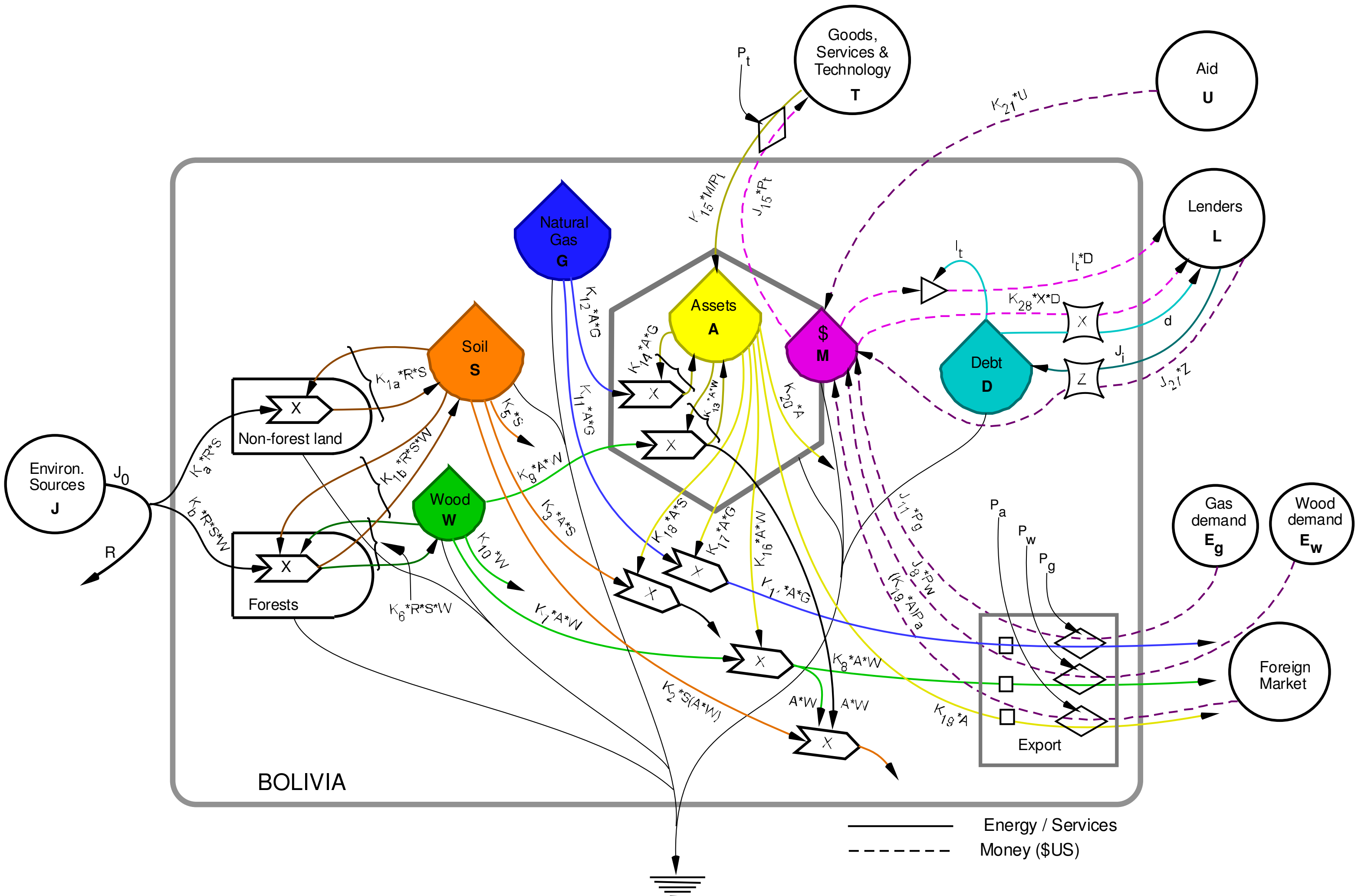


Figure 7.3. Energy systems diagram of simulation model with equations

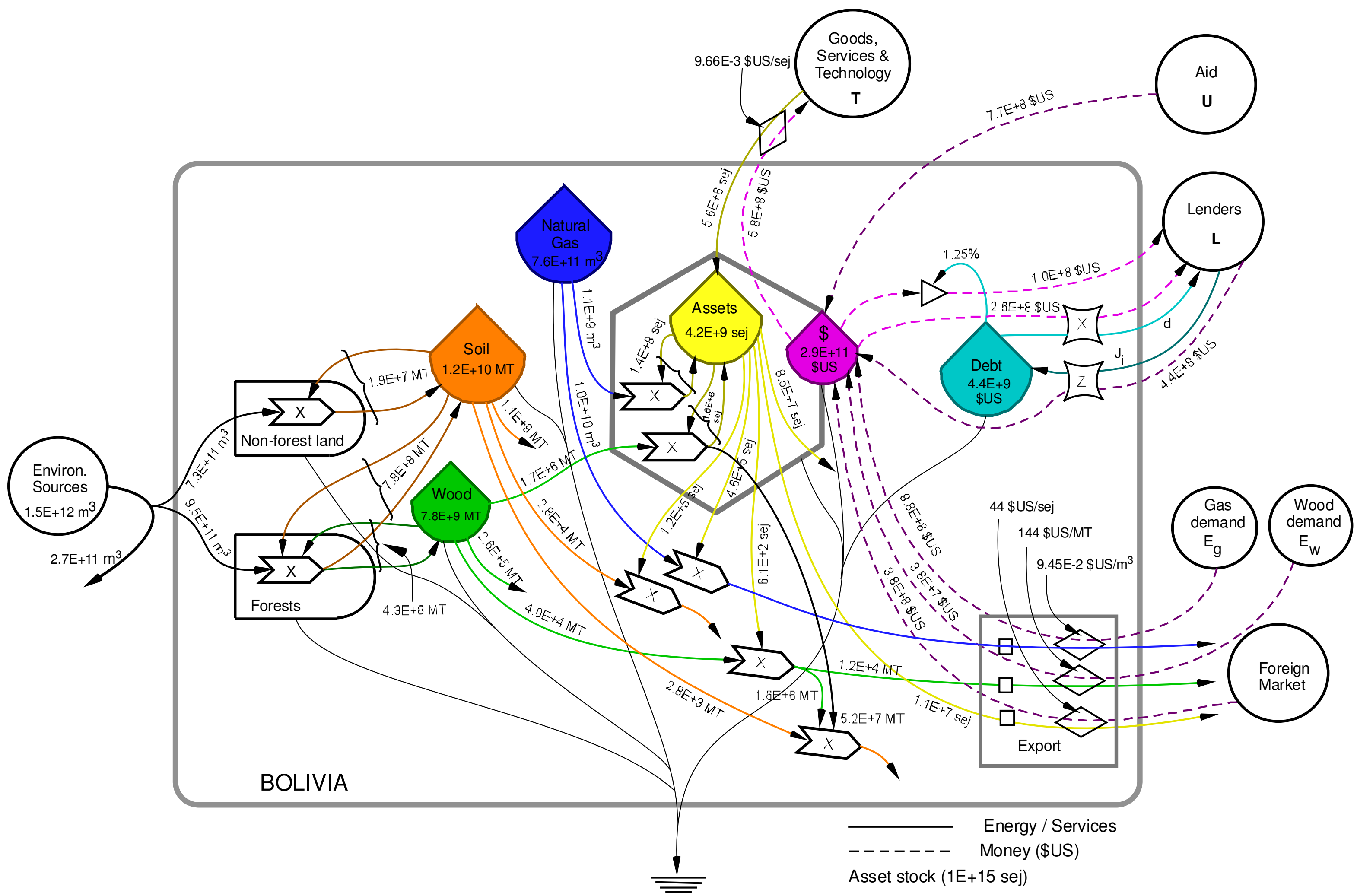


Figure 7.4. Energy systems diagram of simulation model with calibration values

Table 7.2. Numbers and calibration for the model

Item	Description	Variable	Equation	Calibration			Notes	Reference
				Value	Unit	*k*- Value		
Inputs								
1	Environmental sources	J		1.5E+12	m^3/yr		Average annual country precipitation	(SENAMHI, 2006)
2	Remainder	R		2.7E+11	m^3/yr		18% of environmental sources	
3	External aid	U		3.8E+10	$/yr		Global external aid availability	(World Bank, 2004)
4	External demand for wood	E_w		2.7E+07	MT/yr		Potential external market for wood	(INE, 2006)
5	External demand for natural gas	E_g		4.9E+09	m^3/yr		Potential external market for natural gas	(INE, 2006)
6	External demand for assets	E_a		1.5E+06	MT/yr		Potential external market for assets	(INE, 2006)
Flows								
7	Resources flowing into non-forestal land	J_a	k_a*R*S	7.3E+11	m^3/yr	2.33E-10	Non-forest land area x evapotranspiration	(FAO, 2006; University of Oregon, 2004)
8	Resources flowing into forestal land	J_b	k_b*R*S*W	9.5E+11	m^3/yr	3.87E-20	Forest land area x evapotranspiration	(FAO, 2006; University of Oregon, 2004)
9	Soil formation (rate of C increase) non-forest land	J_{1a}	k_{1a}*R*S	1.9E+07	MT/yr	6.23E-15	0.38 MT C x area	(Amado *et al.*, 2006)
10	Soil formation (rate of C increase) forest land	J_{1b}	k_{1b}*R*S*W	7.8E+08	MT/yr	3.20E-23	Above + Belowground det. (13.3 MT C) x area	(Malhi and Grace, 2000)
11	Soil use - Forest lands	J_2	k_2*S(A*W)	2.8E+03	MT/yr	7.36E-27	(9.4E+6 MT C / 9.2E+8 ha) x deforested area	(Malhi and Grace, 2000)
12	Soil use - Non-forest lands	J_3	k_3*A*S	2.8E+04	MT/yr	5.67E-16	(8E+6 MT C / 147E+8 ha) x Non forest land	(Schlesinger, 1984)
13	Soil loss due to domestic used of wood	J_{4a}	A*W	5.2E+07	MT/yr	2.56E-03	Assumed	
14	Soil loss due to wood extraction for export	J_{4b}	A*W	1.6E+06	MT/yr	4.82E-14	Assumed	
15	Soil natural loss	J_5	k_5*S	1.1E+09	MT/yr	9.20E-02	Soil respiration= 9.7 x national area	(Malhi and Grace, 2000)
16	Wood growth	J_6	k_6*R*S*W	8.6E+06	MT/yr	3.53E-25	Net wood accumulation rate 7.34 MT/ha/yr	(Jordan, 1983)
17	Wood export	J_7	k_7*A*W	4.0E+04	MT/yr	1.20E-15	Roundwood + sawnwood exports	(FAO, 2006)
18	Wood products export	J_8	k_8*A*W	1.9E+04	MT/yr	5.78E-16	Panels and furniture exports	(FAO, 2006)

Table 7.2. Numbers and calibration for the model (Continued)

Item	Description	Variable	Equation	Calibration			Notes	Reference
				Value	Unit	*k*- Value		
Flows								
19	Domestic use of wood	J_9	k_9*A*W	1.7E+06	MT/yr	5.06E-14	Wood and fuelwood used	(FAO, 2006)
20	Wood loss	J_{10}	k_{10}*W	2.6E+05	MT/yr	3.34E-05	Wood residues	(FAO, 2006)
21	Natural gas export	J_{11}	k_{11}*A*G	1.0E+10	M^3/yr	3.25E-12	NG exports	(YPFB, 2005)
22	Domestic use of natural gas	J_{12}	k_{12}*A*G	1.1E+09	M^3/yr	3.44E-13	Natural gas consumed domestically	(YPFB, 2005)
23	Assets produced from wood	J_{13}	k_{13}*A*W	1.6E+06	*E15 sej	4.92E-14	Emergy of wood + fuelwood used	Table 5.1 (#14, #15)
24	Assets produced from natural gas	J_{14}	k_{14}*A*G	1.4E+08	*E15 sej	4.43E-14	Emergy of natural gas + oil used	Table 5.2 (N_1)
25	Goods and services import	J_{15}	k_{15}*M/P_t	5.6E+06	*E15 sej	1.86E-07	Flow of imported emergy	Table 5.2 (F, G, P_2I)
26	Assets loss in wood export	J_{16}	k_{16}*A*W	6.1E+02	*E15 sej	1.84E-17	Emergy fraction of service in exports	Table 5.1 (#38)
27	Assets loss in natural gas export	J_{17}	k_{17}*A*G	4.6E+05	*E15 sej	1.43E-16	Emergy fraction of service in exports	Table 5.1 (#38)
28	Assets loss in agricultural production	J_{18}	k_{18}*A*S	1.2E+05	*E15 sej	2.42E-15	Emergy fraction of service in exports	Table 5.1 (#38)
29	Assets export	J_{19}	k_{19}*A	1.1E+07	*E15 sej	2.55E-03	Emergy of goods (- wood) exports	Table 5.2 (B); Table 5.1 (#33)
30	Assets depreciation	J_{20}	k_{20}*A	8.5E+07	*E15 sej	2.00E-02	1/50 of Emergy of assets (A)	Table 5.3
31	Money received from external aid	J_{21}	k_{21}*U	7.7E+08	$/yr	2.01E-02	Donations form international agencies in 2005	(World Bank, 2006)
32	Money received for natural gas export	J_{22}	J_{11}*P_g	9.8E+08	$/yr		Natural gas exported x NG price	(YPFB, 2005)
33	Money received for wood export	J_{23}	J_8*P_w	3.8E+07	$/yr		Logs exported x logs price	(FAO, 2006)
34	Money received for assets export	J_{24}	(k_{19}*A)P_a	3.8E+08	$/yr		Dollars received for exports	Table 5.2 (E)
35	Money spent on imports	J_{25}	J_{15}*P_t	5.8E+08	$/yr	5.78E+08	Dollars paid for imports	Table 5.2 (I)
36	Interest outflow	J_{26}	I_t*D	1.0E+08	$/yr		Money paid as interest in 2005	(BCB, 2006a)
37	Loans	J_{27}*Z		4.4E+08	$/yr		Money received as loans in 2005	(BCB, 2006a)
38	Repayment outflow	J_{28}	k_{28}*X*D	2.6E+08	$/yr	5.33E-02	Money paid as principal in 2005	(BCB, 2006a)
Storages								
39	Soil - Total national carbon storage	S		1.2E+10	MT		162 MTOC/ha (forests) + 40.5 MTOC/ha (non-forests)(0-20 cm)	(Malhi & Grace, 2000; Amado *et al.*, 2006)
40	National land area	S_{a+b}		1.1E+12	m^2		Total national area	(CIA, 2006)

Table 7.2. Numbers and calibration for the model (Continued)

Item	Description	Variable	Equation	Calibration			Notes	Reference
				Value	Unit	*k*- Value		
Storages								
41	Non-forest land area	S_a		5.1E+11	m^2		National land area - forest land area	(FAO, 2006)
42	Forest land area	S_b		5.9E+11	m^2		Area covered by forests	(FAO, 2006)
43	Deforestation in 2004			2.8E+09	m^2		Annual rate of deforestation	(SIF, 2006)
44	Evapotranspiration non-forest land area	ET_a		1.42	m/yr		Annual rate of E.T. in non-forest lands	(University of Oregon, 2004)
45	Evapotranspiration forest land area	ET_b		1.61	m/yr		Annual rate of E.T. in forest lands	(University of Oregon, 2004)
46	Estimated wood reserve	W		7.8E+09	MT		Biomass stock in forests & other wooded land	(FAO, 2006)
47	Natural gas Reserve	G		7.6E+11	m^3		National reserve of natural gas	(YPFB, 2005)
48	Natural gas Production			1.3E+10	M^3/yr		Total amount of NG extraction in 2004	(YPFB, 2005)
49	Assets	A		4.2E+09	*E15 sej		Assets built by emergy accumulation	Table 5.3
50	Money supply for the country (M4)	M		2.9E+11	$		Money in all its forms circulating in the country	(BCB, 2006)
51	Debt	D		4.9E+09	$		Accumulated debt in 2005	(BCB, 2006)
Prices								
52	Price of wood export	P_w		144	$/MT		Avg. price roundwood, sawnwood, panels	(FAO, 2006)
53	Price of round wood export			75	$/MT			(FAO, 2006)
54	Price of sawn wood export			329	$/MT			(FAO, 2006)
55	Price of panels export			260	$/MT			(FAO, 2006)
56	Price of natural gas export	P_g		9.45E-02	$/$m^3$			(YPFB, 2005)
57	Price of assets export	P_a		44	$/sej			Calculated
58	Price of goods, services and technology import	P_t		9.66E-03	$/sej		$ spent on imports/Goods and services import	Calculated
59	Loans interest rate	I_t		1.25	%		Average interest rate	(World Bank, 2004)
60	Switch action for payback X=1 starts	X		1				
61	Switch action for external aid and debt Z=1 starts	Z		1				

7.3. Model Calibration

The process of fitting the model with numbers is known as model calibration and the numbers are basically used to calculate the constant coefficients of equations to be used in the simulation. The values used to calibrate this simulation model are showed on pathways and storages in Figure 7.4. Descriptions of all the flow pathways along with equations, calibration values, pathway coefficients rates, notes and references for the derived calibration values are displayed in Table 7.2.

Most of the numbers used to calibrate this model have been collected from different sources, some have been assumed and others, when necessary, have been calculated. This section explains how coefficients were calculated after figures were found for all the different processes.

Pathway coefficients, designated as k's in this model, indicate how much flow there is on a pathway in terms of contributing forces or concentrations. After numerical values of flows and storages are placed on the emergy systems diagram (Figure 7.4), calibration was accomplished by calculating a table of coefficients from these numbers (Table 7.2). Calculations for this model were made using a spreadsheet Excel® which eased performance of mathematical operations.

Bolivia (the whole country) was the spatial area and the unit of time used for the whole model was years; however, in order to generate a realistic output, the interval time (*dt*) was reduced to 1/10 of a year for each step. The other units used varied according to each storage. For example, for the stock soil, it was considered variations of MT of carbon per year; for wood MT of biomass per year; for assets solar emergy joules per year (sej/yr) and for stock of money and debt $ (Figure 7.5).

7.3.1. Inputs

Environmental sources were taken as the average of annual precipitation for the country at 1.5E+12 m^3/yr (SENAMHI, 2006). During calibration and simulations the remainder (18%) was considered (2.7E+11 m^3/yr). Potential external markets for wood, natural gas and assets estimated by the Bolivian census bureau were taken as constant values for 2005: external demand for wood (E_w) being 2.7E+07 MT/yr, external demand for natural gas (E_g) being 4.9E+09 m^3/yr and external demand for assets (E_a) being 1.5E+06 MT/yr.

7.3.2. State Variables

An example on how the calibration was made each of the state variables can be seen in Figure 7.5, which shows the processes for soil formation and use or loss of soil.

To represent the soil storage in the country, the total national carbon storage was calculated. Based on data provided by Amado *et al.* (2006) and Malhi and Grace (2000) it was found that there are 1.2E+10 MT of carbon in the first 20 cm of soil, at the rate of 162 and 40.5 MT/ha for forest and non-forest areas respectively.

The estimated wood reserve (W) of 7.8E+09 MT (FAO, 2006) represents the stock of biomass for the whole country; however flows of wood represent only the portion of wood extracted from forests as timber. The natural gas reserve (G) corresponds to the proved national reserve of natural gas which according to YPFB (2005) it was 7.6E+11 m^3 in the year 2005. The national assets storage (A) was assumed to be the total emergy used in the country in 2005 (7.93E+23 sej) minus the renewable emergy flow for the same year (5.82E+23 sej) accumulated during the last

20 years; resulting in 4.2E+24 sej that represent the assets built by emergy accumulation. The money stock (M) corresponds to the money in all its forms (M4) circulating in Bolivia in the year 2005 (2.9E+11 $), and the debt variable (D) represents the accumulated debt that the country owes to all its creditors in the same year (4.9E+09 $).

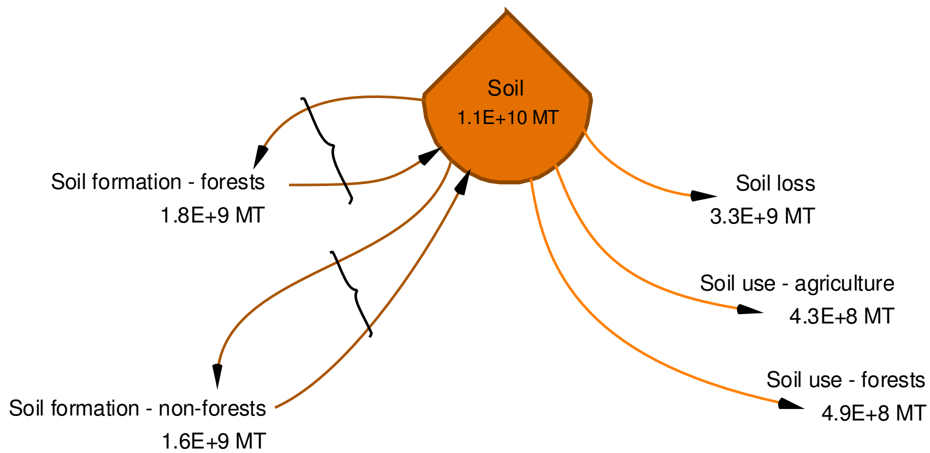


Figure 7.5. Soil stock and calibration numbers (stocks and flows in Carbon-C)

7.4. Results

Four different scenarios for Bolivia's forest economic strategy were simulated using the model DEBBIF. Simulations covered the period between the years 2005 and 2205. This section shows the behavior of the main Bolivian storages for each scenario highlighting the relationship among variables. It also shows the output for each scenario, where each variable for all the scenarios reveals the effect of each policy on each sector and/or stock of the economy.

7.4.1. The Reference Scenario

Figure 7.6 presents the output chart of the Reference Scenario, which represented the best estimate of the "business-as-usual" situation. Under this scenario, natural gas was exported and used domestically at moderate rates which increased assets up until year 2040, while money, debt and wood storages continued to increase up through 2205. Soil shows a rapid decay in the first 20 years, and after that reaches a steady state. Natural gas reserves declined.

