LUNDS UNIVERSITET

Thesis submitted in partial fulfillment of the requirements for LUMES: Lund University Master's Programme in International Environmental Science

Primary Emergy Evaluation of Iceland:

The question of a sustainable natural resource management

by

Bergthora Hlidkvist Skuladottir

November 21st 2005

Author:
Bergthora Hlidkvist Skuladottir
hlidkvist@hotmail.com
LUMES, Sölvegatan 10, Lund
Sweden

Thesis supervisor:
Hördur V. Haraldsson
Hordur.haraldsson@chemeng.lth.se
Department of Chemical Engineering
Lund University
P.O. Box 124 S-22100 Lund
Sweden

Abstract

Iceland is rich in renewable energy resources, such as hydro and geothermal energy, and a tremendous progress has been made in harnessing those resources the past decades. But recently, the current energy policy has been criticised and a more sustainable policy is demanded, where the value of untouched nature is taken into account. Traditional evaluation methods in environmental and ecological economics have been defined narrow and anthropocentric when it comes to estimating the value of ecosystem inputs. The problem is that money only pays for human work, not for contributions from nature. Emergy Evaluation tries to capture the ecocentric value and makes it possible to determine the value of nature to the human economy. An Emergy Evaluation of Iceland revealed that the main renewable solar emergy sources in Iceland are in rain and the earthcycle. Calculated renewable resource base was around 50% bigger than all exports from the country. Various indices calculated in the analysis show the uniqueness of Iceland in the level of self-sufficiency and its sustainability index ranks Iceland among the top in comparison with other countries. What may bias the outcome is a small population and abundant renewable emergy resources. Emergy Evaluation and Ecological Footprint ranked selected countries the same according to their level of sustainability.

Key words: Emergy Evaluation, Iceland, sustainability, natural resource management.

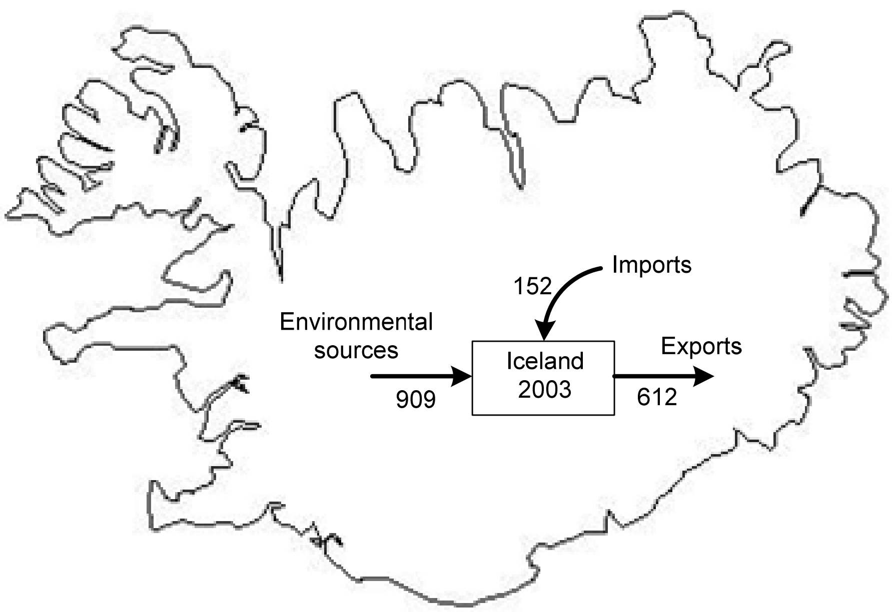


Figure 1. An overview of the economic-environmental system in Iceland in 2003.

Acknowledgements

Thanks to

- my supervisor, Hördur Haraldsson, for introducing me to the concept of emergy, excellent supervision and a pleasant company.
- all the specialists in Iceland that were contacted, for their willingness to assist and quick responses.
- Dan E. Campbell at USEPA for an unexpected assistance and enlightening discussion in time of confusion. It was invaluable.
- my family, Óskar, Birta and Helgi, for tolerating me the past months when my mind has been centered around emergy.