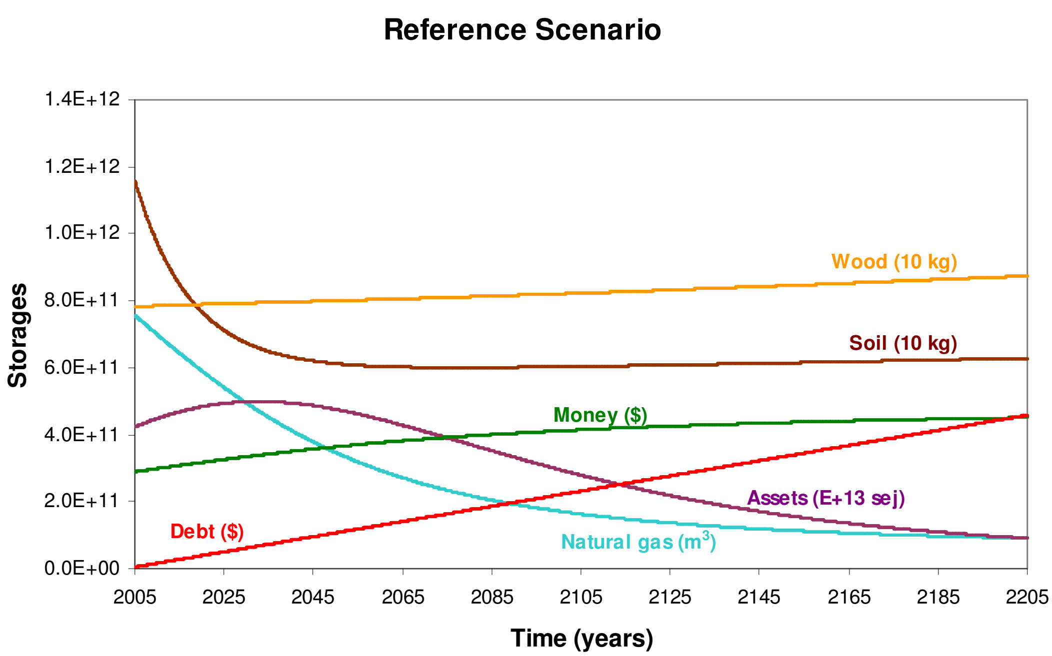


Figure 7.6. The Reference Scenario

The Reference Scenario highlighted the fact that Bolivia's debt will continue to grow and that economic expansion of assets occurs for a relatively brief period of 40 years, before long term decline begins. Each alternative scenario tested will be compared to the Reference Scenario.

Table 7.3 shows the changes made on the k-values of the model to simulate different scenarios.

Table 7.3. Summary of changes that took place to simulate each scenario

			Reference	Increased Export		Increased Domestic Use		National Industrialization	
				2x	10x	2x	10x	2x	10x
Wood	K_7	Export	1.20E-15	2.39E-15	1.20E-14	=	=	=	=
	K_8	Products export	5.78E-16	1.16E-15	5.78E-15	=	=	=	=
	K_9	Domestic use	5.06E-14	=	=	1.01E-13	5.06E-13	1.01E-13	5.06E-13
Natural gas	K_{11}	Export	3.25E-12	6.50E-12	3.25E-11	=	=	=	=
	K_{12}	Domestic use	3.44E-13	=	=	6.88E-13	3.44E-12	6.88E-13	3.44E-12
Assets	K_{13}	From wood	4.92E-14	=	=	=	=	9.84E-14	4.92E-13
	K_{14}	From NG	4.43E-14	=	=	=	=	8.87E-14	4.43E-13
	K_{19}	Export	2.55E-03	=	=	=	=	5.10E-03	2.55E-02
	K_{25}	$ for imports	5.78E+08	=	=	=	=	1.16E+09	5.78E+09

*Changes to the reference scenario; = means that no change took place

7.4.2. Increased Export Scenario

If Bolivia were to embrace economic 'globalization' and participate fully in the World Trade Organization's Global Agreement on Tariffs and Trade (WTO-GATT) as well as in regional trade agreements such as MERCOSUR (Southern Common Market) and the Andean Community, then a probable scenario would be for Bolivia to export more of its natural resources. To simulate the effect on the country of embracing such a policy, the simulation model was manipulated to increase the export of unprocessed wood, finished wood products and natural gas at two different levels over the current rates (2x, and 10x) by increasing pathway coefficients k_7, k_8 and k_{11} in the equations that represent forest exports (k_7*A*W and k_8*A*W) and gas exports (k_{11}*A*G) (Table 7.3).

Figures 7.7 and 7.8 plot the simulation of the Increased Export Scenario at two different levels.

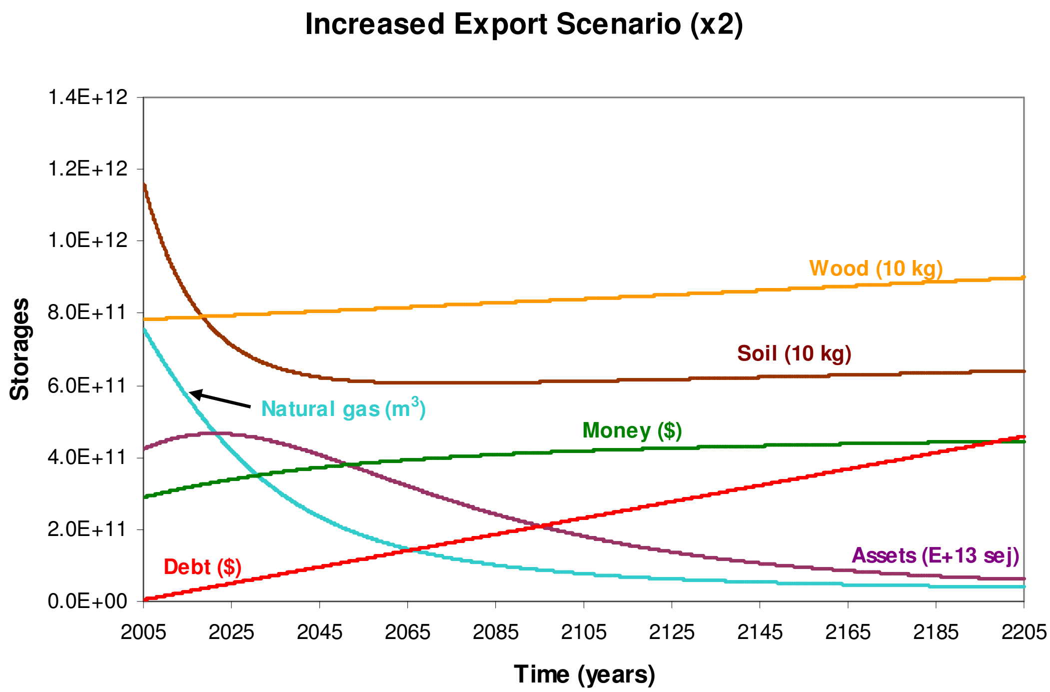


Figure 7.7. Increased Export Scenario with pathway coefficients increased by 2

When pathway coefficients are increased by 2, the patterns of change in major stocks of the model were similar to the Reference Scenario. However, the timing of peaks and levels achieved differed. Specifically, natural gas was depleted faster, but economic assets peaked sooner and at a lower level than in the Reference Scenario (Figure 7.7).

Increasing by 10 times the export of natural gas and wood, affects mainly stock of natural gas, which according to the model, it will vanish by 2060 (Figure 7.8).

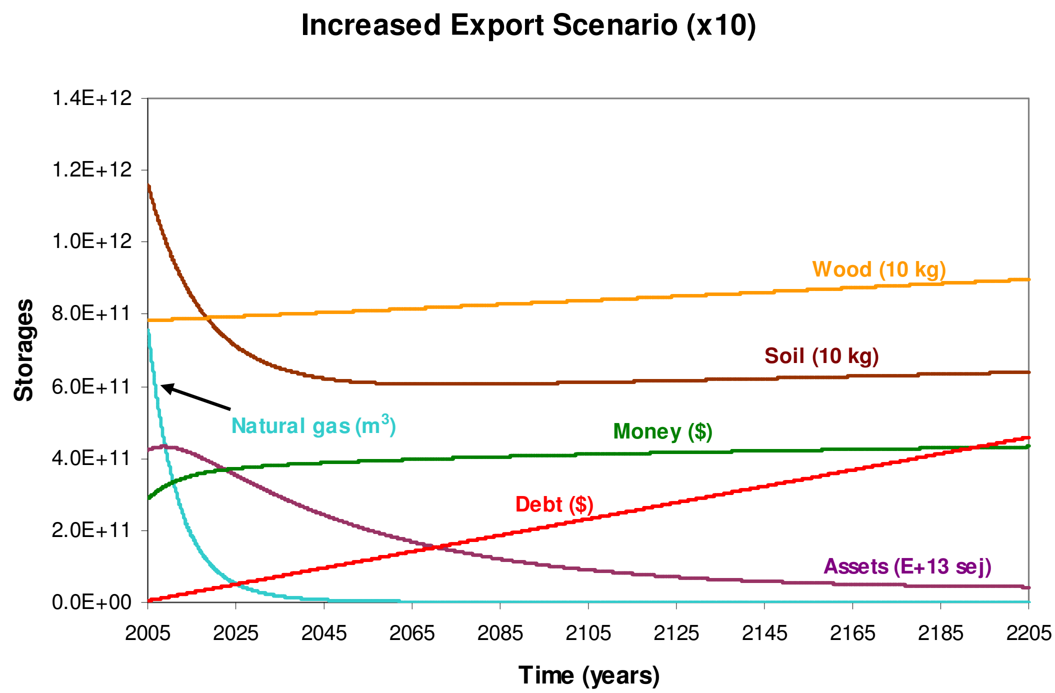


Figure 7.8. Increased Export Scenario with pathway coefficients increased by 10

7.4.3. Increased Domestic Use Scenario

As a result of a national referendum that took place on 2004, Bolivia's population decided to take back control of natural gas and oil production and trade. In May 2006 the new Bolivian president signed a supreme decree (No. 28701) for the nationalization of hydrocarbons. Under the argument that the natural resources are for the Bolivians, the government had clear intentions to increase the domestic use of natural gas and forest resources.

This situation formed the basis of the Increased Domestic Use Scenario. The domestic use of wood and natural gas were manipulated by changing associated pathway coefficients (i.e., k_9, and k_{12}) in the equations k_9*A*W for the wood and $k_{12}*A*G$ for the natural gas (Table 7.3). Wood and natural gas consumed in Bolivia were increased by 2 and 10 times while exports of these products were kept at current rates.

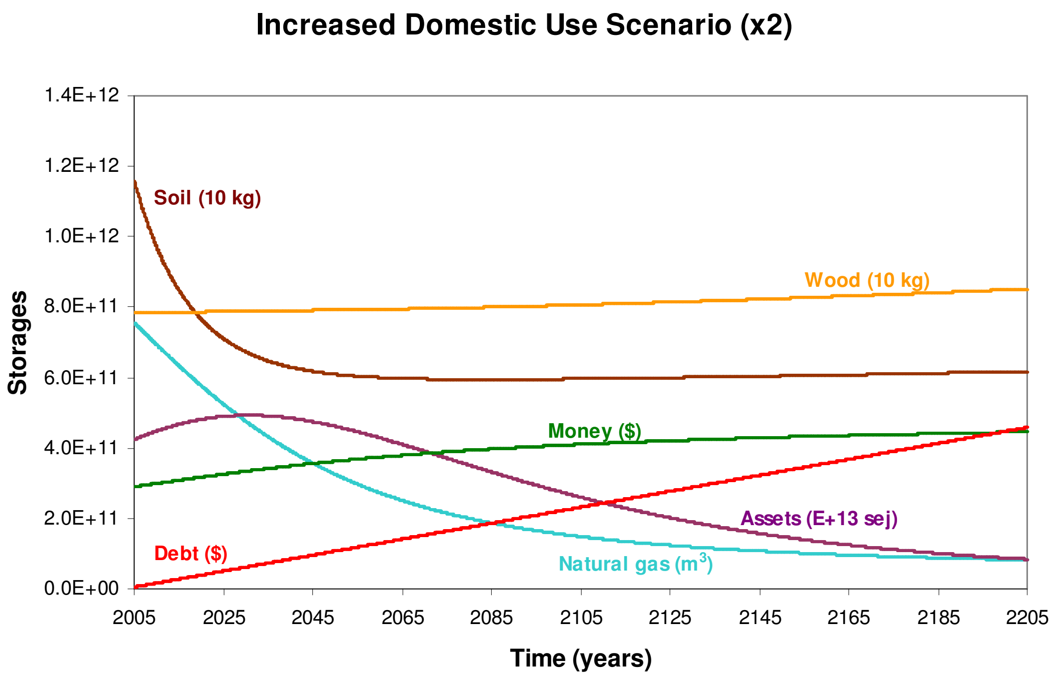


Figure 7.9. Increased Domestic Use Scenario with pathway coefficients increased by 2

The results presented in Figure 7.9 show that general relationships between the main storages reveal similar patterns to Reference Scenario.

When manipulation of pathways are increased 10 times in the Increased Domestic Use Scenario, the outcome reveals a faster decline in natural resources storages (soil, natural gas and especially wood), for a short-term there is an improvement in the national money supply which also suffers a slight decay.

Although it has been proved that countries rich in natural resources have a more self-sufficient and environmental oriented development, this scenario does not reflects a realistic venue for the country.

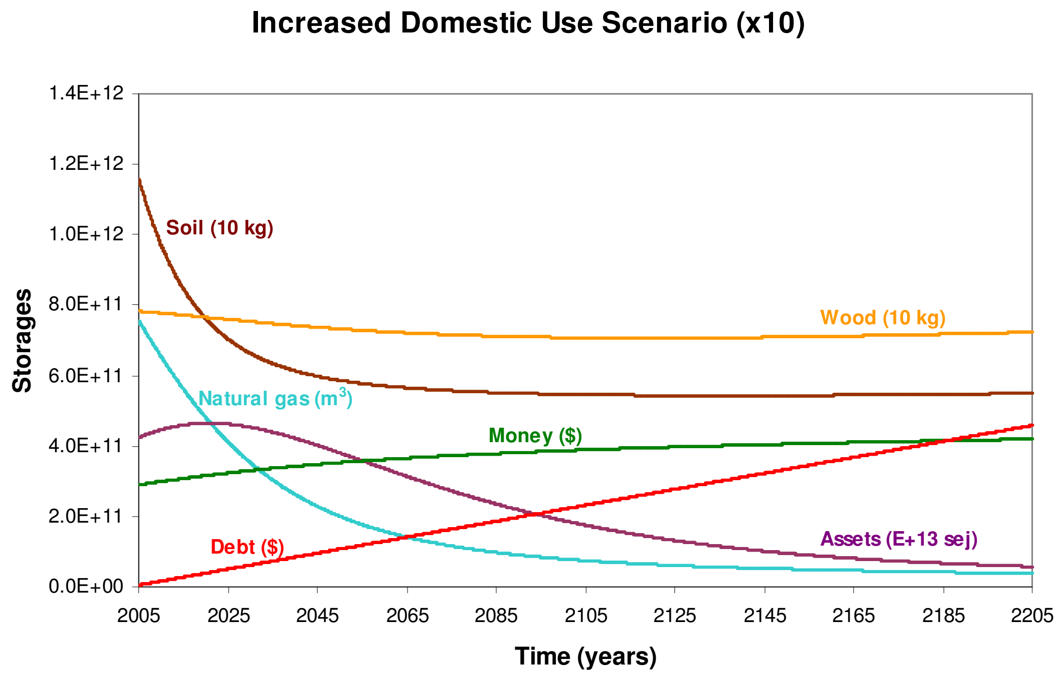


Figure 7.10. Increased Domestic Use Scenario with pathway coefficients increased by 10

7.4.4. National Industrialization Scenario

Parallel to the government incentive to increase the use of natural resources domestically, there are efforts to increase industrialized products for domestic and export markets. In the case of the timber industry, Bolivia is a leading country for tropical forest certification and it is slowly starting to implement a system that tracks the chain of custody for certified finished products. On the other hand, the government has expressed its concern about industrializing the natural gas and liberating Bolivia from its dependency on foreign products (i.e., fertilizers).

To better understand the intended process of industrialization in Bolivia, Niles' idea of theoretical development of a population towards a development stage was used (Niles, 1986), which is shown in Figure 7.11.

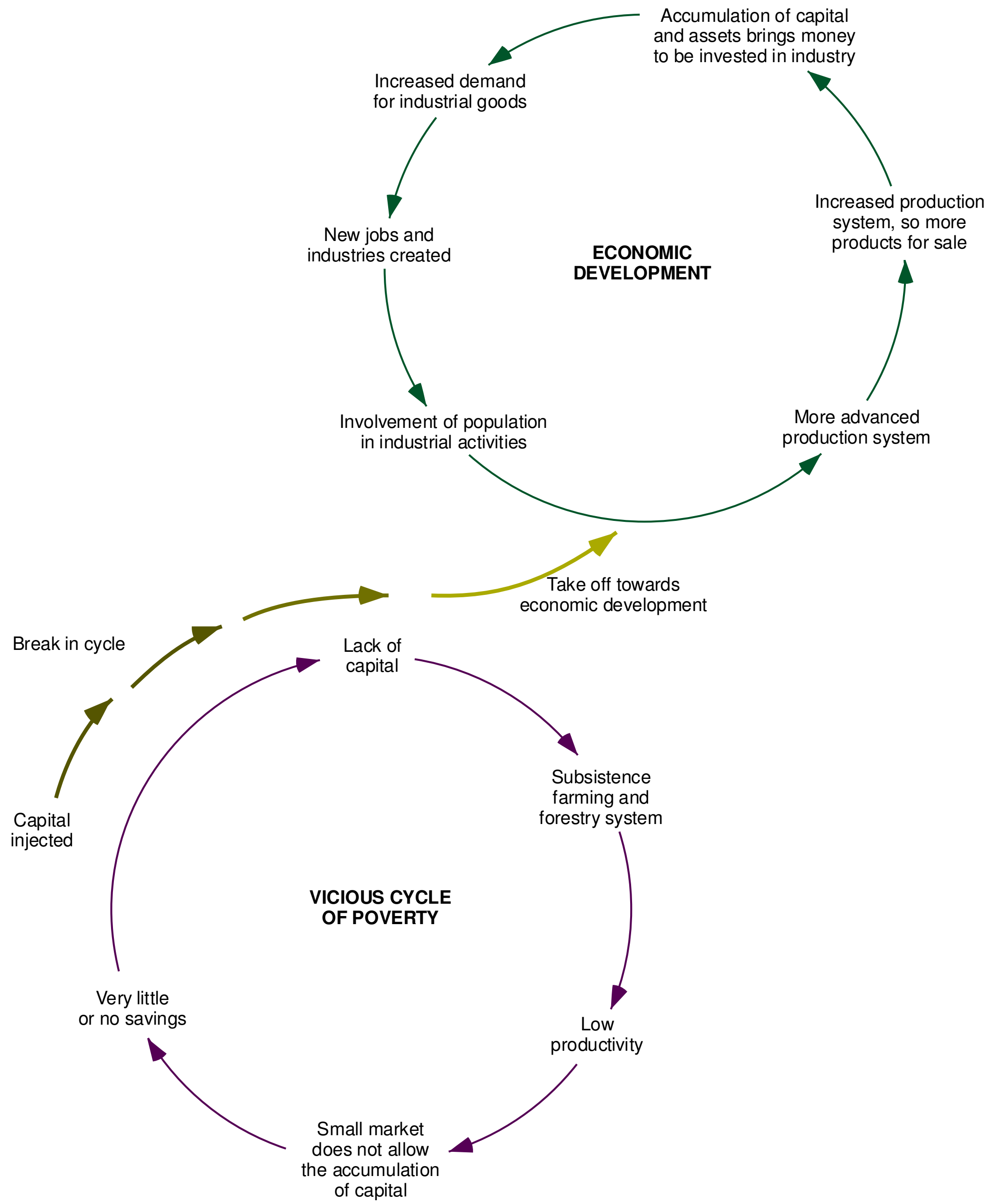


Figure 7.11. Theoretical development of a population from a stage of underdevelopment to development
Redrawn from: Niles (1986).

To explore the effect of increased industrialization on forests and the well-being of Bolivians, the simulation model was manipulated at two levels (2 times and 10 times over the current rates) to increase the processing of wood and natural gas by increasing pathway coefficients (i.e., k_7, k_8, k_9, k_{13} for forest resources, and k_{11}, k_{12}, and k_{14} for natural gas, k_{19} for export of finished products, and k_{25} for the money paid for imported goods) (Table 7.3). In the gas production equations k_{11}*A*G (exports), k_{12}*A*G (domestic use) and k_{14}*A*G (assets produced from natural gas) were changed and in the wood production equations k_7*A*W (exports), k_8*A*W (exports of wooden products) and k_{13}*A*W (assets produced from wood) were altered. Also, the equations k_{19}*A and J_{15}*P_t, which represent exports of processed resources and money spent on imports, respectively, were changed.

To simulate the National Industrialization Scenario, export of unprocessed wood and natural gas were kept at 2005's levels, while exports of processed forest products and the domestic use of natural gas were increased by 2 and 10 times. This would allow to process more raw products, for this reason, building of assets from wood products and natural gas, exports of finished products and money paid for imports were increased at the same corresponding rates. The increased rate of processing and manufacturing of finished products from its raw resources led Bolivia to export finished goods.

As shown in Figures 7.12 and 7.13, the Industrialization Scenario greatly increased Bolivia's assets. When pathways are multiplied by 2, there is a more sustained use of resources and the assets have a peak that remains for a long period of time. Starts growing up in 2020 and starts to decline in 2065. However, when the use of natural resources is estimated as ten times more, natural resources are quickly depleted building a short-term surge in assets.

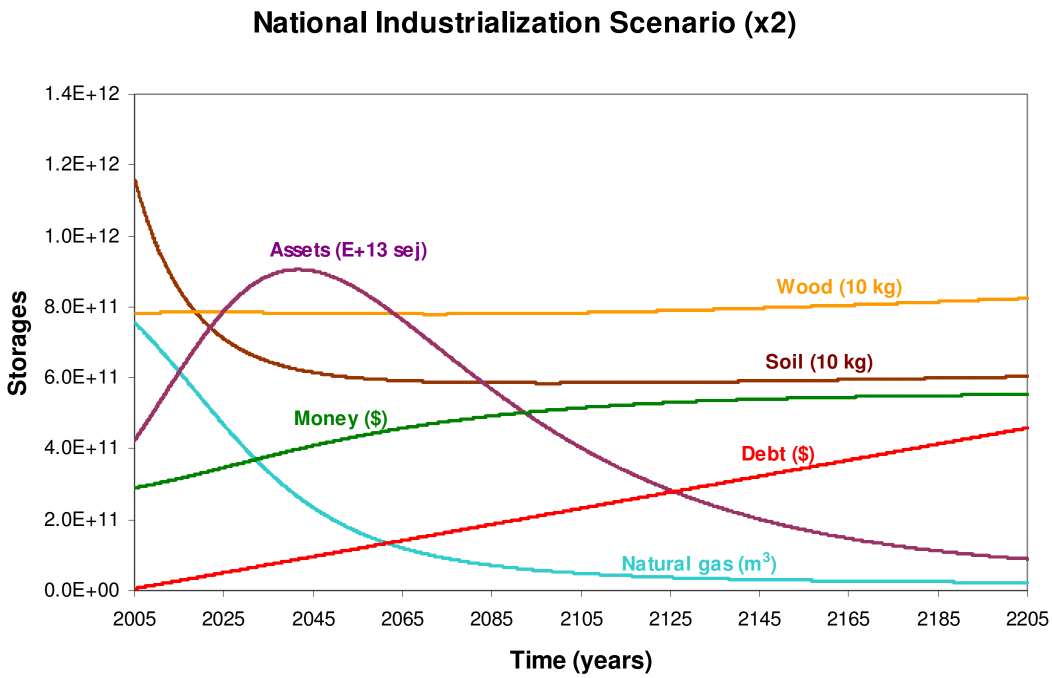


Figure 7.12. National Industrialization Scenario with pathway coefficients increased by 2

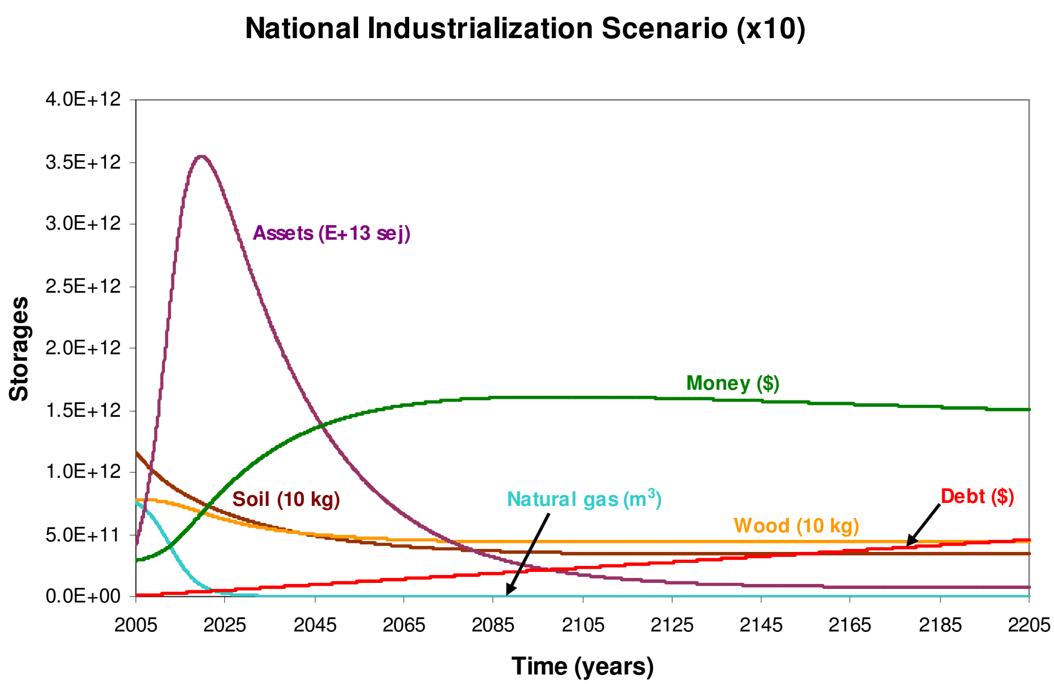


Figure 7.13. National Industrialization Scenario with pathway coefficients increased by 10

7.4.5. Simulation of stocks under different scenarios

Figures 7.14 to 7.21 show the response of each state variable to each of the economic policy scenarios under two different levels of data manipulation.

7.4.5.1. Changes on Natural Gas

Natural gas reserves declined faster under the Increased Export and National Industrialization Scenarios (Figure 7.14), and reserves lasted the longest under the Increased Domestic Use Scenario. The situation was similar when each scenario was manipulated to use the product by 10 times but natural gas reserves declined faster under all three non-reference scenarios (Figure 7.15).

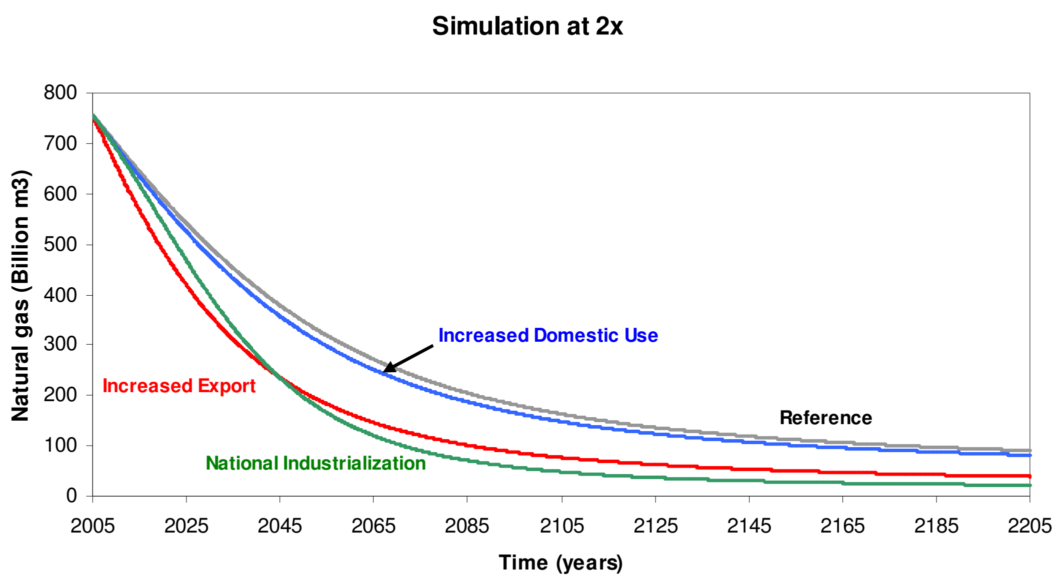


Figure 7.14. Simulation of natural gas under different scenarios and coefficients increased by 2

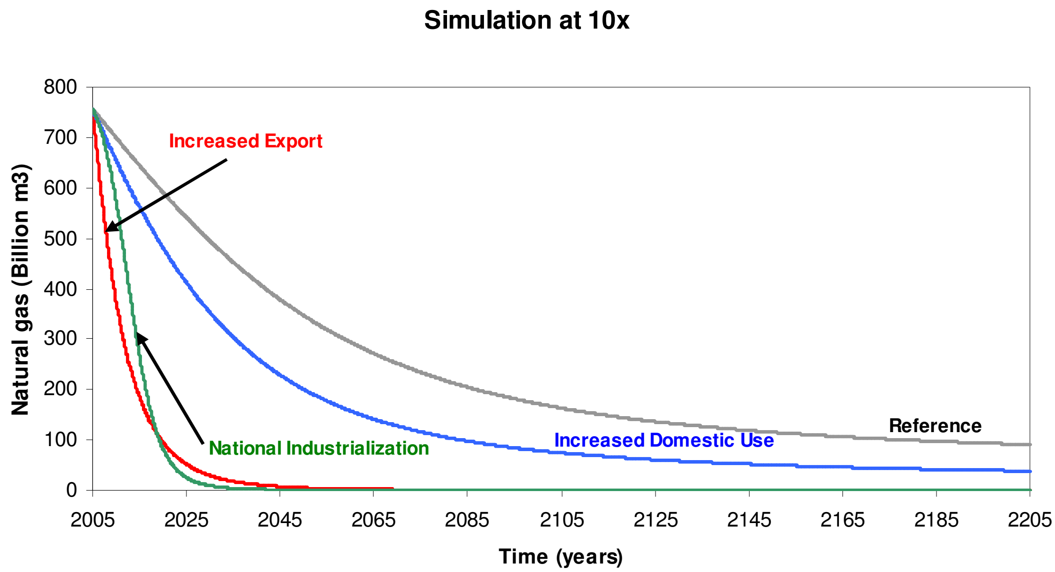


Figure 7.15. Simulation of natural gas under different scenarios and coefficients increased by 10

7.4.5.2. Changes on Wood

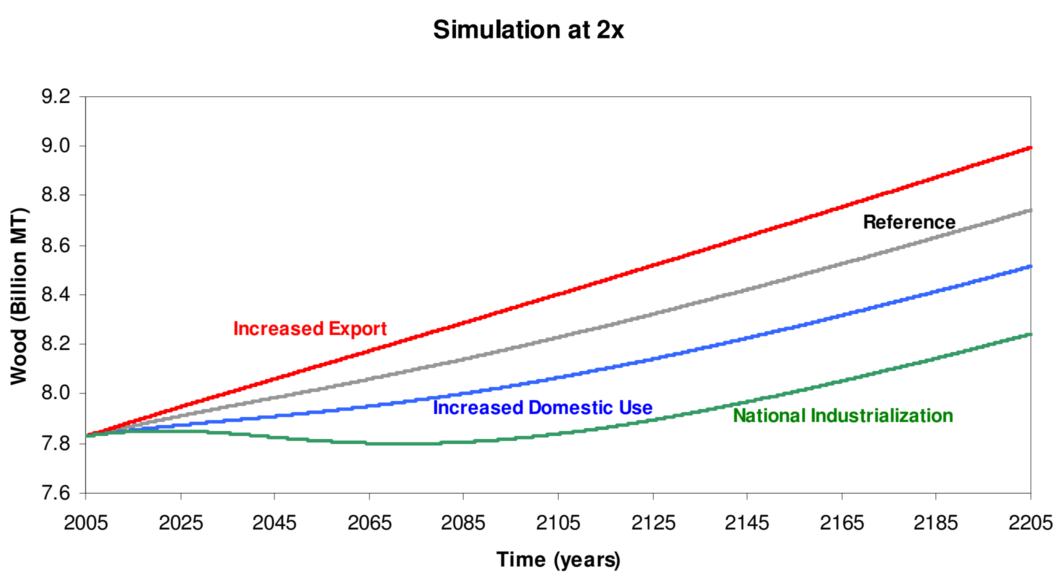


Figure 7.16. Simulation of wood under different scenarios and coefficients increased by 2

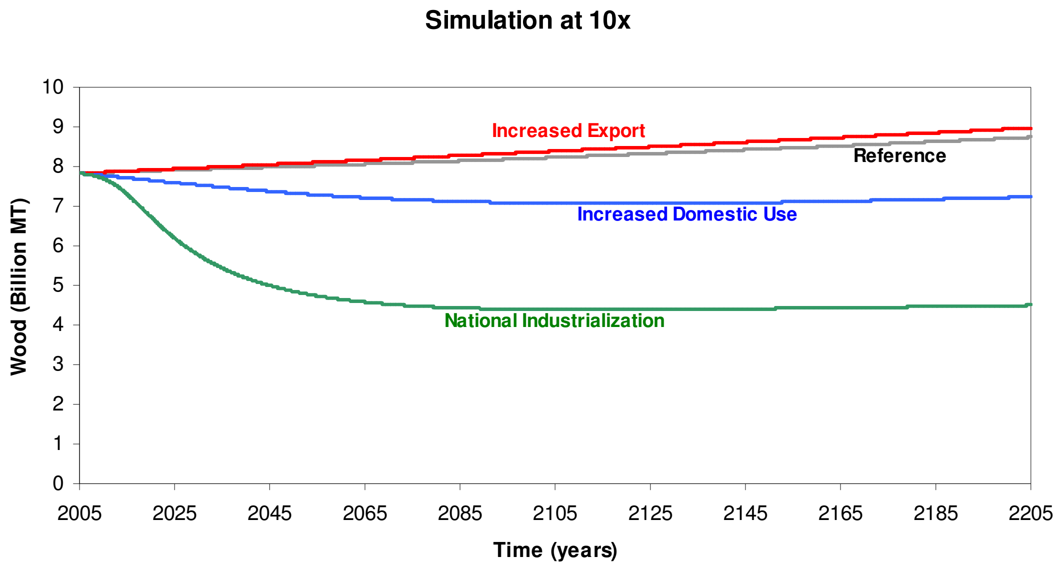


Figure 7.17. Simulation of wood under different scenarios and coefficients increased by 10

When pathways of wood use were increased by 2, there was an exponential growth in wood. Under National Industrialization and Increased Domestic Use Scenarios, this increase was lower compared with the Reference and Increased Exports Scenarios (Figure 7.16).

In the Increased Domestic Use and National Industrialization Scenarios wood stock decreased below the Reference Scenario when pathways were increased 10 times (Figure 7.17).

7.4.5.3. Changes on Money

Money supply gets gradually higher after 50 years under the National industrialization Scenario and pathways increased by 2 (Figure 7.18).

When pathways were increased by 10 times, money reached its maximum in a term of approximately 70 years under the Increased Industrialization Scenario (Figure 7.19).

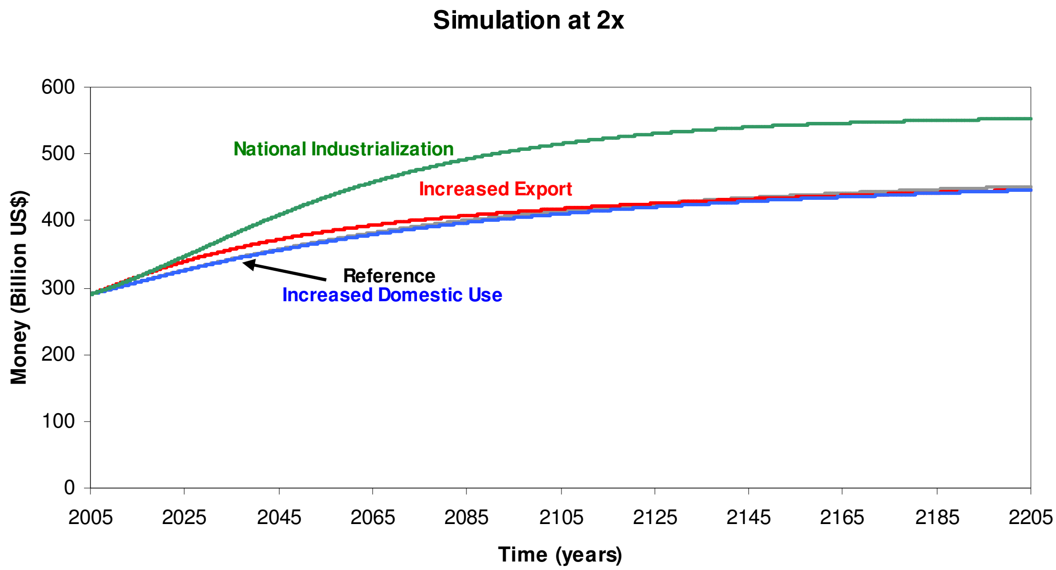


Figure 7.18. Simulation of money under different scenarios and coefficients increased by 2

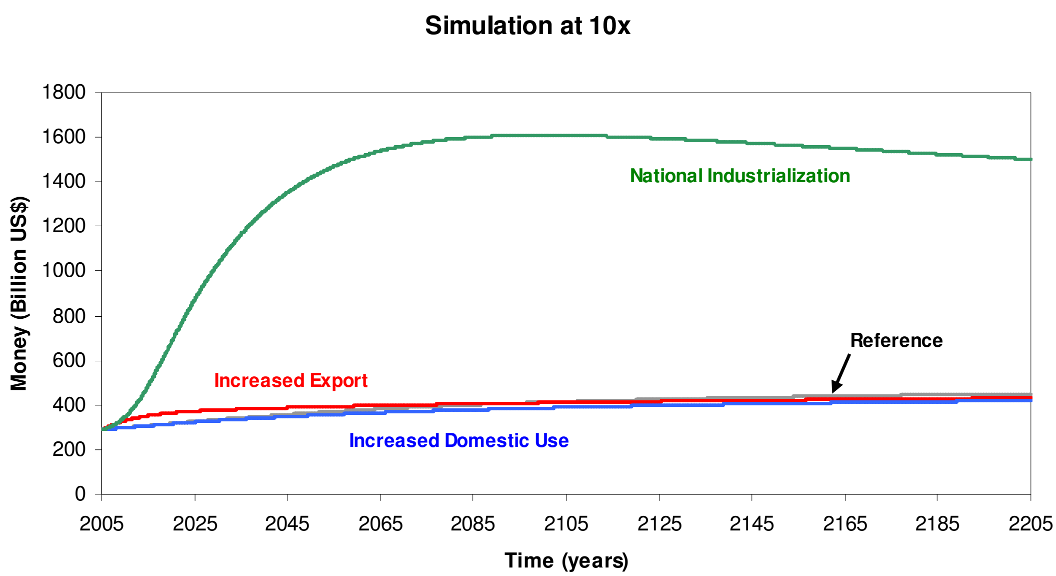


Figure 7.19. Simulation of money under different scenarios and coefficients increased by 10

The last situation may respond to the fact that Bolivia receives more money from exporting finished products at a higher price and maintain its capacity to build assets from domestic use of products.

7.4.5.4. Changes on Assets

National assets were clearly maximized under the National Industrialization Scenario when the scenario was simulated at a 2x or 10x rate of increase (Figures 7.20 and 7.21). The Increased Export Scenario produced lower levels of national assets than the Reference Scenario; however the Increased Domestic Use Scenario produced a higher level compared to the Reference Scenario. When the simulation was done using 10 fold rates, it took place the same phenomenon observed for money.

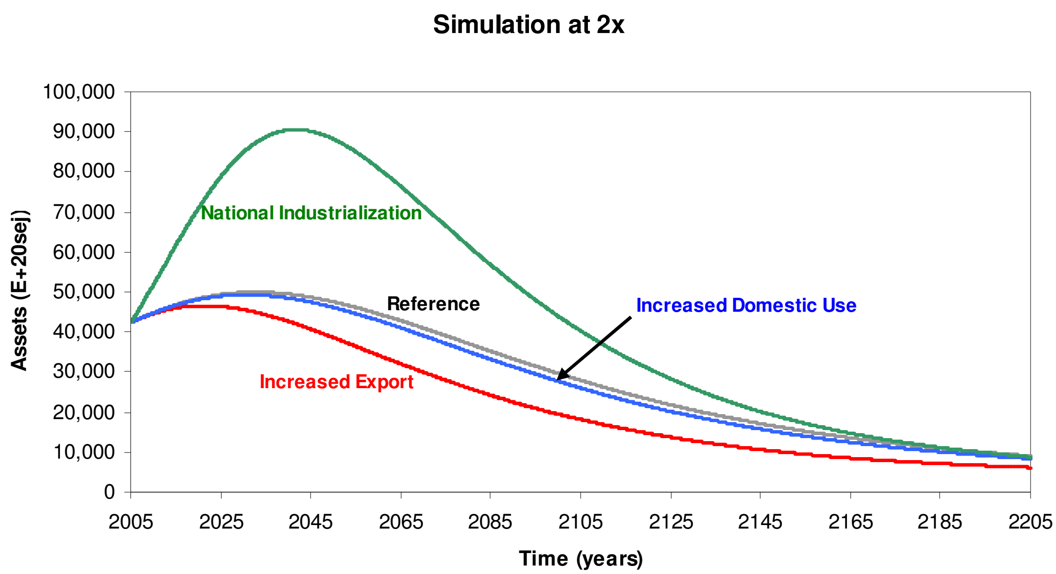


Figure 7.20. Simulation of assets under different scenarios and coefficients increased by 2

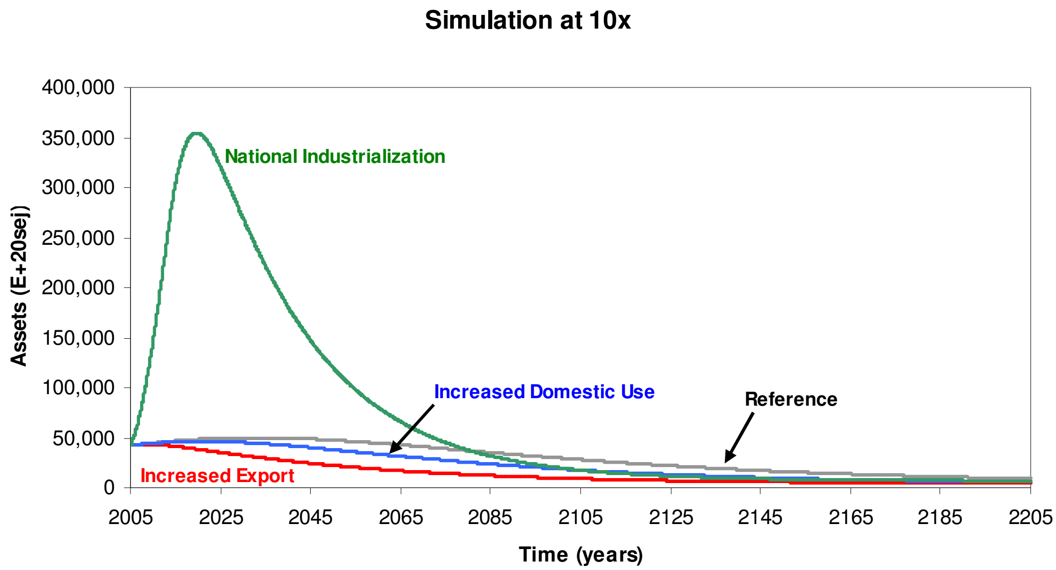


Figure 7.21. Simulation of assets under different scenarios and coefficients increased by 10

7.4.6. Simulating the Flow of Money

Figures 7.22 and 7.23 show the money flow for Bolivia from 2005 to 2205 under two different levels of simulation. Domestic product was the sum of assets produced from wood and natural gas divided by the emergy-to-dollar ratio for Bolivia (3.31E+13 sej/$). Exports and imports represented the money received and paid for goods and services respectively. External aid was the sum of money that came from international loans and donations.