Table of contents

1. Introduction

1.1 Green accounting – adding natural resources to the picture

In an interesting article, published in Scientific American last September, the ecological economist Herman E. Daly writes about economics in a full world (Daly, 2005). There, he emphasizes how important it is that human society realizes that it operates in a finite biosphere and the ongoing focus on economic growth and unsustainable withdrawal from renewable resources will only lead to ecological catastrophe. He, unlike mainstream, or neoclassical economists, is concerned with the issue of sustainability and realizes that the biosphere is non-growing and constrained by the laws of thermodynamics and closed, except for the constant input of solar energy (Daly, 2005). Daly is not the only one with this opinion because the importance of green accounting, where environmental contributions are taken into national accounts, has been discussed extensively recently in scientific literature. Now, it seems that this discussion has reached the ears of those in charge because the World Bank has published a report where it is argued that the current measures of a country's economic welfare, such as gross national product, is not adequate as they ignore the value of natural assets, or the natural capital, in the country (The Economist, 2005).

According to Odum (1996) the natural and economic processes in every part of the world depend on a set of environmental energy flows and storages. In this regard, it is important to understand the relationship between this energy and the cycles of materials and information to gain insight into the complex interrelationship between the biosphere and society. Society uses environmental energies directly from renewable energy flows and storages of materials and also energies that are a former production of the biosphere. This resource use of society places a stress on the biosphere and it is important to gain knowledge in the interplay of society and environment to help in direct planning and policy in the future (Brown and Ulgiati, 1999, Odum, 1996).

Economic evaluation systems in the paradigm of neoclassical economics, is based on utility or the willingness to pay for perceived utility and is therefore highly dependent of human preference. According to Brown and Ulgiati (1999) there is a need for a valuation system for the biosphere that seeks to balance humanity and environment and is free of human bias. This is because human preference cannot value ecological processes or environmental resources since these processes are not within the economic sphere. It is claimed that a shift from the human centered valuing paradigm based on money flow to a biophysical paradigm based on energy flows that sustain the biosphere is needed to help humanity to develop an symbiotic interface with the biosphere (Brown and Ulgiati, 1999).

Even though various valuation methods have been developed within environmental and ecological economics in estimating the value of ecosystem inputs, these have been defined narrow and anthropocentric (Hau and Bakshi, 2004). Emergy Evaluation differs from economic analysis because instead of using the money value of goods, services and resources, a measure of resource quality is used (Brown and McClanahan, 1996). This method tries to capture the ecocentric value and makes it possible to determine the value of nature to the human economy. It assumes that the value of a resource is proportional to the energy required to produce the resource (Hau and Bakshi, 2004).

The main inspiration for choosing the topic of this thesis is a current debate in Iceland over hydropower development in an untouched highland area. The arguments whether to conserve or develop crystallizes in the difference in how people value nature; is it there for man to utilize or should it be kept untouched? This ongoing debate has raised the question on what the value of nature is to the Icelandic economy. In order to answer this question the author studied the Icelandic economy through Emergy Evaluation.

1.2 Disposition

The outline of the thesis is as follows: In chapter 1, a brief geographical and historical background information on Iceland are given, followed by a summary on the Icelandic energy history to give insight to the roots of the current debate. Theoretical framework drawn around the issue, as well as objectives and scope are listed in chapter 2. Chapter 3, Methods and Materials, contains an extensive description of the Emergy Evaluation method. Chapter 4 presents the results and finally the results are discussed in chapter 5.

1.3 Background to case study

Iceland is the second largest island in the North-Atlantic Ocean. It is Europe's westernmost country with a total area of about 103,000 km^2 and approximately 290,000 inhabitants that makes it the most sparsely populated country in Europe (figure 2). The population is concentrated in a narrow coastal belt and on the southwest corner. Active volcanoes, glaciers and arctic deserts make up the central highlands that contain some of the few remaining large wilderness areas in Europe. Geologically speaking, the island is very young and still in the making. Volcanic eruptions are frequent and in no other region in the world does the emission of volcanic material have higher production time per unit (The Ministry of Foreign Affairs, 2005). Vegetation covers only 23% of the country and the most serious environmental problem is the loss of vegetation by wind erosion (Arnalds, 2003). Iceland has a mild sub-arctic maritime climate attributed by the Golf stream. High annual precipitation gives rise to large rivers and glaciers that cover 11% of the country. Iceland holds a modern society with high standard of living and its economy and society rely heavily on its main natural resources, fish in the sea, hydropower and geothermal energy (The Ministry of Foreign Affairs, 2005).

Figure 2. Regional map showing Iceland.