Clearly, Bolivia's national income was greatest under the National Industrialization Scenario. By processing its raw resources into manufactured goods for domestic consumption and increased its exports by 2 times, Bolivia was able to increase Domestic Product by 100% over the Reference Scenario (Figure 7.22).

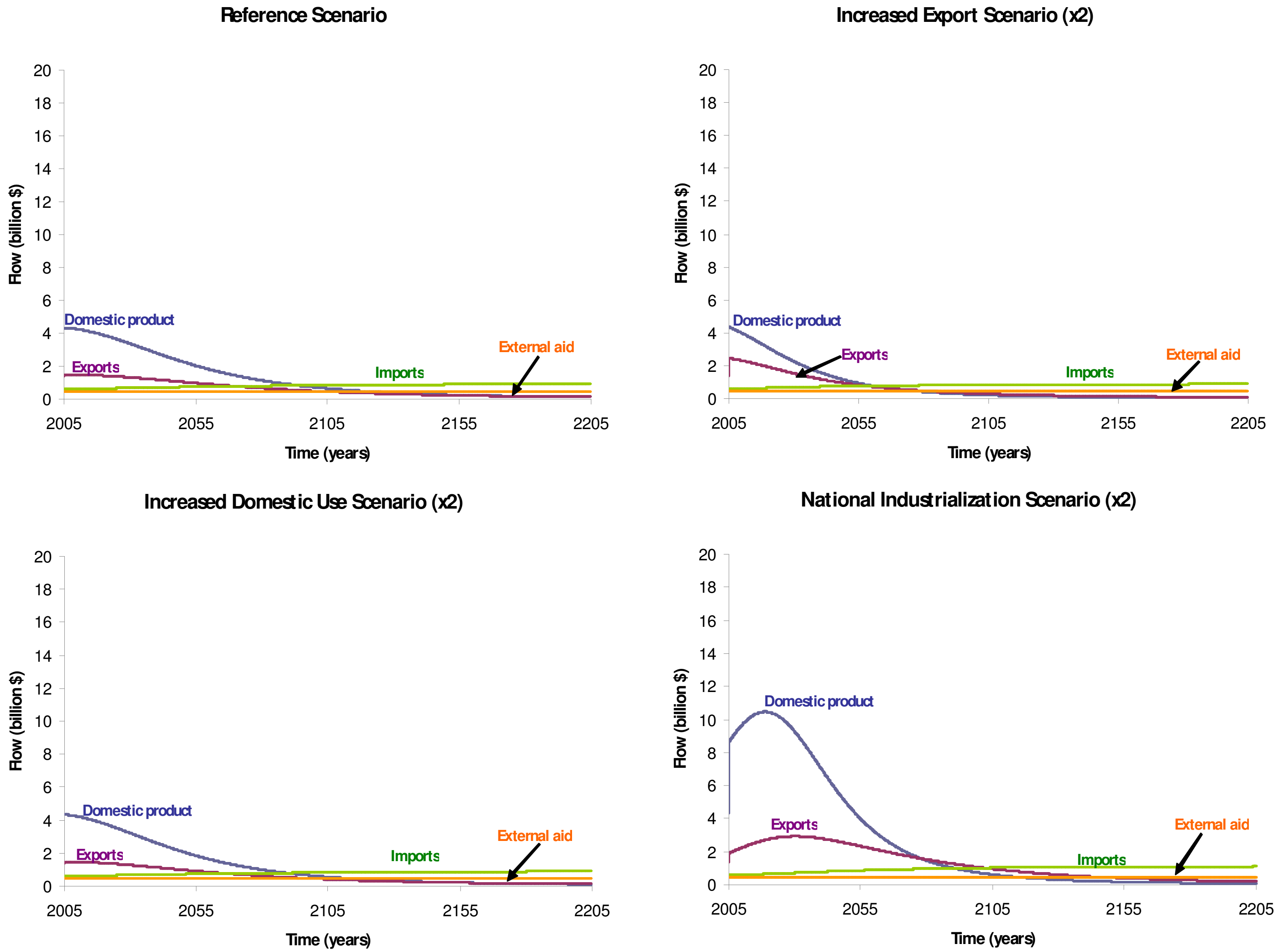


Figure 7.22. Simulation of money flow using model DEBBIF and pathway coefficients increased by 2

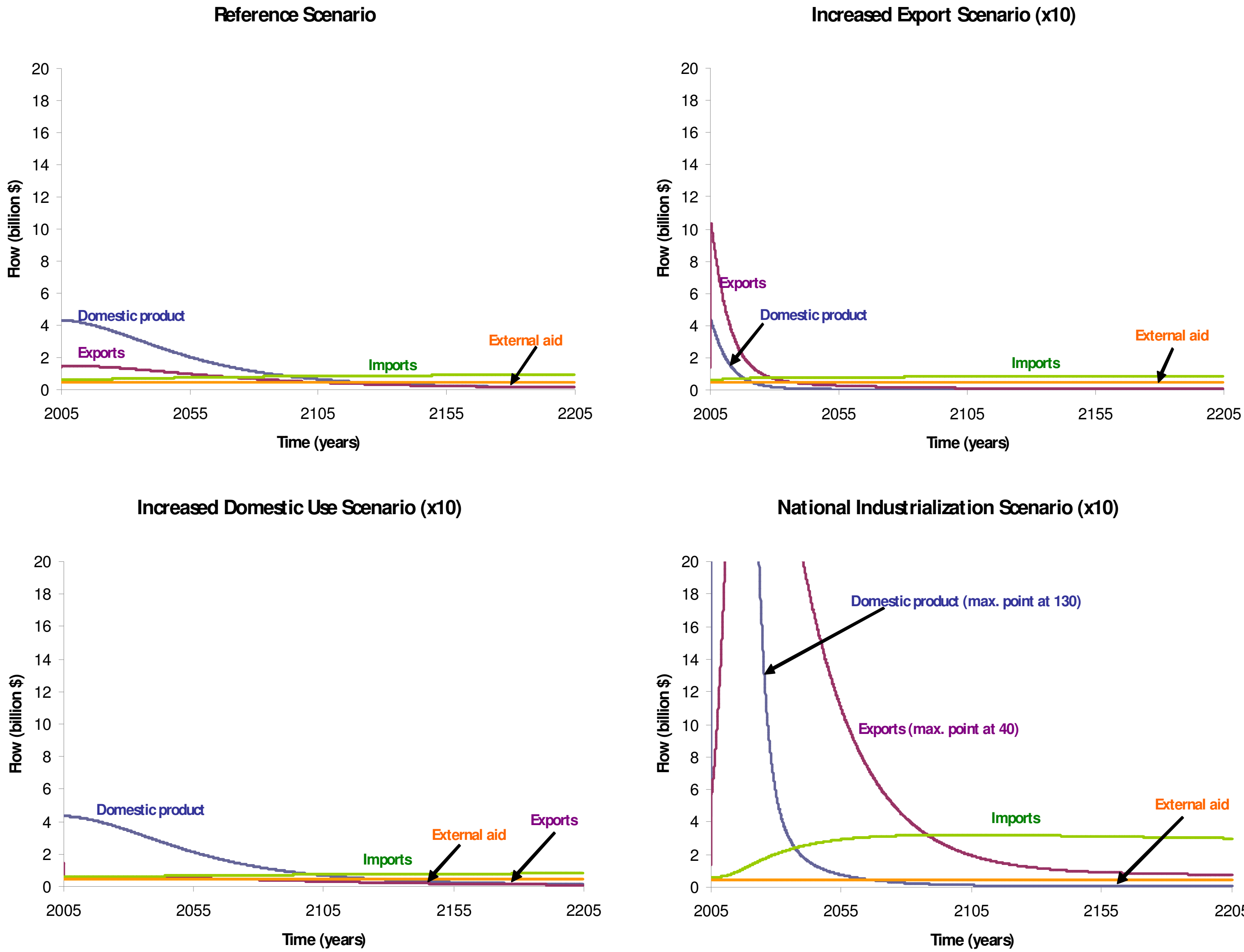


Figure 7.23. Simulation of money flow using model DEBBIF and pathway coefficients increased by 10

When the processing of raw resources into manufactured goods for domestic consumption and export was increased by 10 times, the obtained results surpassed any expectation adjusted to reality (Figure 7.23).

7.4.2. Assets Per Capita

Figures 7.24 and 7.25 show the assets per capita of Bolivia for the following 50 years. This ratio was obtained dividing national assets by the United Nations' population prospect for Bolivia. If assets would be distributed among the population, at least for the first 50 years, all the population will do better with the Increased Industrialization Scenario.

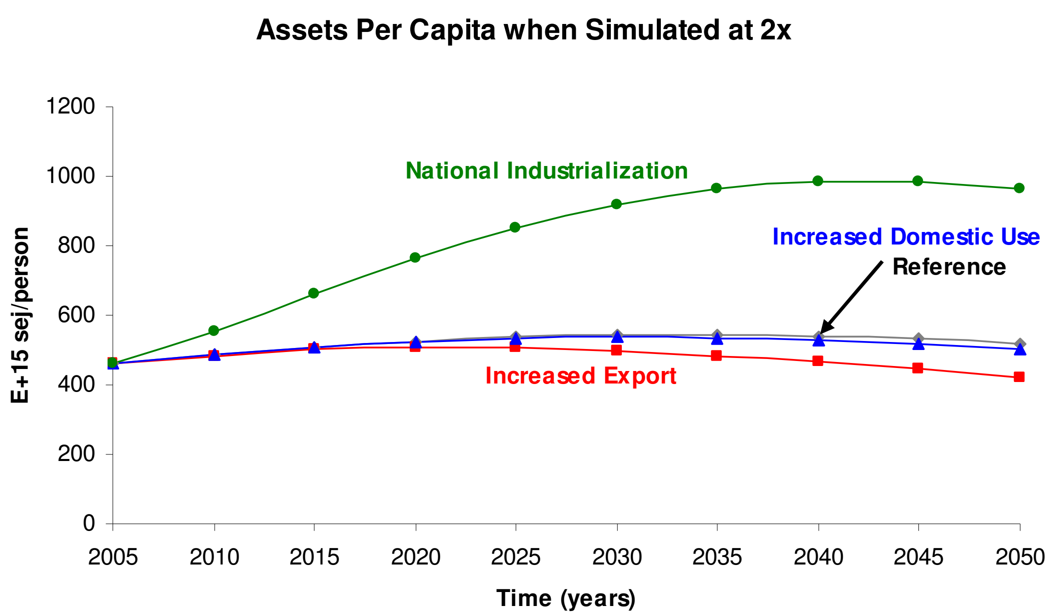


Figure 7.24. Comparison of assets per capita under different scenarios with coefficients increased by 2

Source for population data: (United Nations, 2007)

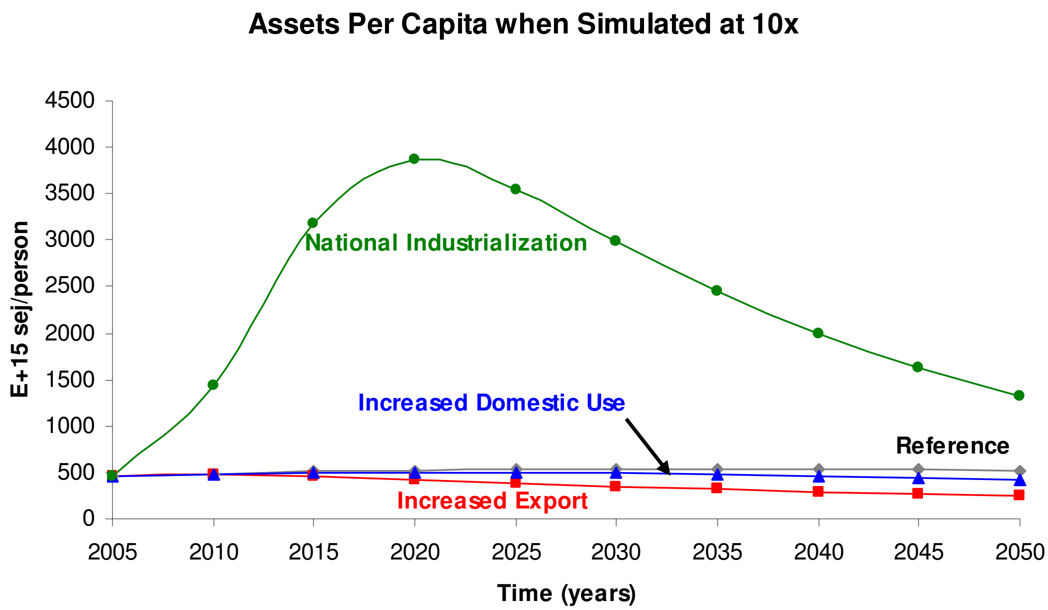


Figure 7.25. Comparison of assets per capita under different scenarios with coefficients increased by 10

Source for population data: (United Nations, 2007)

7.4.3. Domestic Product Per Capita

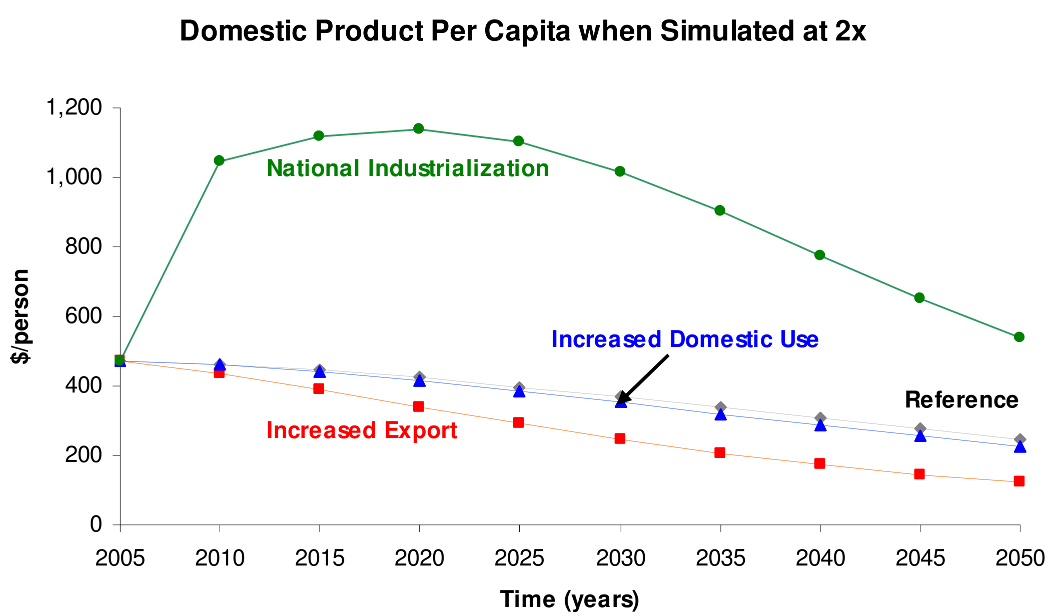


Figure 7.26. Comparison of domestic product per capita under different scenarios with coefficients increased by 2

Source for population data: (United Nations, 2007)

Figures 7.26 and 7.27 represent the evolution domestic product per capita ratio for the following 50 years of Bolivia. These values were obtained dividing national domestic products by the United Nations' population prospect for Bolivia. If domestic product (as money) would be distributed among the population, Bolivians will do better with the Increased Industrialization Scenario.

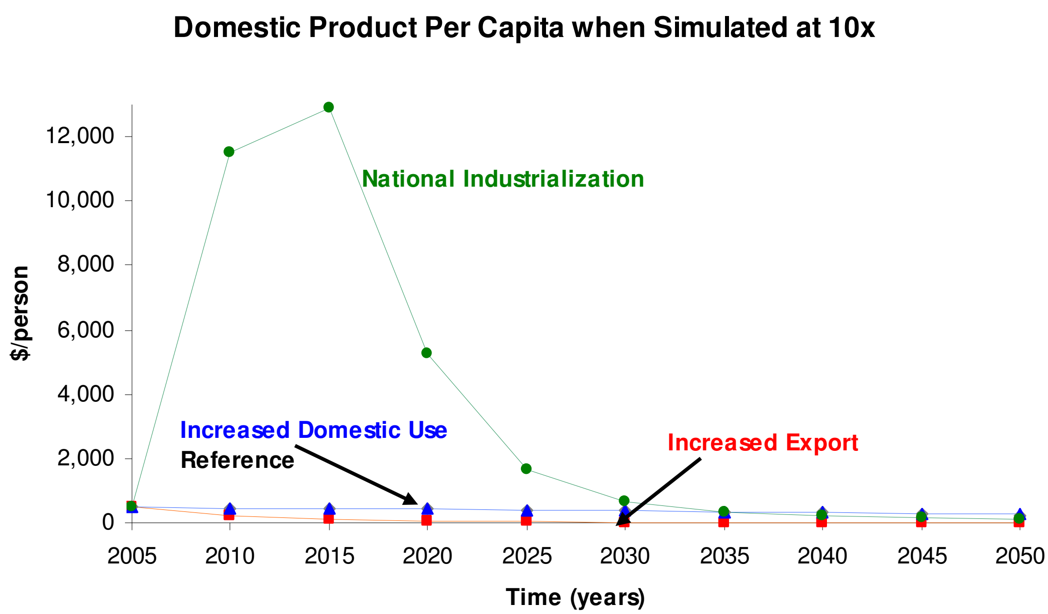


Figure 7.27. Comparison of domestic product per capita under different scenarios with coefficients increased by 10
Source for population data: (United Nations, 2007)

7.5. Concluding remarks about DEBBIF

Simulation of the "Ecologically-based Development for the Bolivian Industrial Forestry System" (DEBBIF) model was calibrated using data for the year 2005. Simulation Period was from 2005 to 2205, considering four different scenarios. The Reference Scenario that represented "business-as-usual" situation for Bolivia, the Increased Exports Scenario, the Increased Domestic Use Scenario and the Increased Industrialization Scenario. All four scenarios were simulated to observe the behavior of the state variables considered in the model (i.e., soil - total national carbon storage, estimated wood reserve, natural gas reserve, national assets, money supply for the country - M4, and total national debt) at two different rates of internal use and export.

Neither the increase on exports of raw natural resources (i.e., natural gas and wood) nor their use exclusively within the country, are good scenarios for the future national wealth. It was found that processing goods from natural resources helps to develop assets for the country and improves the generation of income from exporting the processed items and the ratio of emergy per person as well.

Future improvements for the model could be included for a more advanced and detailed one: detailed process of timber industrialization, incorporation of the education component which furnishes qualified professionals during the different stages of processing, utilizing and marketing natural resources and an optimization of the rates of change of natural resources used for each scenario.

Chapter 8: Discussions and Conclusions

8.1. Introduction

For the last six years, Bolivia has been in social turmoil, where political, social and economic transformations have taken place due to social movements originated by grassroots organizations especially indigenous groups. The single most important aspect of these transformations is that they have occurred through the democratic system, for example: the resignation and presidential succession (2003 and 2005), the constitutional reform (2004), the decentralization of the government and the successful completion of much-anticipated national elections (2005), the people's referendum, during the same year, and the constituent assembly which occurred in 2006.

The triumph of Mr. Evo Morales in the presidential election, not only changed the political climate in the country but also created (and it is still creating) an economic and social transformation. For the first time in almost two decades, a president was directly elected without pacts or alliances between political parties and with more than 50% of citizen support. Evo, elected by 53.7% of the population, is the first indigenous president whose leadership was forged in union and social activism with the clear intention to end the systematic exclusion of rural indigenous people in public life and although he did not put an end, he is changing the patterns of paternalism from international community. As one of the first accomplishments and in a climate of controversy throughout the region, Morales has brought back Bolivia's natural resources production under state control. This means that companies operating the largest gas fields will keep only 18% of what they produce, down from 50%, while retaining 40% at smaller fields.

Viewed the oil and gas nationalization from a Bolivian perspective, is not really nationalization but the return to constitutionality since there is a strong legal argument that the privatization of the natural resources that took place in the mid-1990's was unconstitutional.

Before all these political changes started happening in the country, other measurements took place in regards to the forest resources. Bolivia was one of the first countries to initiate efforts promoting the conservation of its natural tropical forests through sustainable management and forest certification, a trend that began early in the 1990s and grew stronger following the passing of the country's forestry law in 1996. Since then, Bolivia has certified more than two million hectares of its forests, making the country the world leader in tropical forest certification under FSC's standards. In addition to the economic benefits, certification has also had a positive impact on social conditions. For example, certification has improved labor conditions of forestry workers increasing the level of income, safety, hygiene and health, as well as access to opportunities to strengthen their capacities.

Despite the successful results of the forestry sector and the large investments and the discovery of immense reserves of hydrocarbons in 1996, the average Bolivian is worse off than twenty years ago, for example, national exports have declined, personal incomes are stagnant, and the Bolivian population did not perceive real benefits from this reform (half of the population lives on less than $2 a day).

Even though some economy analysts speculated that Bolivia's new nationalization policy would make things worse by scaring off future investments, this does not appear to be true. The principal companies which invested in Bolivia - Brazil's Petrobras, Spain's Repsol and Britain's BG Group- have announced they will continue operating in the country (Anderson, 2007). The companies will still profit but under the new rules. The world needs natural resources like gas, oil, and wood, and Bolivia and its neighbors need to sell it but it seems that Bolivia is just struggling for a way to make the national marketing strategy work.