For centuries, the Icelandic economy has been dependent on fisheries and export of fish products. Therefore it is both an economic as well as environmental priority for Iceland to harvest this resource in a sustainable way. Today, a science-based quota system in fisheries is in place that marine scientists claim is sustainable (Sverrisdóttir, 2004). Concerning the renewable hydropower and geothermal energy, a remarkable progress has been made in harnessing those resources for domestic use and industry for the past 50 years. The main energy source in the 1940s was coal but after that, oil was the dominant source of energy until about 1970 (figure 3) (The National Energy Authority, 2005). The development of hydropower has led to a reduction in the proportion of oil in the energy consumption and currently, imported energy is chiefly used in transport and by the fishing fleet. These two sectors consume about 90% of all imported oil in Iceland and remain the main greenhouse gas emitting activities in Iceland (Sverrisdóttir, 2004)

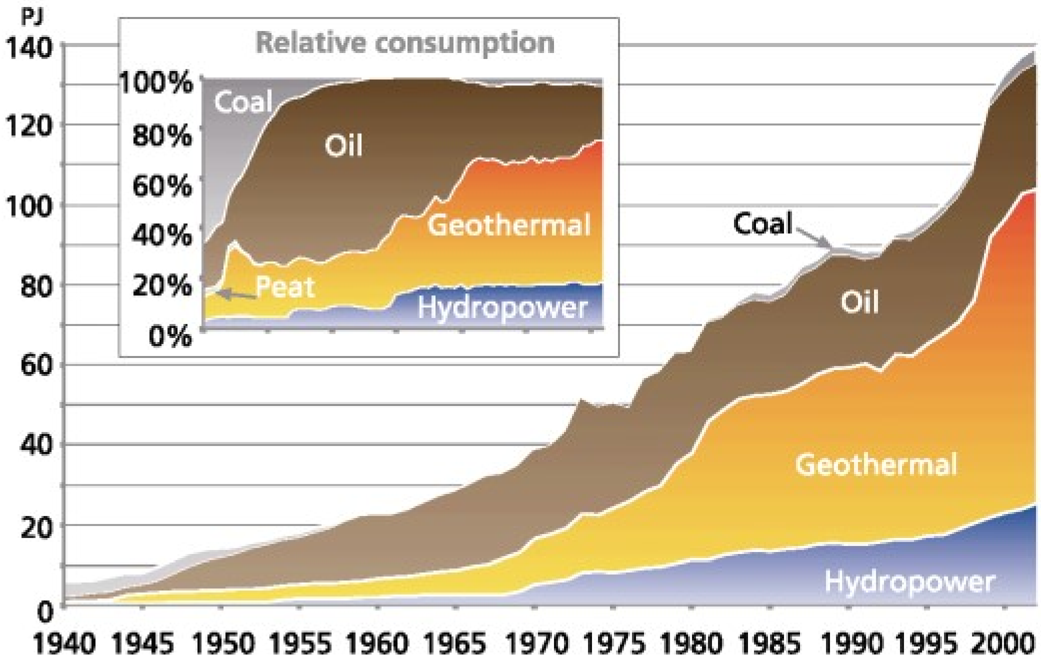


Figure 3. Energy consumption in Iceland from 1940-2000 (The National Energy Authority, 2005).

The growth in Gross National Product (GNP) in Iceland has mainly been driven by the fishing industry for the past decades. As fish stocks are a limiting resource that restricts the expansion potential in the sector, the Icelandic authorities have looked into other ways to increase the variety in exporting industry and to diversify and strengthen the country's economy. The main effort in that direction throughout the years, as part of the energy policy, has been to recruit electricity dependent industry, mainly aluminium smelters to the country and by that using the rich renewable hydropower resources the country holds to provide them with electricity (Gudmundsson, 2003, Hilmarsson, 2003). The first contract with a foreign aluminium smelter was signed in 1969 and today, there are two aluminium smelters operating in Iceland and one under construction. In order to keep up with the electricity demand from this industry, Landsvirkjun, the National Power Company, has increased its electricity production by 60% the last 6-7 years. In 2010, when the new aluminium smelter will be operating and the other two have gone through an allowed expansion, Iceland will become one of the largest aluminium producers in Western Europe (Hilmarsson, 2003).

The decision of building the current aluminum smelters was debated by Icelanders. The reactions to the latest addition of smelters are no exception and have stirred a debate, both in Iceland and abroad (Lynas, 2004). The main matter of dispute is the irreversible changes done to the environment associated with the constructions of the hydropower, which are necessary to provide the aluminium smelter with electricity. Over 57 km^2 of an untouched wilderness area will be submerged under water along with change in flow patterns of Glacier Rivers (Landsvirkjun, 2005). The main pro-acting group in the debate is the government who, with the city of Reykjavík, owns Landsvirkjun, the main power company. Those opposing the plans are the politicians to the far left, different non-governmental organizations (Landvernd, Náttúruverndarrád) and nature conservationists (World Wide Fund, WWF). The general public is also actively taking part in this debate, writing letters in newspapers and protesting. Many opinion polls have been carried out examining attitudes toward this hydropower project among Icelanders. Result show that around 50-60% are in favor and up to 30% against it (Landsvirkjun, 2005).

1.4 Ecocentric values and emergy

What is the value of nature? This is one of the main questions debated in the media regarding the hydropower development. When evaluating the different arguments it becomes evident that there is a large gap between the two groups because they value nature differently and use different set of arguments. The arguments of the people in favor of conservation are usually based on feelings, they talk about the beauty and uniqueness of untouched nature and point out that with ever increasing development in the world, untouched nature will gain more value in the future. Their main concerns are the environmental impacts of both the power plant itself and the smelter and they demand a shift to a more sustainable energy policy and cleaner industry. Those in favor of hydro development differ in their viewpoint. They realize the environmental impacts in the process, but point to all the benefits associated to the energy policy, such as new jobs and economic growth. They claim that it is the responsibility of Icelandic authorities to create good living conditions in Iceland for future generation and a strong industry sector is a prerequisite to reach that goal.

This debate may be considered as a classical dilemma in environmental philosophy where the primary concern is values. The question may be put forth: Does nature have value separate from its role in meeting human needs and if so, why? According to Carter (2001) such difference in conception on value is rooted in how people look at nature and has been categorized into anthropocentrism and ecocentrism. Anthropocentrism is the belief that humans are placed in the center of the universe, separated from nature and given unique values. In this view, only humans with their capacity to experience pleasure and to reason, have intrinsic value. The rest of the nature is of instrumental value and deserves moral consideration only if it enhances human well-being. Carter further elaborates on that ecocentrism rejects anthropocentrism and argues that non-human entities also have intrinsic value. Ecocentrism argues for intrinsic values in nature that may prove to be a powerful instrument in defending the environment (Carter, 2001). Conventional economics are rooted in anthropocentrism and assume that the environment is a subsystem of the economic system. There, it is believed that humans will be able to replace scarce resources. On the other pole, the ecological economics, rooted in ecocentrism, see the economic system as a subsystem of the environment. There, it is claimed that conventional economic growth will, in the long run, be unsustainable because it depletes the foundation of the ecosystem, namely natural resources (Miller, 2004)

According to Hau and Bakshi (2004) Emergy Evaluation tries to capture the ecocentric value and makes it possible to determine the value of nature to the human economy. Unlike economic cost-benefit analysis, that also is a valuation process, emergy does not consider nature as an externality. Instead, it values the work of nature by using energy as a common basis. As it put values on processes that fall outside the moneyed economy, Emergy Evaluation is able to eliminate problems connected to monetary valuation (Brown and Herendeen, 1996). In the emergy theory, the value of a resource depends on the energy, time and materials invested in it, i.e. the more previous work done, or energy dissipated to produce the resource, the greater is its value (Odum, 1996, Brown and McClanahan, 1996, Haden, 2003). Emergy Evaluation has indeed been useful where conflict has arisen over economic development and environmental protection (Brown and McClanahan, 1996). To be able to directly compare the value of natural resources and economic activity, the work of the economy and the environment is put on the same scale by converting the flows of energy done by both the economic and environmental flows to emergy (Campbell *et al*., 2004).