The social demand for a more active participation of the state in the natural resources management and people's request for industrialization of natural resources instead of exporting a raw material, offers the chance to strength the possibility for a better national industry with a possible synergic integration of the most promising sectors i.e., forestry and natural gas.

My research has led me to examine how these two most significant natural resources can play a crucial role in the national economy and the livelihoods of Bolivian population. In studying each of these resource systems I have directed my attention to their value in terms of emergy units and the changes that may incur over the time, under different scenarios.

8.2. General Points

a. Almost half of Bolivia's territory is covered by natural forests (53 million ha) from which, 30 million has the potential for timber extraction. The country has proven natural gas reserves of 26.7 trillion cubic feet and its production reached 1.4 billion cubic feet per day.

b. Since 1990, forest activities have generated for the country around $122 million annually and total wood production and timber industry represents 3% of the national GDP. Ninety thousand people work in the different forestry processes and around 250,000 people are involved indirectly in the sector.
c. The Bolivian forest industry is very inefficient in using its installed capacity, mainly operating only at 50% of its potential, mainly due to lack of roads and up-to-date machinery. As a result, the wood producing chain has higher costs than their competitors.

8.3. Maximum Empower for Bolivia

Emergy has been used in this study as an environmental accounting tool that allowed comparing the work of the environment with the work of the human economy on a common basis. Emergy, for example, assisted estimating the natural value of forestry based on the work of the environment to create and maintain the Bolivian forests, whereas an approach based on a human's perspective might value the timber only according to the market price of the timber extracted. Once estimated the timber's natural value, emergy accounting estimated its value to the market by considering the human controlled energies used for its extraction and processing and the potential economic gain the forests could represent in the Bolivian economy (Buenfil, 1998).

According to Richardson and Odum (1981), in order to maximize the combined economy of humanity and nature, it is required to maximize the emergy production and use at each level of hierarchy at the same time. This way, the emergy flux of the whole system is maximized when the oscillation frequencies on each scale are adjusted for maximum average emergy. This useful emergy flux, also known as empower inspired to H.T. Odum to correlate emergy with the maximum power principle and established the Maximum Empower Principle.

8.3.1. Example

The empower (emergy per time) of natural resources that contribute to the economy of Bolivia can be expressed as emdollars (EM$) by dividing the solar empower by the solar emergy-to-money ratio, which places solar empower in a more conventional unit of information framework for people (i.e., money) that makes easier to contextualize. Emdollars indicate how much the forest and/or the natural gas contribute to the national economy. This way all the environmental contributions, which are free to an economy, can be compared to more traditional macroeconomic measures.

8.4. The Bolivian Forest Certification System

The cost of forest certification (payment for fees and pre-harvesting planning) is a major expense in the certification process. So, one of the issues often addressed in relation to certification is whether a price bonus sufficient to pay the certification costs is reachable (Hjortsø *et al.*, 2006). In a conventional forestry system it may be arguable how to get the extra contribution of forests towards the achievement of economic goals. Forest development can be affected either by extensive growth through an expanded use of resources or by intensive growth through a more efficient use and value added. The first alternative usually implies selective logging, which may lead to genetic erosion (i.e., Mahogany), whereas the second could reduce employment opportunities for the poorest non-skilled sector. If Bolivia decides to set into a more entrepreneurial system in its natural gas and forestry sectors, it may highlight the need for educational programs targeted at the (now) non-skilled workers.

The primary aim of Bolivia, with regards to its tropical forests should be to contain deforestation providing a balance between conservation and development needs, keep supporting and protecting interests of indigenous forest dwellers but at the same time introducing new productive activities that harmonize with a comprehensive and sustainable environmental, social and economic development. Also, increased efforts should be made by the government to promote local participation to achieve conservation and development goals.

8.4.1. Example

This approach has already been experienced in Bolivia. Thirty thousand ha of forest in the Lomerio community has been certified under the own community management. A substantial price bonus was obtained in the initial stages - up to four times the Bolivian domestic prices (Markopoulos, 1998). Hanrahan *et al.* (1997) reported that in general a price bonus of 83 and 75% were paid for first and second grade timber on the other hand, Nebel *et al*. (2003) in a study of the Bolivian export market, based on sales figures from 2000 and 2001 reported a price bonus of 5-51% and they concluded that the price premium has at least compensated the forest enterprises for the direct costs of certification, which in the best case can facilitate positive changes in the natural capital and the economy of the country.

8.5. Changes in the Natural Capital and Economy of Bolivia

In the last years, Bolivia's trade with neighboring countries has been growing, in part because of several regional preferential trade agreements it has negotiated. As a member of the Andean Community, the country enjoys nominally free trade with other member countries like Peru, Ecuador, Colombia, and Venezuela. In March 1997, Bolivia began to implement an association agreement with MERCOSUR (Southern Cone Common Market). With the aim to obtain the benefits of free trade area that the agreement offers. A Bilateral Investment Treaty between the United States and Bolivia came into effect in 2001 allows numerous Bolivian products to enter the United States free of duty on a unilateral basis, including alpaca and llama products and, subject to a quota, cotton textiles. This way, the United States remains Bolivia's largest trading partner. Bolivia's major exports to the United States are tin, gold, jewelry, and wood products. Its major imports from the United States are computers, vehicles, wheat, and machinery.

Despite the growing export activity, the government of Bolivia remains heavily dependent on foreign assistance to finance development projects. At the end of 2005, the government owed $4.9 billion to its foreign creditors. Most payments to other governments have been rescheduled on several occasions since 1987 through the Paris Club mechanism. External creditors have been willing to do this because the Bolivian Government has generally achieved the monetary targets set by IMF programs since 1987. The situation doesn’t look very promising for Bolivia since economic crises in recent years have undercut the country’s normally good paying record. As a result, some countries have forgiven substantial amounts of Bolivia's bilateral debt (for example the U.S. and Spain Governments)

For this study we looked into the issue of natural resource dependence in Bolivia With its rising exports of natural gas, Bolivia is embarking on its second major episode of natural resource reliance in recent times, after the mining booms of the previous several decades.

8.6. Key Findings

The study's key findings are listed according to the Research Questions from Chapter 1.

1. In respect to how much is the wealth of Bolivia's national system in emergy dollars, and what is the emergy exchange ratio with its international trading partners, it was found that:
   - For the year 2005, the total emergy-to-dollar ratio of Bolivia was 3.3.1E+13 sej/$. This means that 8.55E+23 sej/yr of emergy were necessary to produce the GDP of $25.8 billion for the country in the year 2005.
   - In the same year, the overall net emergy exchange ratio between Bolivia and its trading partners was 6.27 to 1. This means that for each $ that the country received it delivered 6.27 times more in emdollar value.
   - The overall net emergy exchange ratio between Bolivia and its trading partners was found disadvantageous. The same trend was followed when considered natural gas' emergy exchange ratio; however, there is a comparative advantage when Bolivia exports forest products. This advantage is even greater when the forest products are certified.

2. As for the benefits of certified forestry for the Bolivian forest ecosystems and its national economy, it can be concluded that:
   - Forest certification is positive because it takes less from the environment, producing less natural capital waste, but its economic advantage to Bolivia depends on international demand for certified products and the price assigned on external markets.
   - In the year 2005, total emergy removed from Bolivian forests was 1.49E+19 sej/yr/ha for certified and 2.36E+19 sej/yr/ha for uncertified; meaning that in certified forestry less trees are taken and less damage due to soil erosion and tree damage is caused.
3. In reference to how the Bolivian natural capital changes under different trade scenarios in a time frame of 200 years, the study showed that:
   - National industrialization is the best scenario for the future of Bolivia. Increasing by two the rate of use of natural resources in industrialization processes, gives the country a higher level of assets and a better emergy per person.

Under the same scenario, which is increased industrialization based on forest and natural resources, Bolivia has the ability to improve its wealth without compromising the integrity of renewable natural resources such as wood and soil.

8.7. Plans for Future Research

The challenge for integrating a non-renewable resource into a strategy of vibrant economic growth supporting industrial development needs to be studied more deeply to achieve a strategy where fossil fuel revenues can be put to work in order to impel growth in other sectors of the economy and converting natural capital into physical and human capital. This should be an important role of Bolivian policymakers as an effort to secure a solid foundation for long-term national sustainable growth.

Considering the previous thought, this study's results could be improved performing complementary tasks, mostly obtaining some data to be included in the simulation model. The data suggested to be included is: the life cycle assessment of the forestry and natural gas industries at a local, regional and national level; the chain of custody that takes place within the forest certification process; finally, the accountability of real workforce related to the most promising sectors in Bolivia such as timber and natural gas.

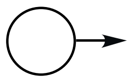
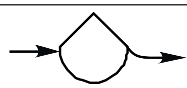
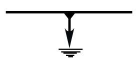
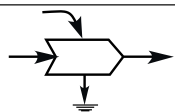
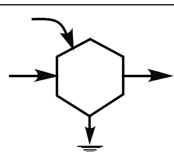
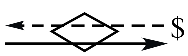
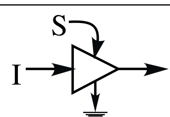
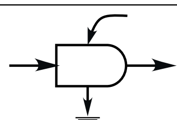
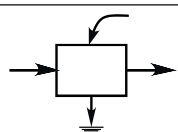
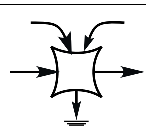
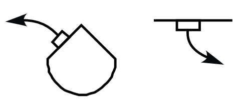
Appendices

Appendix 1. Parameters and costs for sawnwood production in Bolivia, 2004

Activity	Component	Costs	
		$\$/m^3$	%
Forest	*-Stumpage*	*10.77*	*3.41*
	-Patent	6.67	2.11
	-Management plan	0.10	0.03
	-Pre-harvesting inventory	4.00	1.27
	-Harvesting	*19.73*	*6.25*
	-Planning / Supervision / Control	2.50	0.79
	-Road and woodyard construction	6.23	1.97
	-Felling	1.06	0.34
	-Skidding and piling	9.94	3.15
	-Transportation	*12.70*	*4.02*
	-Loading	1.10	0.35
	-Transport	10.50	3.32
	-Unloading	1.10	0.35
	Subtotal	**43.20**	**13.68**
Industry	-Processing	50.00	15.83
	-Transformation losses	52.80	16.72
	-Transport (sawmill - kiln drying facility)	52.80	16.72
	-Drying and classification	45.00	14.25
	Subtotal	**200.60**	**63.52**
Trading	-Trading	2.00	0.63
	-Transport (kiln drying facility - port)	70.00	22.17
	Subtotal	**72.00**	**22.80**
	Total	**315.80**	**100.00**

Source: (STCP, 2000; UDAPE, 2005)

Appendix 2. Symbols and definitions of the energy systems language

	System or sub-system frame: A rectangular box that represents the boundaries that are selected.
	Energy circuit: A pathway whose flow is proportional to the quantity in the storage or source upstream.
	Source: Outside source of energy delivering forces according to a program controlled from outside; a forcing function.
	Tank: A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.
	Heat sink: Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.
	Interaction: Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.
	Consumer: Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.
	Transaction: A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line).
	Constant-gain amplifier: A unit that delivers an output in proportion to the input I but is changed by a constant factor as long as the energy source S is sufficient.
	Producer: Unit that collects and transforms low-quality energy under control interactions of high-quality flows.
	Box: Miscellaneous symbol to use for whatever unit or function is labeled.
	Switching action: A symbol that indicates one or more switching actions.
	Small box: A small box on a pathway or on the side of a storage tank, used to initiate another circuit that is driven by a force in proportion to the pathway or storage. Sometimes is called a “sensor”.

Source: (Odum, 1996)

Appendix 3. Footnotes to Table 5.1: Emergy evaluation of Bolivia, 2005

RENEWABLE RESOURCES:

1 **Sunlight, J**

Annual energy =	(Avg, total annual insolation J/yr)(Area)(1-albedo)(4186 J/Kcal)		
Insolation:	1.27E+06	Kcal/m^2/yr	(Odum and Arding, 1991)
Area:	1.10E+12	m^2	(CIA, 2006)
Albedo:	0.30	Fraction absorbed at surface (Barry and Chorley, 1992)	
Annual energy:	4.09E+21	J	
Emergy per unit input =	1	sej/J	By definition

2 **Rain Chemical, J**

Annual energy =	(Area)(rainfall)(1000 kg/m^3)(Gibbs free energy 4.94 J/g)		
Area:	1.10E+12		(CIA, 2006)
	Area (m^2)	Rainfall (m/yr)	
Altiplano (28%):	3.08E+11	1.43	(SENAMHI, 2006)
Valles (13%):	1.43E+11	2.29	(SENAMHI, 2006)
Llanos (59%):	6.48E+11	3.88	(SENAMHI, 2006)
Annual energy:	1.62E+19	J	
Emergy per unit input =	2.59E+04	sej/J	(Odum, 2000)

3 **Rain Geopotential, J**

Annual energy =	(area)(rainfall)(runoff)(avg elevation - min elev)(1000 kg/m^3)(9.8m/s^2)		
Area:	1.10E+12	m^2	(CIA, 2004)
Rainfall:	7.60	m/y	(SENAMHI, 2006)
Avg. Elevation:	1470.00	m	(ReliefWeb, 2003)
Min. Elevation:	90.00	m	(CIA, 2004)
Runoff rate:	0.23	m/y	(NREL, 2002)
Annual energy:	2.56E+19	J	
Emergy per unit input =	1.49E+04	sej/J	(Tilley, 1999)

Appendix 3. Footnotes to Table 5.1 (Continued)

4 **Wind, J** (Tilley, 1999)

Table wind. Equations and data used to calculate annual wind energy absorbed within a 1000 m prism overlying a country.

Height above ground (m)	Wind speed, mph	Wind speed, m/s	Wind energy absorbed over interval (Eh), J/m^3	Annual wind energy absorbed (Ea), J/y	Vertical profile (fractional change in speed with elevation)	Air exchange, m3/y
1000	9.17	4.10				
900	9.08	4.06	0.19	2.37E+17	0.0091	1.28E+18
800	8.95	4.00	0.30	6.43E+17	0.0153	2.12E+18
700	8.81	3.94	0.30	6.33E+17	0.0155	2.12E+18
550	8.62	3.85	0.41	1.20E+18	0.0221	2.95E+18
400	8.32	3.72	0.61	2.82E+18	0.0355	4.58E+18
300	8.06	3.60	0.54	2.26E+18	0.0334	4.18E+18
200	7.68	3.43	0.72	4.15E+18	0.0484	5.77E+18
100	6.82	3.05	1.55	2.08E+19	0.1273	1.35E+19
50	6.29	2.81	0.84	6.86E+18	0.0833	8.13E+18
20	5.89	2.63	0.60	3.74E+18	0.0682	6.23E+18
0.1	5.75	2.57	0.20	4.36E+17	0.0244	2.17E+18

Total wind energy absorbed (E_{total}), J/y = 43.80E+18

Footnotes to Table wind

Surface wind speed: 5.75 mph

Surface wind speed: 2.57 m/s

Area of country: 1.10E+12 m^2

Annual wind speed @ surface averages 60% of that @ 1000m. (assumed)

Emergy per unit input = 2,520 sej/J (Odum, 2000)

Shape of the vertical wind profile was approximated based on Barry & Chorley 1996.

Equations

h = height of top of interval; h' = height of bottom of interval

E_h = Energy absorbed over each height interval, J/m^3

E_h = ((wind speed @ h, m/s)^2-(wind speed @ h', m/s)^2)x(1.23 kg/m^3/ 2)

E_a = Energy absorbed over each height interval, J/y

E_a = (E_h,J/m^3)x((wind speed @ h, m/s)-(wind speed @ h', m/s))x (surface area,m^2)x (seconds per time)

E_{total} = Total energy absorbed over control volume, J/y.

E_{total} = Sum of E_a for each height interval

Appendix 3. Footnotes to Table 5.1 (Continued)

5 Evapotranspiration, J			
Annual energy =	(Evapotranspiration)(Land area)(Gibb's free energy)		
Evapotranspiration Forest land:	1.61	m/y	(University of Oregon, 2004)
Evapotranspiration Non-forest land:	1.42	m/y	(University of Oregon, 2004)
Area Forest land:	5.87E+11	m^2	(FAO, 2006)
Area Non-forest land:	5.11E+11	m^2	
Gibb's free energy number:	4.94	g/J	
Annual energy forest land:	4.67E+18	J	
Annual energy non-forest:	3.59E+18	J	
Annual energy:	4.13E+18	J	
Emergy per unit input =	2.59E+04	sej/J	(Odum *et al.*, 2000)
6 Earth Cycle, J			
Annual energy =	(area)(heat flow/area)		
Area:	1.10E+12	m^2	(CIA, 2006)
Heat flow/Area:	2.57E+06	J/m^2	(Pollack *et al.*, 1991)
Annual energy:	2.82E+18	J	
Emergy per unit input =	5.71E+04	sej/J	(Odum, 2000)

INDIGENOUS RENEWABLE ENERGY

7 Agriculture Production, J			
Annual energy =	(Production)(1E+06 g/MT)(3.5 Kcal/g)(4186 J/Kcal)		
Agricultural Production:	2.23E+07	MT	(FAO, 2006)
Annual energy:	3.27E+17	J	
Emergy per unit input =	4.00E+05	sej/J	(Brandt-Williams, 2001)
8 Livestock Production, J			
Annual energy =	(Production)(1E+06 g/MT)(5 kcal/g)(4186 J/Kcal)		
Livestock Production:	3.12E+06	MT	(FAO, 2006)
Annual energy:	6.52E+16	J	
Emergy per unit input =	8.60E+05	sej/J	(Brandt-Williams, 2001)
9 Coca leaf Production, g			
Annual energy =	(Production)(1E+06 g/MT)		
Production:	3.69E+04	MT	(Harman, 2005)
Annual energy:	3.69E+10	g	
Emergy per unit input =	5.48E+10		Table 5.8
10 Coca leaf Consumption, g			
Annual energy =	(Consumption)(1E+06 g/MT)		
Consumption:	2.09E+04	MT	(Harman, 2005)
Annual energy:	2.09E+10	g	
Emergy per unit input =	5.48E+10	sej/g	Table 5.8

Appendix 3. Footnotes to Table 5.1 (Continued)

11	**Hydroelectricity, J**			
	Annual energy =	(kWh/yr)(3.606E+06 J/kWh)		
	Kilowatt Hrs/yr:	2.13E+09	kWh/yr	(Superintendencia de Electricidad de Bolivia, 2006)
	Annual energy:	7.68E+15	J	
	Emergy per unit input =	2.77E+05	sej/J	(Odum, 1996)
12	**Forest growth, J**			
	Annual energy =	(Forest land)(1E+06 g/MT)(19,200 J/g dry wt)		
	Forest land:	5.87E+07	ha	(FAO, 2006)
	Net wood accumulation rate:	7.34	MT/ha/y	(Jordan, 1983)
	New growth:	(land area)(accumulation rate)		
	New growth:	4.31E+08	MT	
	Annual energy:	8.28E+18	J	
	Emergy per unit input =	2.76E+04	sej/J	From Table 5.5
13	**Wood extraction, J**			
	Annual energy =	(Harvest)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
	Harvest:	3.06E+06	m^3	(FAO, 2006)
	Annual energy:	2.94E+16	J	
	Emergy per unit input =	6.89E+04	sej/J	(Tilley, 1999)
14	**Fuelwood Use, J**			
	Annual energy =	(Use)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
	Harvest:	2.25.E+06	m^3	(FAO, 2006)
	Annual energy:	2.16E+16	J	
	Emergy per unit input =	6.89E+04	sej/J	(Tilley, 1999)
15	**Wood Consumption, J**			
	Annual energy wood=	(Use)(6.5E+05 g)(0.5 g dry wt/g green wt)(1.92E+04 J/g dry wt)		
	Domestic use:	3.28E+05	m^3/yr	(FAO, 2006)
	Annual energy:	2.05E+15	J	
	Emergy per unit input =	6.89E+04	sej/J	(Tilley, 1999)

NONRENEWABLE RESOURCE USE WITHIN Bolivia

16	**Natural Gas Production, J**			
	Annual energy =	(Consumption)(1.10E+06 J/ft^3)		
	Production:	4.43E+11	ft^3/yr	(YPFB, 2005)
	Annual energy:	4.87E+17	J	
	Emergy per unit input =	8.06E+04	sej/J	(Odum *et al.*, 2000)
17	**Natural Gas Consumption, J**			
	Annual energy =	(Consumption)(1.10E+06 J/ft^3)		
	Consumption:	3.89E+10	ft^3/yr	(YPFB, 2005)
	Annual energy:	4.28E+16	J	
	Emergy per unit input =	8.06E+04	sej/J	(Odum, 1996)

Appendix 3. Footnotes to Table 5.1 (Continued)