1.5 Sustainability – how can it be measured?

According to Mayer *et al* (2004), sustainability is hard to measure because it has a vague definition. What complicates all efforts to come up with an acceptable measuring tool is the fact that sustainability is a multidisciplinary issue and to be able to assess it, one must incorporate knowledge from various disciplines. These disciplines are mainly rooted in three different areas of science, namely ecology, economics and thermodynamics. The various tools that have been used are for example Ecological Footprint, within ecology (Wackernagel and Rees, 1996), "Green" National Net Production, NNP, within economics (Mayer, 2004) and Emergy, within thermodynamics (Odum, 1996). The multidisciplinary background appears to cause a great problem because each discipline defends its own measuring tool and criticizes the others. In fact, all the methods developed so far have both positive and negative aspects. Recently, it has been suggested that a combination of tools that covers all the above-mentioned disciplines would most likely provide an accurate assessment of sustainability (Mayer *et al*, 2004, Giannantoni *et al*, 2005).

2. Theoretical framework

2.1 Objectives and scope

The objective of this thesis is to compare the value of natural resources and economic activity in the Icelandic economy using Emergy Evaluation. By expressing natural resources (i.e. rivers and geothermal energy) and economic activity (i.e. fisheries and aluminium industry) with the same terms or units, a holistic picture of the economic-environmental system in Iceland can be established. It is the hope of the author that, by describing environmental resources and economic activity in the same term, emergy, it will be possible to value the natural resources to the Icelandic economy.

The scope of the case study is Iceland and included in the evaluation, according to the Emergy Evaluation methodology, are the continental shelf, the earth crust (3 km) and the air 1000 m above the country. The case study is of macroscopic scale and limited to data availability. Emergy Evaluation has a standardized approach that will be followed (see Methods and Material).

The thesis aims at answering the following research questions:

- How much emergy is in the renewable natural resources in Iceland compared to economic activity?
- What is the renewable emergy base for the Icelandic economy?
- How sustainable is the Icelandic economy in emergy terms and how do the results correlate with other methods that measure sustainability?
- How is the emergy balance in Iceland compared to other countries?

3. Methods and Materials

This chapter introduces the Emergy Evaluation method in general with explanation on glossary and terms and furthermore, the material used in the Emergy Evaluation on the national economy in Iceland, which is presented in the results chapter 4. Data was retrieved mainly from Campbell *et al* (2005), Doherty *et al* (2002) and Haden (2003).

3.1 Methodology

Emergy Evaluation originates in the work of ecosystem science. It is a part of a much larger theory developed by H.T. Odum about the functioning of ecological and other systems (Odum, 1996). It is an example of a conceptual framework, with a corresponding methodology, that has been adapted to the study of ecologically and economically coupled systems. According to Odum (1996), the theoretical foundation of systems ecology and Emergy Evaluation comes from the observation that both ecological systems and human, social and economic systems are energetic systems, that exhibit characteristic designs that reinforce energy use. The dynamic of these systems have found to be measurable and therefore they can be compared on an equal basis using energy metrics (Haden, 2003).

Emergy Evaluation is a quantitative method where an extensive amount of secondary data on natural resources and the economy are collected from various sources. In general, governmental sources are the first choice because they are most likely to provide detailed description of assumptions and methods through governmental institutions working on national affairs (Campbell *et al*, 2005). A fundamental prerequisite for Emergy Evaluation is a clear understanding of the system of interest. Therefore, prior to the analysis, it is important to review current and historic information to be able to characterize the system as an environmental system. That includes economic and social infrastructure as well as the storages, flows and processes of the ecosystem. This holistic view helps in understanding how renewable and nonrenewable resources have shaped the current economy in the system (Campbell *et al*., 2005).

3.2 Key words and concepts in Emergy Evaluation

Emergy Evaluation considers the earth to be a closed system where the major constant energy inputs are solar energy, deep earth heat and tidal energy. All other energy sources need to be taken from the storages of the biosphere's previous work, such as hydrocarbon fossil fuels (Odum, 1996). The conceptual basis of today's systems ecology view is the observation that possibly all systems are organized in hierarchies because it maximizes useful energy processing. According to Odum, energy hierarchy explains how, in all systems, greater amount of energy is needed in order to produce a product containing less energy of a higher quality. This process of energy transformations in systems of all types indicates that there is a natural order to how energies of differing qualities can be grouped. Energy quality explains how different kinds of energies vary in their ability to do useful work. When, for example, coal and electricity are compared, four joules of coal energy must be transformed to supply one joule of electric power. Because of this necessary transformation, electricity is at a higher position than coal in the energy hierarchy and is considered to be of a higher quality (Haden, 2003). Given these information, it can be stated that in a closed system all living systems sustain each other by participating in a network of energy flow, where lower quality energy is converted into both higher quality energy and degraded heat energy (figure 4). As solar energy is the main energy input, all other energies are scaled to solar equivalents to give the same unit. This incorporation into an energy flow network is possible through energy transformations, even for the economy because it originates from environmental resources measured by energy (Odum, 1996, Hau and Bakshi, 2004).