18	**Oil, J**				
	Annual energy =	(Consumption)(6.28E+09 J/bbl)			
	Consumption:	1.52E+07	(bbl/yr)		(INE, 2006)
	Annual energy:	9.53E+16	J		
	Emergy per unit input =	8.90E+04	sej/J		(Odum, 1996)
19	**Cement, g**				
	Annual energy =	(Consumption)(1E+06 g/MT)			
	Consumption:	1.42E+06	MT		(INE, 2006)
	Annual energy:	1.42E+12	g		
	Emergy per unit input =	3.31E+09	sej/g		(Brown and Bardi, 2001)
20	**Electricity, J**				
	Annual energy =	(Consumption)(3,606E+03 J/kWh)			
	Consumption:	3.36E+09	kWh/yr		(INE, 2006)
	Annual energy:	1.21E+16	J		
	Emergy per unit input =	2.77E+05	sej/J		(Odum, 1996)
21	**Metals (mined - Au, Ag, Sn, Cu, Pb, Zn, Sb)**				
				Transformity (sej/g)	
	Gold =	2.45E+00	MT	4.22E+12	(Odum and Arding, 1991)
	Silver =	1.95E+01	MT	4.22E+10	(Odum and Arding, 1991)
	Tin =	2.06E+03	MT	2.82E+09	(Odum, 1996)
	Copper =	3.10E+00	MT	1.61E+08	(Odum and Arding, 1991)
	Lead =	3.82E+02	MT	2.82E+09	(Odum, 1996)
	Zinc =	8.73E+03	MT	6.12E+07	(Odum and Arding, 1991)
	Other =	3.05E+07	MT	2.82E+09	(Odum, 1996)
	Consumption =	3.05E+07	MT	2.82E+09	(Ministerio de Minería y Metalurgia, 2005)
	Mass:	(metals mined)(1+E06 g/MT)			
	Annual energy:	3.05E+13	g		
	Emergy per unit input =	2.82E+09	sej/g	(weighted)	
22/23	**Top soil and SOM**				
	Harvested cropland:	2.35E+10	m^2		(INE, 2006)
	Soil loss =	840	g/m^2/yr		(Bloodworth and Berc, 1998)
	Average organic content =	3	%		
	Mass =	(Harvested cropland)*(Soil loss)			
	Mass :	1.97E+13	g/yr		
	Annual energy =	(Harvested cropland)*(Soil loss)*(% OM)*(5.4 Kcal/g)(4186 J/Kcal)			
	Annual energy:	4.01E+16	J/yr		
	Emergy per unit input of soil =	2.82E+09	sej/g		(Odum, 1996)
	Emergy per unit input of SOM =	1.24E+05	sej/J		(Odum, 1996)

Appendix 3. Footnotes to Table 5.1 (Continued)

IMPORTS OF OUTSIDE ENERGY SOURCES:

24	**Petroleum Products, J**				
	Annual energy =	(Petroleum imported)(6.28E+09 J/bbl)			
	Imports:	2.02E+06	(bbl/yr)		(EIA, 2005)
	Annual energy:	1.27E+16	J		
	Emergy per unit input =	1.11E+05	sej/J		(Odum, 1996)
25	**Fertilizers (Nitrogen, Phosphorus and Potash), g**				
	Annual energy =	(Fertilizer imported)(1.00E+06 g/MT)			
	Imports:	2.57E+04	MT/yr		(IBCE, 2005)
	Annual energy:	2.57E+10	g		
	Emergy per unit input =	2.87E+09	sej/g	Ammonia	(Felix, 2006)
26	**Machinery and Transportation Machinery, g**				
	Annual energy =	(Machinery imported)(1.00E+06g/MT)			
	Machinery imported:	9.07E+04	MT		(IBCE, 2005)
	Annual energy:	9.07E+10	g		
	Emergy per unit input =	1.13E+10	sej/g		(Odum and Arding, 1991)
27	**Pulp, Paper and Wood Products, J**				
	Annual energy =	(Imports)(1.00E+06 g/MT)(4 kcal/g)(4,186 J/kcal)			
	Imports:	9.01E+04	MT/y		(FAO, 2006)
	Annual energy:	1.51E+15	g		
	Emergy per unit input =	1.01E+05	sej/g		(Tilley, 1999)
28	**Goods, $**				
	Dollar Value Goods:	6.07E+08	$		(IBCE, 2005)
29	**Services, $**				
	Dollar Value Services:	5.78E+08	$		(World Bank, 2004)
30	**Foreign Aid, $**				
	Dollar Value =	7.67E+08	$		(World Bank, 2006)

EXPORTS OF ENERGY, MATERIALS AND SERVICES

31	**Natural Gas, J**				
	Annual energy =	(Exports)(1.10E+06 J/ft^3)			
	Exports:	3.7E+11	ft^3/yr		(YPFB, 2005)
	Annual energy:	4.04E+17	J		
	Emergy per unit input =	9.88E+04	sej/g		(Odum, 1996)
32	**Oil, J**				
	Annual energy =	(Exports)(6.28E+09 J/bbl)			
	Exports:	5.47E+06	bbl/yr		(IBCE, 2005)
	Annual energy:	3.43E+16	J		
	Emergy per unit input =	1.11E+05	sej/g		(Odum, 1996)

Appendix 3. Footnotes to Table 5.1 (Continued)

33 **Wood and Wood Products, J**

Annual energy wood=	(Exports)(6.5E+05 g/m^3)(0.5 g dry wt/g green wt)(1.92E+04 J/g dry wt)			
Exports wood:	1.18E+05	m^3/yr		(CFB, 2006)
Annual energy:	7.38E+14	J		
Emergy per unit input =	6.89E+04	sej/J		(Tilley, 1999)

34 **Agriculture products, J**

Annual energy =	(Exports)(1E+06 g/MT)(3.5 Cal/g)(4,186 J/Cal)			
Exports:	1.68E+06	MT		(IBCE, 2005)
Annual energy:	2.47E+16	J		
Emergy per unit input =	4.00E+05	sej/J		(Odum, 1996)

35 **Livestock, J**

Annual energy =	(Exports)(1.00E+06 g/MT)(4 Kcal/g)(4,186 J/Cal)			
Exports:	2.63E+03	MT		(IBCE, 2005)
Annual energy:	4.40E+13	J		
Emergy per unit input =	8.60E+05	sej/J		(Odum, 1996)

36 **Metals, g**

			Transformity (sej/g)	
Gold =	5.36E+00	MT	4.22E+12	(Odum and Arding, 1991)
Silver =	3.99E+02	MT	4.22E+10	(Odum and Arding, 1991)
Tin =	1.64E+04	MT	2.82E+09	(Odum, 1996)
Cooper =	3.20E+01	MT	1.61E+08	(Odum and Arding, 1991)
Lead =	1.08E+04	MT	2.82E+09	(Odum, 1996)
Zinc =	1.50E+05	MT	6.12E+07	(Odum and Arding, 1991)
Others =	8.00E+04	MT	2.82E+09	(Odum, 1996)
Consumption =	2.57E+05	MT	1.36E+09	(Ministerio de Minería y Metalurgia, 2005)
Mass:	(metals mined)(1+E06 g/MT)			
Annual energy:	2.57E+11	g		
Emergy per unit input =	1.36E+09	sej/g	(weighted)	

37 **Coca Leaf, g**

Annual energy =	(Exports)(1.00E+06 g/MT)			
Exports:	1.60E+04	MT		(Harman, 2005; UNODC, 2005)
Annual energy:	1.60E+10	g		
Emergy per unit input =	5.48E+10	sej/g		Table 5.8

38 **Services in exports, $**

Dollar Value =	3.84E+08	$	(BCB, 2006b)

39 **Tourism services, $**

Dollar Value =	2.65E+08	$	(BCB, 2006b)

40 **Service on debt, $**

Dollar Value =	5.13E+08	$	(BCB, 2006b)

Appendix 4. Footnotes to Table 5.4: Emergy evaluation of the Bolivian forestry system, 2005

RENEWABLE RESOURCES:

1 **Sunlight, J**

Annual energy =	(Avg. Total Annual Insolation J/yr)(Forest land)(1-albedo)(4186 J/Cal)		
Insolation:	1.27E+06	Kcal/m^2/yr	(Odum and Arding, 1991)
Forest land:	5.87E+11	m^2	(FAO, 2006)
Albedo:	0.30	Frac. absorbat surface	(Barry and Chorley, 1992)
Annual energy:	2.19E+21	J	
Emergy per unit input =	1	sej/J	

2 **Rain Chemical, J**

Annual energy =	(Forest land)(1000 kg/m^3)(Gibbs free energy 4.94 J/g)		
Forest land:	5.87E+11	m^2	(FAO, 2006)
Rainfall:	3.88	m/y	(SNMH Bolivia, 2006)
Annual energy:	1.13E+19	J	
Emergy per unit input =	3.05E+04	sej/J	(Odum, 2000)

3 **Rain Geopotential, J**

Annual energy =	(area)(rainfall)(runoff)(avg elev - min elev)(1000 kg/m^3)(9.8m/s^2)		
Forest land:	5.87E+11	m^2	(FAO, 2006)
Rainfall:	3.88	m/y	(SNMH Bolivia, 2006)
Avg. Elevation:	1470.00	m	(Reliefweb International, 2003)
Min. Elevation:	90.00	m	(CIA, 2004)
Runoff rate:	0.23	m/y	(NREL Colorado State University, 2002)
Annual energy:	6.98E+18	J	
Emergy per unit input =	8.89E+03	sej/J	(Odum and Arding, 1991)

Appendix 4. Footnotes to Table 5.4 (Continued)

4 **Wind, J** (Tilley, 1999)

Table wind. Equations and data used to calculate annual wind energy absorbed within a 1000 m prism overlying a country.

Height above ground, m	Wind speed, mph	Wind speed, m/s	Wind energy absorbed over interval (Eh), J/m3	Annual wind energy absorbed (Ea), J/y	Vertical profile (fractional change in speed with elevation)	Air exchange, m3/y
1000	9.17	4.10				
900	9.08	4.06	0.19	1.27E+17	0.0091	6.84E+17
800	8.95	4.00	0.30	3.43E+17	0.0153	1.13E+18
700	8.81	3.94	0.30	3.38E+17	0.0155	1.13E+18
550	8.62	3.85	0.41	6.42E+17	0.0221	1.58E+18
400	8.32	3.72	0.61	1.50E+18	0.0355	2.45E+18
300	8.06	3.60	0.54	1.21E+18	0.0334	2.23E+18
200	7.68	3.43	0.72	2.22E+18	0.0484	3.08E+18
100	6.82	3.05	1.55	1.11E+19	0.1273	7.18E+18
50	6.29	2.81	0.84	3.66E+18	0.0833	4.34E+18
20	5.89	2.63	0.60	2.00E+18	0.0682	3.33E+18
0.1	5.75	2.57	0.20	2.33E+17	0.0244	1.16E+18

Total wind energy absorbed (E_{total}), J/y = 2.34E+19

Footnotes to Table wind

Surface wind speed:	5.75	Mph	
Surface wind speed:	2.57	m/s	
Area of forest land:	5.87E+11	m^2	
Annual wind speed @ surface averages 60% of that @ 1000m. (assumed)			
Emergy per unit input =	2,520	sej/J	(Odum, 2000)

Shape of the vertical wind profile was approximated based on Barry & Chorley 1996.

Equations

h = height of top of interval; h' = height of bottom of interval

E_h = Energy absorbed over each height interval, J/m^3

E_h = [((wind speed @ h, m/s)^2-(wind speed @ h', m/s)^2)x(1.23 kg/m^3/ 2)

E_a = Energy absorbed over each height interval, J/y

E_a = (E_h,J/m^3)x((wind speed @ h, m/s)-(wind speed @ h', m/s))x (surface area,m^2)x (seconds per time)

E_{total} = Total energy absorbed over control volume, J/y.

E_{total} = Sum of E_a for each height interval

5 **Evapotranspiration, J**

Annual energy =	(Evapotranspiration)(Forest land)(1000 kg/m^3)(Gibb's free energy)		
Evapotranspiration Forest land:	1.61	m/y	(University of Oregon, 2004)
Forest land:	5.87E+11	m^2	(FAO, 2006)
Gibb's free energy number:	4940.00	J/kg	
Annual energy:	4.67E+18	J	
Emergy per unit input =	3.05E+04	sej/J	(Odum, 1996)

Appendix 4. Footnotes to Table 5.4 (Continued)

6 **Earth Cycle, J**

Annual energy =	(area)(heat flow/area)		
Forest land:	5.87E+11	m^2	(FAO, 2006)
Heat flow/Area:	2.57E+06	J/m^2	(Pollack et al., 1991)
Annual energy:	1.51E+18	J	
Emergy per unit input =	3.40E+04	sej/J	(Odum, 1996)

IMORTED ENERGY SOURCES:

7 **Timbering, services, $**

Annual energy =	(Total logs harvested m^3/yr)(Cost of services $/m^3)		
Harvest:	3.06E+06	m^3/yr	(FAO, 2006)
Cost of services:	4.32E+01	$/m^3	(UDAPE - Bolivia,2005)
Annual energy:	1.32E+08	$/yr	
Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

8 **Timbering, fuels, J**

Annual energy =	(Fuel consumed l/yr)(1 bbl/159 l)(6.28E9J/bbl)		
Gasoline consumption:	(3.06E+6 m^3 of wood/yr)/(12 m^3 per truck load)(50 km average distance)(4 km/l average consumption)		
Oil consumption:	(3.06E+6 m^3 of wood/yr)/(12 m^3 per truck load)(50 km average distance)/(5000 km oil change)(10l/change)		
Gasoline consumption:	3.04E+06	l/yr	(UDAPE - Bolivia,2005)
Oil consumption:	2.55E+04	l/yr	(UDAPE - Bolivia,2005)
Annual energy:	1.21E+14	J	
Emergy per unit input =	4.80E+04	sej/J	(Odum, 1996)

9 **Non-Timber Forest Products (NTFPs), services, $**

Annual energy =	(Total NTFP harvested MT/yr)(Cost of services $/MT)		
NTFP harvest:	5.36E+04	MT/yr	(SIF - Bolivia, 2006)
Cost of services:	1.20E+04	$/MT	(Carvalho et al., 2002; Bergo, 2005 and Aboboreira, 2005)
Annual energy:	6.44E+08	$/yr	
Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

INTERNAL PROCESSES:

10 **Net Primary Production (NPP) - aboveground coarse wood, J**

Annual energy =	(Forest land)(1E+06 g/MT)(19,200 J/g dry wt)		
Net wood accumulation rate:	7.34	MT/ha/y	(Jordan, 1983)
New growth:	(Forest land)(accumulation rate)		
New growth:	4.31E+08	MT	
Annual energy:	8.28E+18	J	
Emergy per unit input =	2.76E+04	sej/J	From Table 5.5

Appendix 4. Footnotes to Table 5.4 (Continued)

11 Soil erosion, J

Authorized logging area:	1.98E+09	m^2	(SIF - Bolivia, 2006)
Soil loss =	62	g/m^2/yr	(Wiersum, 1984)
Average organic content =	3	%	
Mass =	(Authorized logging area)(Soil loss)		
Mass :	1.23E+11	g/yr	
Annual energy =	(Authorized logging area)(Soil loss)(% OM)(5.4 Kcal/g)(4186 J/Kcal)		
Annual energy:	2.50E+14	J/yr	
Emergy per unit input of soil =	1.68E+09	sej/g	(Odum, 1996)
Emergy per unit input of SOM =	7.40E+04	sej/J	(Brown, 2001)

12 Wood lost, J

Annual energy =	(Use m^3)(650 kg)(1E3 g) (3.5 Kcal/g)(4186 J/Cal)		
Use:	4.02E+05	m^3	(FAO, 2006)
Annual energy:	3.83E+15	J	
Emergy per unit input =	5.88E+04	sej/J	(Odum, 1996)

DOMESTIC USE

13 Timber without service, J

Annual energy =	(Use m^3)(650 kg)(1E3 g) (3.5 Kcal/g)(4186 J/Cal)		
Use:	2.25E+06	m^3	(FAO, 2006)
Annual energy:	2.14E+16	J	
Emergy per unit input =	5.88E+04	sej/J	(Odum, 1996)

14 Timber with service, J

Annual energy =	(Use m^3)(650 kg)(1E3 g) (3.5 Kcal/g)(4186 J/Cal)		
Use:	3.28E+05	m^3	(FAO, 2006)
Annual energy:	3.12E+15	J	
Emergy per unit input =	5.30E+04	sej/J	(Odum, 1996)

15 Non-timber products (NTFPs), $

Use:	2.91E+07	$	(UDAPE-Bol., 2005)
Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

EXPORTS

16 Timber without service, J

Annual energy =	(Exports m^3)(650 kg)(1E3 g) (3.5 Kcal/g)(4186 J/Cal)		
Exports:	2.00E+03	m^3	(FAO, 2006)
Annual energy:	1.90E+13	J	
Emergy per unit input =	5.88E+04	sej/J	(Odum, 1996)

Appendix 4. Footnotes to Table 5.4 (Continued)

17	**Timber with service, J**			
	Annual energy =	(Exports m^3)(650 kg)(1E3 g) (3.5 Kcal/g)(4186 J/Cal)		
	Exports:	7.81E+04	m^3	(FAO, 2006)
	Annual energy:	7.44E+14	J	
	Emergy per unit input =	5.30E+04	sej/J	(Odum, 1996)
18	**Non-timber products (NTFP), $**			
	Exports:	5.81E+07	$	(UDAPE-Bol., 2005)
	Emergy per unit input =	1.50E+12	sej/$	From Table 5.2
	Bolivia Gross Domestic Product	2.58E+10	$	From Table 5.2
	Bolivia, Total emergy used	8.55E+23	sej/y	From Table 5.3

Appendix 5. Footnotes to Table 5.5: Emergy evaluation of forest growth in Bolivia, 2005

1 **Sunlight, J**

Annual energy =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)(4186 J/Kcal)		
Insolation:	1.27E+06	Kcal/m^2/yr	(Odum and Arding, 1991)
Forest land:	5.87E+11	m^2	(FAO, 2006)
Albedo:	0.30	Frac. absorbat surface	(Barry and Chorley, 1992)
Annual energy:	2.19E+21	J	
Emergy per unit input =	1	sej/J	

2 **Evapotranspiration, J**

Annual energy =	(Area)(evaporation rate)(1000 kg/m^3)(Gibbs free energy 4.94 J/g)		
Forest land:	5.87E+11	m^2	(FAO, 2006)
Rainfall:	3.88	m/y	(SENAMHI, 2006)
Evapotranspiration rate:	1.61	m/y	(University of Oregon, 2004)
Annual energy:	4.67E+18	J	
Emergy per unit input =	3.05E+04	sej/J	(Odum, 2000)

3 **Earth heat cycle, J**

Annual energy =	(area)(heat flow/area)		
Forest land:	5.87E+11	m^2	(CIA, 2006)
Heat flow/Area:	2.57E+06	J/m^2	(Pollack *et al.*, 1991)
Annual energy:	1.51E+18	J	
Emergy per unit input =	5.71E+04	sej/J	(Odum, 2000)

4 **Soil erosion, J**

Authorized logging area:	1.98E+09	m^2	(SIF, 2006)
Soil loss =	62	g/m^2/yr	(Wiersum, 1989)
Average organic content =	3	%	
Mass =	(Authorized logging area)*(Soil loss)		
Mass :	1.23E+11	g/yr	
Annual energy =	(Authorized logging area)(Soil loss)(% OM)(5.4 Kcal/g)(4186 J/Kcal)		
Annual energy:	2.50E+14	J/yr	
Emergy per unit input of SOM =	7.40E+04	sej/J	(Brown and Bardi, 2001)

5 **Forest growth, J**

Annual energy =	(Forest land)(1E+06 g/MT)(19,200 J/g dry wt)		
Forest land:	5.87E+07	ha	(FAO, 2006)
Net wood accumulation rate:	7.34	MT/ha/y	(Jordan, 1983)
New growth:	(land area)(accumulation rate)		
New growth:	4.31E+08	MT kg	
Annual energy:	8.28E+18	J	

6 **Transformity of forest growth, sej**

Transformity of forest growth =	(Rain used + geologic input)/(energy of forest growth)		
Rain used:	1.42E+03	m^3	(FAO, 2006)
Geologic input:	8.61E+02	J	
Energy of forest growth:	8.28E+18	sej/J	(Romitelli, 2000)
Transformity =	2.76E+04	sej	

Appendix 6. Footnotes to Table 5.6: Emergy evaluation of logging industry in Bolivia, 2005

1 **Services, $**

Annual energy =	(Cost of services $/m^3)(Total logs harvested m^3)		
Cost of services:	43.2	$/m^3	(UDAPE, 2005)
Stumpage	*10.77*	$/m^3	
-Patent	6.67	$/m^3	
-Management plan	0.1	$/m^3	
-Pre-harvesting inventory	4	$/m^3	
Harvesting	*19.73*	$/m^3	
-Planning / Supervision / Control	2.5	$/m^3	
-Road and woodyard construction	6.23	$/m^3	
-Felling	1.06	$/m^3	
-Skidding and piling	9.94	$/m^3	
Transportation	*12.7*	$/m^3	
-Loading	1.1	$/m^3	
-Transport	10.5	$/m^3	
-Unloading	1.1	$/m^3	
Harvest:	3.06E+06	m^3	(FAO, 2006)
Annual energy:	1.32E+08	$/yr	
Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

2 **Biomass, J**

Annual energy =	(Harvest)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
Harvest:	3.06E+06	m^3	(FAO, 2006)
Annual energy:	2.94E+16	J	
Emergy per unit input =	2.76E+04	sej/J	From Table 5.5

3 **Fuels, J**

Annual energy =	(Fuel consumed l)(1 bbl/159 l)(6.28E9J/bbl)		
Gasoline consumption:	(3.06E+6 m^3 of wood)/(12 m^3 per truck load)(50 km average distance)(4 km/l average consumption)		
Oil consumption:	(3.06E+6 m^3 of wood)/(12 m^3 per truck load)(50 km average distance)/(5000 km oil change)(10l/change)		
Gasoline consumption:	3.04E+06	l/yr	(UDAPE, 2005)
Oil consumption:	2.55E+04	l/yr	(UDAPE, 2005)
Annual energy:	1.21E+14	J	
Emergy per unit input =	4.80E+04	sej/J	(Odum, 1996)

4 **Electricity, J**

Annual energy =	(Electricity consumed)(3.61E6 J/kWh)		
Electricity consumption:	2.13E+07	kWh	(UDAPE, 2005)
Annual energy:	7.69E+13	J	
Emergy per unit input =	1.60E+05	sej/J	(Odum, 1996)

Appendix 6. Footnotes to Table 5.6 (Continued)

5 **Timber output, J**

Output of logs =	(Total trees harvested)(recovery rate)		
Total trees harvested:	3.06E+06	J	
Recovery rate:	45	%	(UDAPE, 2005)
Output of logs =	1.38E+06	J	

6 **Timber output transformity, sej/J**

Timber output transformity = (sum of 1-4)/(output energy of logs)

7 **Emergy/$ ratio for logs, sej/$**

Emergy/$ ratio for logs = (sum of 1-4)/(output energy of logs)

Bolivia GDP	2.58E+10	From Table 5.2
Bolivia, Total emergy used	8.55E+23	From Table 5.3

Appendix 7. Footnotes to table 5.7: Emergy evaluation of wood-based panel industry in Bolivia, 2005

1 **Services, $**

Annual energy =	(Cost of services $/m^3)(Total logs harvested m^3)		
Cost of services:	588.6	$/m^3	(UDAPE, 2005)
Preparation	*200.6*	$/m^3	
-Processing	50	$/m^3	
-Transformation losses	52.8	$/m^3	
-Transport (sawmill - kiln drying)	52.8	$/m^3	
-Drying and classification	45	$/m^3	
Manufacturing	*316*	$/m^3	
-Panels	316	$/m^3	(CIMAL, pers. Communication, 2006)
Marketing	*72*	$/m^3	
-Trading	2	$/m^3	
-Transport (kiln drying facility - port)	70	$/m^3	
Processed wood:	4.08E+05	m^3	(FAO, 2006)
Cost of services:	2.40E+08	$/m^3/yr	
Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

2 **Biomass, J**

Annual energy =	(Harvest)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
Processed wood:	4.08E+05	m^3	(FAO, 2006)
Annual energy:	3.92E+15	J	
Emergy per unit input =	2.76E+04	sej/J	From Table 5.5

3 **Fuels, J**

Annual energy =	(Fuel consumed l)(1 bbl/159 l)(6.28E9J/bbl)		
Gasoline consumption:	(3.06E+6 m^3 of wood)/(12 m^3 per truck load)(50 km average distance)(4 km/l average consumption)		
Oil consumption:	(3.06E+6 m^3 of wood)/(12 m^3 per truck load)(50 km average distance)/(5000 km oil change)(10l/change)		
Gasoline consumption:	3.04E+06	l/yr	(UDAPE, 2005)
Oil consumption:	2.55E+04	l/yr	(UDAPE, 2005)
Annual energy:	1.21E+14	J	
Emergy per unit input =	4.80E+04	sej/J	(Odum, 1996)

4 **Electricity, J**

Annual energy =	(Electricity consumed)(3.61E6 J/kWh)		
Electricity consumption:	4.26E+07	kWh	(UDAPE, 2005)
Annual energy:	1.54E+14	J	
Emergy per unit input =	1.60E+05	sej/J	(Odum, 1996)

5 **Timber output, J**

Output of logs =	(Total trees harvested)(recovery rate)		
Processed wood:	4.08E+05	J	
Recovery rate:	45	%	(UDAPE, 2005)
Output of logs =	1.84E+05	J	

Appendix 7. Footnotes to Table 5.7 (Continued)

6 **Timber output transformity, sej/J**

Timber output transformity = (sum of 1-4)/(output energy of logs)

7 **Emergy/$ ratio for logs, sej/$**

Emergy/$ ratio for logs = (sum of 1-4)/(output energy of logs)

Bolivia GDP	2.58E+10	$	From Table 5.2
Bolivia, Total emergy used	8.55E+23	sej/y	From Table 5.3

Appendix 8. Footnotes to Table 5.8: Emergy evaluation of coca leaf production in Bolivia, 2005

1	**Sunlight, J**			
	Annual energy =	(Total Annual Insolation J/yr)(Production area)(1-albedo)(4186 J/Kcal)		
	Insolation:	1.27E+06	Kcal/m^2/yr	(Odum and Arding, 1991)
	Production area:	2.54E+04	ha	(UNODC, 2005)
	Albedo:	0.30	Frac. absorbat surface	(Barry and Chorley, 1992)
	Annual energy:	9.45E+17	J	
	Emergy per unit input =	1	sej/J	By definition
2	**Rain, J**			
	Annual energy =	(Production area)(Evapotranspiration)(Gibbs free energy 4.94 J/g)		
	Production area:	2.54E+04	ha	(UNODC, 2005)
	Evapotranspiration:	1.61	m/y	(University of Oregon, 2004)
	Gibb's free energy number:	4.94	J/g	
	Annual energy:	2.02E+15	J	
	Emergy per unit input =	1.54E+04	sej/J	(Odum, 1996)
3	**Soil erosion, J**			
	Production area:	2.54E+04	ha	(UNODC, 2005)
	Soil loss =	62	g/m^2/yr	(Wiersum, 1989)
	Average organic content =	3	%	
	Annual energy =	(Production area)*(Soil loss)*(% OM)*(5.4 Kcal/g)(4186 J/Kcal)		
	Annual energy:	3.20E+13	J/yr	
	Emergy per unit input of SOM =	7.40E+04	sej/J	(Brown and Bardi, 2001)
4	**Supplies, $**			
	Annual energy =	(Production area)(Supplies used)		
	Production area:	2.54E+04	ha	(UNODC, 2005)
	Supplies used:	468.00	$/ha	(Torres, 2000)
	Annual energy:	1.19E+07	$	
	Emergy per unit input =	3.31E+13	sej/$	From Table 5.2
5	**Tools, $**			
	Annual energy =	(Production area)(Tools purchased)		
	Production area:	2.54E+04	ha	(UNODC, 2005)
	Tools purchased:	6.00	$/ha	(Torres, 2000)
	Annual energy:	1.52E+05	$	
	Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

Appendix 8. Footnotes to Table 5.8 (Continued)

6	**Labor, J**				
	Annual energy =	(# of workers)(Production area)(2500 kcal/d)(4186 J/kcal)(365 d/yr)			
	Production area:	2.54E+04	ha		(UNODC, 2005)
	Annual labor costs:	607	$/yr/ha		
	Average wage rate:	0.39	$/hr		
	Work period:	12	months @ 40 hrs/week		
	Number of workers:	(Annual labor costs)/(Average wage rate)/(Work period)			
	Number of workers:	0.81	ind/ha		
	Annual energy:	7.86E+13	J		
	Emergy per unit input =	(Use per person)/(emergy per person)			
	Use per person:	8.07E+16	sej/ind/yr @ 9.8E06 ind		
	Emergy per person:	(2500 kcal/d)(365 d/yr)(4186 J/kcal)=		3.82E+09	J/ind/yr
	Emergy per unit input =	2.11E+07			
7 & 8	**Coca leaf output, J & g**				
	Annual energy =	(Coca leaf production)(3.5 kcal/J)(4186 J/Kcal)			
	Production:	4.90E+10	g		(UNODC, 2005)
	Coca leaf output:	7.18E+14	J		
9	**Specific Emergy of coca leaf output, sej/J**				
	Emergy/$ ratio for coca leaf =	(sum of 2-6)/(output energy coca leaf)			
10	**Transformity of coca leaf output, sej/$**				
	Emergy/$ ratio for coca leaf =	(sum of 2-6)/(output energy coca leaf)			
	Bolivia GDP	2.58E+10	$		From Table 5.2
	Bolivia, Total emergy used	8.55E+23	sej/y		From Table 5.3

Appendix 9. Footnotes to Table 5.10: Annual emergy value of important resource flows in Bolivia, 2001

1	**NG domestic use**			
	Consumption =	4.40E+10	(cu. ft./yr)	(EIA, 2000)
	Energy(J) =	(____cu. ft./yr)*(1.10e6 J/cu. ft.)		
	Energy(J) =	4.84E+16		
2	**NG exported**			
	Exports =	7.30E+10	(cu. ft./yr)	(EIA, 2000)
	Energy(J) =	(____cu. ft./yr)*(1.10e6 J/cu. ft.)		
	Energy(J) =	8.03E+16		
3	**Oil products domestic use**			
	Consumption =	1.57E+07	(bbl/yr)	(EIA, 2000)
	Energy(J) =	(____bbl/yr)*(6.28e9 J/bbl)		
	Energy(J) =	9.86E+16		
4	**Oil exported**			(EIA, 2000)
	Exports =	3.07E+05	(bbl/yr)	
	Energy(J) =	(____bbl/yr)*(6.28e9 J/bbl)		
	Energy(J) =	1.93E+15		
5	**Cash crops domestic use**			
	Consumption =	8.08E+06	MT	
	Energy(J) =	(_____MT/y)*(1E+06 g/MT)*(3.5 Cal/g)*(4186 J/Cal)		
	Energy(J) =	1.18E+17		
6	**Cash crops exported**			
	Exports:			(MCEIB, 2001)
	Soja products	8.89E+05	MT	
	Other cereal products	1.18E+05	MT	
	Oilcrops	8.70E+04	MT	
	Other Agricultural Products	1.34E+04	MT	
	Total	1.E+06	MT	
	Energy(J) =	(MT/y)*(1E+06 g/MT)*(3.5 Cal/g)*(4186 J/Cal)		
	Energy(J) =	1.62E+16		
7	**Livestock exported**			
	Exports =	9.19E+03	MT	(MCEIB, 2001)
	Energy(J) =	(___ MT/yr)(1E6 g/MT)(4 Kcal/g)(4186 J/Cal)		
	Energy(J) =	1.54E+14		
8	**Forest products domestic use**		2.97E+16	
8a	**Wood products domestic use**			
	Harvest =	9.35E+05	m^3	(ITTO, 2001)
	Energy(J) =	(___ m^3)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
	Energy(J) =	8.98E+15		
8b	**Fuelwood domestic use**			
	Use =	2.16.E+06	m^3	(FAO, 2001)
	Energy(J) =	(___ m^3)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
	Energy(J) =	2.08E+16		

Appendix 9. Footnotes to Table 5.10 (Continued)

9	**Forest products exported**				
		Wood =	6.88E+04	m^3/y	(MCEIB, 2001)
		Energy of wood, J =	(___ m^3)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
		Total energy, J =	4.29E+14		
10	**Gold exported**				
		Exported =	1.32E+01	MT/y	(MCEIB, 2001)
		Energy(g) =	(__ MT/yr)*(1E6 g/MT)		
		Energy(g) =	1.32E+07	g/y	
11	**Silver exported**				
		Exported =	2,386,733	kg/y	(MCEIB, 2001)
		Energy(g) =	(__ kg/yr)*(1E3 g/kg)		
		Energy(g) =	2.39E+09	g/y	

Appendix 10. Footnotes to Table 5.11: Emergy values of the main storages of Bolivia natural capital, 2001

1	**Soil organic matter**			
	National stock =	(Area m^2)(Deep 1 m)(1E+6 m^3/cm^3)(% arable + ag. lands) (1.47g/cm^3)(1%MO)(5.4Kcal/g)(4186 J/Kcal)		
	Area:	1.10E+12	m^2	(CIA, 2000)
	Arable lands:	1.73%		
	permanent crops:	0.21%		
	Depth:	1.00	m	
	Density:	1.47	g/cm^3	
	OM:	1.00%		
	Assume :	1 m deep, 1% organic content, 5.4 kcal/g		
	Stock's Energy =	7.08E+18	J	
2	**Forests**			
	National stock =	(Forest Area m^2)(Aboveground biomass) (1E+6 g)(dry weight)(19,200 J/g)		
	Area:	4.83E+07	ha	(Min. Presindencia Bolivia, 2000)
	Aboveground biomass:	230.00	t/ha	
	Dry weight:	0.5	g dry wt/g green wt	
	Stock's Energy =	1.07E+20	J	
3	**Natural gas**			
	National stock =	(Proven reserves)(energy j/m^3)		
	Proven reserves:	1.32E+12	m^3	(EIA, 2000)
	Energy =	3.77E+07	J/m^3	
	Stock's Energy =	4.99E+19	J	
4	**Crude oil**			
	National stock =	(Proven reserves)(energy j/bbl)		
	Proven reserves:	8.29E+08	barrels	(EIA, 2000)
	Energy =	6.28E+09	J/bbl	
	Stock's Energy =	5.21E+18	J	

Fresh water occupies an important place among the storages of Bolivian natural capital. However, the data available is not enough to quantify the fresh water stock at a national level (Mattos and Crespo, 2000)

Appendix 11. Footnotes to Table 5.12: Annual emergy value of important resource flows in Bolivia, 2005

1	**NG domestic use**				
		Consumption =	3.89E+10	(cu. ft./yr)	(YPFB - INE, 2005)
		Energy(J) =	(____cu. ft./yr)*(1.10e6 J/cu. ft.)		
		Energy(J) =	4.28E+16		
2	**NG exported**				
		Exports =	3.7E+11	(cu. ft./yr)	(YPFB - INE, 2005)
		Energy(J) =	(____cu. ft./yr)*(1.10e6 J/cu. ft.)		
		Energy(J) =	4.04E+17		
3	**Oil products domestic use**				
		Consumption =	1.52E+07	(bbl/yr)	(INE - Bolivia, 2005)
		Energy(J) =	(____bbl/yr)*(6.28e9 J/bbl)		
		Energy(J) =	9.53E+16		
4	**Oil exported**				
		Exports =	5.47E+06	(bbl/yr)	(IBCE, 2006)
		Energy(J) =	(____bbl/yr)*(6.28e9 J/bbl)		
		Energy(J) =	3.43E+16		
5	**Cash crops domestic use**				
		Consumption =	9.21E+06	MT	(INE - Bolivia, 2005)
		Energy(J) =	(_____MT/y)*(1E+06 g/MT)*(3.5 Cal/g)*(4186 J/Cal)		
		Energy(J) =	1.35E+17		
6	**Cash crops exported**				
		Exports =	1.68E+06	MT	(INE - Bolivia, 2005)
		Energy(J) =	(MT/y)*(1E+06 g/MT)*(3.5 Cal/g)*(4186 J/Cal)		
		Energy(J) =	2.47E+16		
7	**Livestock exported**				
		Exports =	2.63E+03	MT	(INE - Bolivia, 2005)
		Energy(J) =	(___ MT/yr)(1E6 g/MT)(4 Kcal/g)(4186 J/Cal)		
		Energy(J) =	4.40E+13		
8	**Forest products domestic use**			2.37E+16	
8a	**Wood products domestic use**				
		Harvest =	3.28E+05	m^3/yr	(FAO, 2006)
		Energy(J) =	(___ m^3)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
		Energy(J) =	2.05E+15		
8b	**Fuelwood domestic use**				
		Use =	2.25.E+06	m^3	(FAO, 2006)
		Energy(J) =	(___ m^3)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
		Energy(J) =	2.16E+16		
9	**Forest products exported**				
		Wood =	1.18E+05	m^3/yr	(FAO, 2006)
		Energy of wood, J =	(___ m^3)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
		Total energy, J =	7.38E+14		

Appendix 11. Footnotes to Table 5.12 (Continued)

10	**Gold exported**				
		Exported =	5.36E+00	MT/y	(INE - Bolivia, 2005)
		Energy(g) =	(__ MT/yr)*(1E6 g/MT)		
		Energy(g) =	5.36E+06	g/y	
11	**Silver exported**				
		Exported =	3.99E+02	MT/y	(INE - Bolivia, 2005)
		Energy(g) =	(__ kg/yr)*(1E6 g/kg)		
		Energy(g) =	3.99E+08	g/y	

Appendix 12. Footnotes to Table 5.13: Emergy values of the main storages of Bolivia natural capital, 2005

1 **Soil organic matter**

National stock =	(Area m^2)(Deep 1 m)(1E+6 cm^3) (1.47g/cm^3)(1% MO)(5.4Kcal/g)(4186 J/Kcal)		
Area:	1.10E+12	m^2	(CIA, 2006)
Arable lands:	2.78%		
permanent crops:	0.19%		
Depth:	1.00	m	
Density:	1.47	g/cm^3	
OM:	1.00%		
Assume :	1 m deep, 1% organic content, 5.4 kcal/g		
Stock's Energy =	1.08E+19	J	

2 **Forests**

National stock =	(Forest Area m^2)(Aboveground biomass) (1E+6 g)(dry weight)(19,200 J/g)		
Area:	5.87E+07	ha	(FAO 2006)
Aboveground biomass:	230.00	t/ha	
Dry weight:	0.5	g dry wt/g green wt	
Stock's Energy =	1.30E+20	J	

3 **Natural gas**

National stock =	(Proven reserves)(energy j/m^3)		
Proven reserves:	6.80E+11	m^3	EIA, 2005
Energy =	3.77E+07	J/m^3	
Stock's Energy =	2.56E+19	J	

4 **Crude oil**

National stock =	(Proven reserves)(energy j/bbl)		
Proven reserves:	4.41E+08	barrels	EIA, 2005
Energy =	6.28E+09	J/bbl	
Stock's Energy =	2.77E+18	J	

Fresh water occupies an important place among the storages of Bolivian natural capital. However, the data available is not enough to quantify the fresh water stock at a national level (Mattos and Crespo, 2000)

Appendix 13. FSC's Principles and criteria for forest certification

PRINCIPLE #1: COMPLIANCE WITH LAWS AND FSC PRINCIPLES
Forest management shall respect all applicable laws of the country in which they occur, and international treaties and agreements to which the country is a signatory, and comply with all FSC Principles and Criteria.

PRINCIPLE #2: TENURE AND USE RIGHTS AND RESPONSIBILITIES
Long-term tenure and use rights to the land and forest resources shall be clearly defined, documented and legally established.

PRINCIPLE #3: INDIGENOUS PEOPLES' RIGHTS
The legal and customary rights of indigenous peoples to own, use and manage their lands, territories, and resources shall be recognized and respected.

PRINCIPLE #4: COMMUNITY RELATIONS AND WORKER'S RIGHTS
Forest management operations shall maintain or enhance the long-term social and economic well being of forest workers and local communities.

PRINCIPLE # 5: BENEFITS FROM THE FOREST
Forest management operations shall encourage the efficient use of the forest's multiple products and services to ensure economic viability and a wide range of environmental and social benefits.

PRINCIPLE #6: ENVIRONMENTAL IMPACT
Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest.

PRINCIPLE #7: MANAGEMENT PLAN
A management plan -- appropriate to the scale and intensity of the operations -- shall be written, implemented, and kept up to date. The long-term objectives of management, and the means of achieving them, shall be clearly stated.

PRINCIPLE #8: MONITORING AND ASSESSMENT
Monitoring shall be conducted -- appropriate to the scale and intensity of forest management -- to assess the condition of the forest, yields of forest products, chain of custody, management activities and their social and environmental impacts.

PRINCIPLE # 9: MAINTENANCE OF HIGH CONSERVATION VALUE FORESTS
Management activities in high conservation value forests shall maintain or enhance the attributes which define such forests. Decisions regarding high conservation value forests shall always be considered in the context of a precautionary approach.

PRINCIPLE # 10: PLANTATIONS
Plantations shall be planned and managed in accordance with Principles and Criteria 1 - 9, and Principle 10 and its Criteria. While plantations can provide an array of social and economic benefits, and can contribute to satisfying the world's needs for forest products, they should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests.
(FSC, 2007)

Appendix 14. Data on tree harvesting and calculation of age and weighted solar transformity

Uncertified logging system

DBH (m)	Approximate Age (yrs)	Trees Harvested (# tress/ha)	Harvested Volume (m^3)	Harvested Biomass (J)	Solar Transformity (sej/J)	Solar Emergy (sej)
0.40	215	0.89	3.13	3.01E+10	215,000	6.46E+15
0.50	245	0.74	4.07	3.91E+10	250,000	9.76E+15
0.60	255	0.69	5.46	5.24E+10	260,000	1.36E+16
0.70	278	0.78	8.41	8.07E+10	275,000	2.22E+16
0.80	294	0.73	10.27	9.86E+10	290,000	2.86E+16
0.90	313	0.72	12.83	1.23E+11	320,000	3.94E+16
1.00	328	0.54	11.88	1.14E+11	332,000	3.78E+16
1.10	369	0.33	8.78	8.43E+10	364,000	3.07E+16
1.20	420	0.20	6.33	6.08E+10	400,000	2.43E+16
1.30	443	0.03	1.11	1.07E+10	425,000	4.55E+15
1.40	466	0.03	1.29	1.24E+10	448,000	5.56E+15
1.50	488	0.01	0.49	4.75E+09	460,000	2.19E+15
1.60	510	0.02	1.13	1.08E+10	470,000	5.08E+15
1.70	533	0.02	1.27	1.22E+10	485,000	5.92E+15
	Totals	**5.73**	**76.46**	**7.34E+11**	**321,808(*)**	**2.36E+17**

Certified logging system

DBH (m)	Approximate Age (yrs)	Trees Harvested (# tress/ha)	Harvested Volume (m^3)	Harvested Biomass (J)	Solar Transformity (sej/J)	Solar Emergy (sej)
0.40	215	0.27	0.95	9.12E+09	215,000	1.96E+15
0.50	245	0.25	1.37	1.32E+10	250,000	3.30E+15
0.60	255	0.81	6.41	6.16E+10	260,000	1.60E+16
0.70	278	0.90	9.70	9.31E+10	275,000	2.56E+16
0.80	294	0.84	11.82	1.13E+11	290,000	3.29E+16
0.90	313	0.41	7.30	7.01E+10	320,000	2.24E+16
1.00	328	0.20	4.40	4.22E+10	332,000	1.40E+16
1.10	369	0.14	3.73	3.58E+10	364,000	1.30E+16
1.20	420	0.04	1.27	1.22E+10	400,000	4.86E+15
1.30	443	0.03	1.11	1.07E+10	425,000	4.55E+15
1.40	466	0.03	1.29	1.24E+10	448,000	5.56E+15
1.50	488	0.02	0.99	9.50E+09	460,000	4.37E+15
1.60	510	0.00	0.00	0.00E+00	470,000	0.00E+00
1.70	533	0.00	0.00	0.00E+00	485,000	0.00E+00
	Totals	**3.94**	**50.35**	**4.83E+11**	**307,435(*)**	**1.49E+17**

V = 0.7854* DBH^2 * sf*h*# of trees (González and Cruz, 2004)
V: Commercial volume (m^3)
DBH: Diameter Breast Height (m)
sf: Shape factor (0.70 for latifoliade and 0.47 pine)
h: Tree height (commercial)
Biomass = (Volume m^3)(1E+06 g/m^3)(0.5 g dry weight/g green wt)(19,200 J/g dry wt) (Odum, 1996)
Average height: 40 m (Oliveira *et al.*, 2005)
(*) Weighted average of transformity = ∑ Solar emergy/ ∑ Harvested biomass (Bastianoni and Marchettini, 2000)

Appendix 15. Footnotes to Table 6.4: Emergy evaluation of uncertified logging in 1ha per year of tropical forest, 2005

1 **Sunlight, J**

Annual energy =	(Avg. Total Annual Insolation J/yr)(1-albedo)(4186 J/Kcal)		
Insolation:	1.27E+06	Kcal/m^2/yr	(Odum and Arding, 1991)
Forest land:	10,000	m^2	
Albedo:	0.30	Fraction absorbed at surface (Barry and Chorley, 1992)	
Annual energy:	3.72E+13	J	
Emergy per unit input =	1	sej/J	

2 **Rain Chemical, J**

Annual energy =	(Forest land)(1000 kg/m^3)(Gibbs free energy 4.94 J/g)		
Forest land:	10,000	m^2	
Rainfall:	3.88	m/y	(SENAMHI, 2006)
Annual energy:	1.92E+11	J	
Emergy per unit input =	3.05E+04	sej/J	(Odum, 2000)

3 **Wood harvested, J**

DBH (m)	# Trees (ind/ha)	Age (yrs)	Volume (m^3)	Biomass (J)	Transformity (sej/J)	Emergy (sej)
0.40	0.89	215	3.13	3.01E+10	215,000	6.46E+15
0.50	0.74	245	4.07	3.91E+10	250,000	9.76E+15
0.60	0.69	255	5.46	5.24E+10	260,000	1.36E+16
0.70	0.78	278	8.41	8.07E+10	275,000	2.22E+16
0.80	0.73	294	10.27	9.86E+10	290,000	2.86E+16
0.90	0.72	313	12.83	1.23E+11	320,000	3.94E+16
1.00	0.54	328	11.88	1.14E+11	332,000	3.78E+16
1.10	0.33	369	8.78	8.43E+10	364,000	3.07E+16
1.20	0.20	420	6.33	6.08E+10	400,000	2.43E+16
1.30	0.03	443	1.11	1.07E+10	425,000	4.55E+15
1.40	0.03	466	1.29	1.24E+10	448,000	5.56E+15
1.50	0.01	488	0.49	4.75E+09	460,000	2.19E+15
1.60	0.02	510	1.13	1.08E+10	470,000	5.08E+15
1.70	0.02	533	1.27	1.22E+10	485,000	5.92E+15
Total	5.73		76.46	7.34E+11	**321,808**	2.36E+17

Volume = (0.7854)(DBH^2 m)(shape factor 0.70)(height m)(# of trees/ha) (González and Cruz, 2004)

Biomass = (Volume)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)

Average height = 40 m (Oliveira *et al.*, 2005)

Age: For trees with DBH 0.40 to 1.10 m, age was estimated based on DHB/age measurements for canopy species in La Selva, Costa Rica using stochastic simulation technique developed by Lieberman and Lieberman (1985) (Lieberman and Lieberman, 1987).

For trees with DBH 1.10 to 1.70 m, age was extrapolated from plotted data for 0.40 to 1.10 DBH data (Lieberman and Lieberman, 1987) using equations generated on Excel ®: For minimum estimated age: y = -3E-05x2 + 0.225x - 2.7273 and for maximum estimated age: y = 196.37Ln(x) - 862.03

Transformity: Estimations based on results of simulation using EMERGYDYN (Tilley, 1999)

Appendix 15. Footnotes to Table 6.4 (Continued)

4	**Soil erosion, J**			
	Annual energy =	(Area disturbed)(Soil loss MT/ha/yr)(1E6 g/MT)(% OM)(5.4 Kcal/g)(4186 J/Kcal)		
	Ground area disturbed =	1,006	m^2/ha	(Holmes *et al.*, 2000)
	Soil loss =	154	MT/ha/yr	(Sun and McNulty, 1998)
	Average organic content =	3	%	
	Annual energy:	3.15E+10	J/yr	
	Emergy per unit input of SOM =	7.40E+04	sej/J	(Brown and Bardi, 2001)
5	**Wood loss, J**			
	Source of wood wasted			
a	High stumps	0.28	m^3/ha	
b	Split logs	0.87	m^3/ha	
c	Bucking waste	1.97	m^3/ha	
d	Logs lost	0.96	m^3/ha	
e	*Total in forest (a+b+c+d)*	*4.08*	m^3/ha	
f	*Total in log deck*	*1.97*	m^3/ha	
g	Subtotal (e+f)	6.05	m^3/ha	
h	FCTs killed during felling	5.49	m^3/ha	
i	FCTs killed in skid trailing	2.01	m^3/ha	
j	Subtotal (h+i)	7.50	m^3/ha	
	Total (g+j)	*13.55*	m^3/ha	
	Annual energy =	(Wood wasted m^3)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
	Average log volume:	3.66	m^3/tree	(Krueger, 2004)
	Annual energy:	1.30E+11	J	
	Emergy per unit input =	2.76E+04	sej/J	From Table 5.5
6	**Access costs, $**			
	Annual energy =	(Cost of concession $/ha)+(Payment for certification $/ha)		
	Cost of concession:	20.00	$/ha	(UDAPE, 2005)
	Cost of certification:	0.00	$/ha	
	Cost of access:	20.00	$/ha	
	Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

Appendix 15. Footnotes to Table 6.4 (Continued)

7 **Services, $**

Activity			(Holmes *et al.*, 2000)
Pre-harvest	0.00	$/m^3	
Harvest planning	0.14	$/m^3	
Infrastructure	0.57	$/m^3	
Felling and bucking	0.49	$/m^3	
Skidding	1.99	$/m^3	
Log deck operations	2.01	$/m^3	
Waste adjustement	0.40	$/m^3	
Stumpage cost	9.09	$/m^3	
Training	0.00	$/m^3	
Overhead/support	0.97	$/m^3	
Total	*15.66*	$/m^3	
Annual energy =	(Cost of services $/m^3)(m^3/ha)		
Harvest:	25.36	m^3/ha	(Holmes *et al.*, 2000)
Cost of services:	397.14	$/ha	(Holmes *et al.*, 2000)
Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

8 **Uncertified timber output, J**

Annual energy =	(Uncertified timber harvested m^3)(650 kg)(1E3 g) (3.5 Kcal/g)(4186 J/Kcal)		
Total trees harvested:	76.46	m^3	(Holmes *et al.*, 2000)
Output of logs =	7.28E+11	J	

9 **Uncertified timber output, g**

Annual energy =	(Uncertified timber harvested m^3)(650 kg)(1E3 g) (3.5 Kcal/g)		
Total trees harvested:	76.46	m^3	(Holmes *et al.*, 2000)
Output of logs =	1.74E+08	g	

10 **Timber output transformity, sej/J**

Timber output transformity = (output energy of logs, J)/(sum of 2+6+7-4-5)

11 **Timber output transformity, sej/g**

Timber output transformity = (output energy of logs, g)/(sum of 2+6+7-4-5)

Price of uncertified wood	254.24	$/m^3	(Hanrahan and Grimes, 1997)
Bolivia GDP	2.58E+10	$	From Table 5.2
Bolivia, Total emergy used	8.55E+23	sej/y	From Table 5.3

Appendix 16. Footnotes to Table 6.5: Emergy evaluation of certified logging in 1ha per year of tropical forest, 2005

1 **Sunlight, J**

Annual energy =	(Avg. Total Annual Insolation J/yr)(1-albedo)(4186 J/Kcal)		
Insolation:	1.27E+06	Kcal/m^2/yr	(Odum and Arding, 1991)
Forest land:	10,000	m^2	
Albedo:	0.30	Fraction absorbed at surface (Barry and Chorley, 1992)	
Annual energy:	3.72E+13	J	
Emergy per unit input =	1	sej/J	

2 **Rain Chemical, J**

Annual energy =	(Forest land)(1000 kg/m^3)(Gibbs free energy 4.94 J/g)		
Forest land:	10,000	m^2	
Rainfall:	3.88	m/y	(SENAMHI, 2006)
Annual energy:	1.92E+11	J	
Emergy per unit input =	3.05E+04	sej/J	(Odum, 2000)

3 **Wood harvested, J**

DBH (m)	# Trees (ind/ha)	Age (yrs)	Volume (m^3)	Biomass (J)	Transformity (sej/J)	Emergy (sej)
0.40	0.27	215	0.95	9.12E+09	215,000	1.96E+15
0.50	0.25	245	1.37	1.32E+10	250,000	3.30E+15
0.60	0.81	255	6.41	6.16E+10	260,000	1.60E+16
0.70	0.90	278	9.70	9.31E+10	275,000	2.56E+16
0.80	0.84	294	11.82	1.13E+11	290,000	3.29E+16
0.90	0.41	313	7.30	7.01E+10	320,000	2.24E+16
1.00	0.20	328	4.40	4.22E+10	332,000	1.40E+16
1.10	0.14	369	3.73	3.58E+10	364,000	1.30E+16
1.20	0.04	420	1.27	1.22E+10	400,000	4.86E+15
1.30	0.03	443	1.11	1.07E+10	425,000	4.55E+15
1.40	0.03	466	1.29	1.24E+10	448,000	5.56E+15
1.50	0.02	488	0.99	9.50E+09	460,000	4.37E+15
1.60	0.00	510	0.00	0.00E+00	470,000	0.00E+00
1.70	0.00	533	0.00	0.00E+00	485,000	0.00E+00
Total	5.73		50.35	4.83E+11	**307,435**	1.49E+17

Volume = (0.7854)(DBH^2 m)(shape factor 0.70)(height m)(# of trees/ha) (González and Cruz, 2004)

Biomass = (Volume)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)

Average height = 40 m (Oliveira *et al.*, 2005)

Age: For trees with DBH 0.40 to 1.10 m, age was estimated based on DHB/age measurements for canopy species in La Selva, Costa Rica using stochastic simulation technique developed by Lieberman and Lieberman (1985) (Lieberman and Lieberman, 1987).

For trees with DBH 1.10 to 1.70 m, age was extrapolated from plotted data for 0.40 to 1.10 DBH data (Lieberman and Lieberman, 1987) using equations generated on Excel ®: For minimum estimated age: y = -3E-05x2 + 0.225x - 2.7273 and for maximum estimated age: y = 196.37Ln(x) - 862.03

Transformity: Estimations based on results of simulation using EMERGYDYN (Tilley, 1999)

Appendix 16. Footnotes to Table 6.5 (Continued)

4	**Soil erosion, J**			
	Annual energy =	(Area disturbed)(Soil loss MT/ha/yr)(1E6 g/MT)(% OM)(5.4 Kcal/g)(4186 J/Kcal)		
	Ground area disturbed =	518	m^2/ha	(Holmes *et al.*, 2002)
	Soil loss =	66	MT/ha/yr	(Sun and McNulty, 1998)
	Average organic content =	3	%	
	Annual energy:	6.96E+09	J/yr	
	Emergy per unit input of SOM =	7.40E+04	sej/J	(Brown and Bardi, 2001)
5	**Wood loss, J**			
	Source of wood wasted			
a	High stumps	0.10	m^3/ha	
b	Split logs	0.31	m^3/ha	
c	Bucking waste	0.85	m^3/ha	
d	Logs lost	0.06	m^3/ha	
e	*Total in forest (a+b+c+d)*	*1.32*	m^3/ha	
f	*Total in log deck*	*0.60*	m^3/ha	
g	Subtotal (e+f)	1.92	m^3/ha	
h	FCTs killed during felling	1.83	m^3/ha	
i	FCTs killed in skid trailing	0.00	m^3/ha	
j	Subtotal (h+i)	1.83	m^3/ha	
	Total (g+j)	3.75	m^3/ha	
	Annual energy =	(Wood wasted m^3)(1E+06 g/m^3)(0.5 g dry wt/g green wt)(19,200 J/g dry wt)		
	Average log volume:	3.66	m^3/tree	(Krueger, 2004)
	Annual energy:	3.60E+10	J	
	Emergy per unit input =	2.76E+04	sej/J	From Table 5.5
6	**Access costs, $**			
	Annual energy =	(Cost of concession $/ha)+(Payment for certification $/ha)		
	Cost of concession:	20.00	$/ha	(UDAPE, 2005)
	Cost of certification:	35.67	$/ha	(CFB, 2007; CFV, 2006)
	Cost of access:	55.67	$/ha	
	Emergy per unit input =	3.31E+13	sej/$	From Table 5.2

Appendix 16. Footnotes to Table 6.5 (Continued)

7	**Services, $**			
	Activity			(Holmes *et al.*, 2000)
	Pre-harvest	1.18	\$/m^3	
	Harvest planning	0.16	\$/m^3	
	Infrastructure	0.59	\$/m^3	
	Felling and bucking	0.62	\$/m^3	
	Skidding	1.24	\$/m^3	
	Log deck operations	1.28	\$/m^3	
	Waste adjustement	0.09	\$/m^3	
	Stumpage cost	7.61	\$/m^3	
	Training	0.21	\$/m^3	
	Overhead/support	0.86	\$/m^3	
	Total	*13.84*	\$/m^3	
	Annual energy =	(Cost of services \$/m^3)(m^3/ha)		
	Harvest:	25.36	m^3/ha	(Holmes *et al.*, 2000)
	Cost of services:	350.98	\$/ha	(Holmes *et al.*, 2000)
	Emergy per unit input =	3.31E+13	sej/\$	From Table 5.2
8	**Certified timber output, J**			
	Annual energy =	(Certified timber harvested m^3)(650 kg)(1E3 g) (3.5 Kcal/g)(4186 J/Kcal)		
	Total trees harvested:	50.35	m^3	(Holmes *et al.*, 2000)
	Output of logs =	4.79E+11	J	
9	**Certified timber output, g**			
	Annual energy =	(Certified timber harvested m^3)(650 kg)(1E3 g) (3.5 Kcal/g)		
	Total trees harvested:	50.35	m^3	(Holmes *et al.*, 2000)
	Output of logs =	1.15E+08	g	
10	**Timber output transformity, sej/J**			
	Timber output transformity =	(output energy of logs, J)/(sum of 2+6+7-4-5)		
11	**Timber output transformity, sej/g**			
	Timber output transformity =	(output energy of logs, g)/(sum of 2+6+7-4-5)		
	Price of certified wood	466.10	\$/m^3	(Hanrahan and Grimes, 1997)
	Bolivia GDP	2.58E+10	\$	From Table 5.2
	Bolivia, Total emergy used	8.55E+23	sej/y	From Table 5.3

Appendix 17. List of acronyms

AAA	Area de Aprovechamiento Annual (Annual cutting areas)
ASL	Asociaciones Sociales del Lugar (Social Communal Groups)
BCB	Banco Central de Bolivia (Bolivian Central Bank)
BIAPE	Banco Internacional de Ahorro y Préstamo (International Bank Ltd.)
CADEFOR	Centro Amazónico de Desarrollo Forestal (Amazonic Center for Sustainable Forest Enterprise)
CAF	Andean Development Corporation
CC	Chain of Custody
CFB	Cámara Forestal de Bolivia (Forestry Chamber of Bolivia)
CFV	Consejo Boliviano para la Certificación Forestal Voluntaria (Bolivian Council for Voluntary Forest Certification)
CIA	Central Intelligence Agency
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
EIA	Energy Information Administration
FAO	Food and Agriculture Organization of the United Nations
FELCN	Fuerza de Lucha Contra el Narcotráfico (Bolivia's counter-narcotics police force)
FONABOSQUE	Fondo Nacional de Desarrollo Forestal (Forest Development Fund)
FONPLATA	Financial Fund for the Plata Basin
FRA	Global Forest Resources Assessment (FAO)
FSC	Forest Stewardship Council
GATT	World Trade Organization's Global Agreement on Tariffs and Trade

GFTN	Global Forest & Trade Network at WWF
IADB	Inter American Development Bank
IFAD	International Fund for Agricultural Development
IMF	International Monetary Fund
INE	Instituto Nacional de Estadísctica (Bolivian Census Buraeu)
INRA	Instituto Nacional de Reforma Agraria (National Agrarian Reform Institute)
ITTO	International Tropical Timber Organization
LDA	Ley de Descentralización Administrativa (Administrative Decentralization Law)
LPP	Ley de Participación Popular (Law of Popular Participation)
MACIA	Ministerio de Asuntos Campesinos Indígenas y Agropecuarios (Ministry of Peasant, Indigenous and Agricultural Affairs)
MAS	Movimiento al Socialismo – Bolivian political party (Movement for Socialism)
MDSP	Ministerio de Desarrollo y Planificacion (Ministry of Planning and Development)
MERCOSUR	Mercado Común de Sur (Southern Common Market)
NDF	Nordic Development Fund
NGO	Non-Governmental Organization
NREL	National Renewable Energy Laboratory
NTFP	Non-Timber Forest Product
OLADE	Organización Latinoamericana de Energía (Latin American Energy Organization)
OPEC	Organization of the Petroleum Exporting Countries
OTB	Organizaciones Territoriales de Base (Base Territorial Organizations)

PGMF	Plan General de Manejo Forestal (Forestry Management General Plan)
PIERS	Port Import Export Reporting Service (U.S.)
POAF	Plan Operativo Anual Forestal (Annual Operative Forestry Plan)
RIL	Reduced Impact Logging
SENAMHI	Servicio Nacional de Meteorología e Hidrología (Bolivia's National Service of Meteorology and Hydrology)
SFM	Sustainable Forest Management
SIF	Superintendencia Forestal (Forestry superintendent’s office)
SIRENARE	Sistema de Regulación de Recursos Naturales Renovables (Natural Resource Regulatory System)
SPE	Society of Petroleum Engineers
STCP	Engenharia de Projetos (Brazilian firm: Project Engineering Ltd.)
TCO	Tierra Comunitaria de Origen (Original Community Land)
UDAPE	Unidad de Análisis de Políticas Sociales y Económicas (Unit of Social and Policy Analysis)
UNODC	United Nations Office on Drugs and Crime
USGS	United States Geological Survey
WB	World Bank
WTO	World Trade Organization
WWF	World Wildlife Fund
YPFB	Yacimientos Petrolíferos Fiscales Bolivianos (Bolivian Oil Company)

Glossary

Available energy – Also called exergy. It is the energy with the potential to do work.

BCF – Short for 1 billion cubic feet. Used in the oil and gas industry. The term billion in this case refers to 1E+9.

DBH – Diameter at breast height. Tree DBH is the outside bark diameter measured at breast height. (Generally 1.3 m)

Emdollar value – Emergy Dollar value. Dollars of gross economic product obtained by dividing the emergy of a product by the appropriate emergy to money ratio. The dollars of gross economic product equivalent to the wealth measured in emergy units.

Emergy (spelled with an "M") – The sum of all available energy of one form needed to develop a flow of energy of another form, over a period of time.

Emergy exchange ratio (EER) – Ratio of emergy received to emergy paid out in barter, trade, purchases, or other exchanges.

Emergy investment ratio (EIR) – The ratio of emergy brought into an area from outside its economy to the local, free environmental emergy used in the interaction processes.

Emergy yield ratio (EYR) – Is the emergy of an output divided by the emergy of those inputs to the process that are fed back from the economy and it was used for interpretation of the net benefit. The ratio of the emergy yield to that required for processing.

Emjoule – The unit of emergy; a joule of available energy of one kind of energy previously used up to make a service or product.

Energy – A property of all systems which can be turned into heat and measured in heat units (Calories, BTUs or joules).

Energy hierarchy – The convergence and transformation of energy from many small units into smaller amounts of higher–level types of energy.

Energy systems diagrams – General systems overview that represent parts and connections of any system, including flows and storages of materials, energy, information, and money.

Environmental loading ratio (ELR) – Ratio of purchased emergy plus non-renewable indigenous emergy divided by the free environmental emergy.

Exergy – Also known as available energy. Is the energy with the potential to do useful work and that is used up in the process.

FCT – Future Crop Trees. FCTs account for all species of commercial timber value, for future harvesting.

GDP – Short for Gross Domestic Product. A country's gross domestic product is one of the ways to measure the size of its economy. The GDP of a country is defined as the total market value of all final goods and services produced within a country in a given period of time (usually a calendar year).

ha – Hectare, a unit commonly used for measuring land area. One ha equals to 10,000 square meters, one square hectometer (100 square meters).

m^3 – Symbol for cubic meter. Cubic meter is the SI derived unit of volume

Maximum empower principle – Self organization selects designs by reinforcing network pathways that maximize empower. This is a clarification of the maximum power principle to recognize that each level in the natural energy hierarchy self organizes with the same principle at the same time.

Maximum power principle – An explanation from Alfred Lotka and others for the designs observed in self organizing systems (energy transformations, hierarchical patterns, feedback controls, amplifier actions, etc.). Designs prevail because they draw in more available energy and use it with more efficiency than alternatives.

Net emergy – The emergy yield from a resource after all the emergy used in the process has been subtracted.

NTFP – Short for Non–timber Forest Products. NTFPs comprise all goods derived from forests of both plant and animal origin other than timber. NTFPs contribute to household income and subsistence and are of cultural importance in many rural societies. Recently, their role in sustainable development has been emphasized.

Real wealth – Entities and flows containing available energy (exergy) capable of depreciating according to the second Law; usable products and services; Examples: food, fuels, material concentrations, houses, organisms, information, land, labor, controls.

Solar emergy – Solar energy required directly and indirectly to make a product or service. Units are solar emjoules (abbreviated sej).

Solar transformity – Solar emergy per unit energy, expressed in solar emjoules per joule (sej/J).

Sustainable development – Socio-ecological process characterized by the fulfilment of human needs while maintaining the quality of the natural environment indefinitely.

Sustainable use – Resource use that can be continued by society in the long run because the use level and system design allow resources to be renewed by natural or man–aided processes.

Systems ecology – The field which came from the union of systems theory and ecology and provides a world view for energy analysis.

TCF – Short for 1 trillion cubic feet. Used in the oil and gas industry. The term trillion in this case refers to 1E+12.

Transformity – The emergy of one type required to make a unit of energy of another type.

Turnover time or replacement time – The time for a flow to replace a stored quantity.

Wealth – Ambiguous term which needs an adjective to distinguish monetary wealth (state of being rich with money) from real wealth (definition above).

*Modified from Campbell (1996)

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