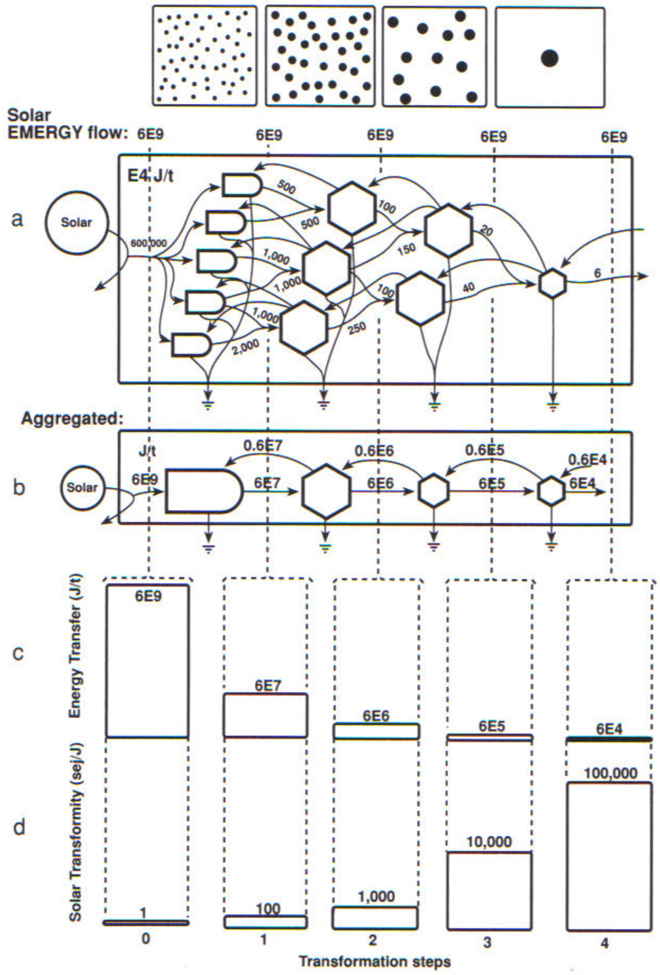


Figure 4. Energy transformation hierarchy (Haden, 2003:21). Distribution of size and territories of units in each category are shown, a) Web of energy flows, b) energy transformation chain that results from web aggregation by hierarchical position, c) energy flow at each hierarchical level, and d) the resulting transformity at each hierarchical level

In Emergy Evaluation several key words and concepts are used that need to be defined. They are:

Energy: A property of all things that can be turned into heat and measured in heat units such as Joules and calories. It has also been defined as the ability to do work (Brown and McClanahan, 1996).

Emergy: Emergy (spelled with an “m”) stands for Energy Memory. It is a scientifically based measure of wealth and expresses all types of resources on a common basis: the energy it took to generate them. The resources can be as varied as energy, raw material, finished goods and human services (Odum, 1996, Brown and McClanahan, 1996).

Solar emergy: Solar emergy of a resource is the emergy of the resource expressed in equivalent solar emergy that was needed to produce it (Odum, 1996, Brown and McClanahan, 1996).

Solar Emergy Joule – sej: Emergy is measured in solar embodied joules, abbreviated sej. All products and services in Emergy Evaluation are characterized in equivalents of solar energy, i.e. how much energy would be needed if solar energy was the only input (Hau and Bakshi, 2004).

Transformity: Transformity is the ratio obtained when the total emergy used up to make a product is divided by the energy remaining in the product. It has the dimension of emergy/energy and measured in sej/J. Solar transformity is a very important concept in Emergy Evaluation. It is used, as the name implies, to "transform" a given energy into emergy by multiplying the energy by the transformity and hence, provides an energy quality factor (Brown and McClanahan, 1996, Haden, 2003). Transformity of a resource increases with more energy transformations contributing to the production of the resource because at each transformation, available energy is used up to produce a smaller amount of energy of another form. So, the emergy increases but the energy decreases that results in sharp increase in emergy per unit energy, i.e. transformity (Hau and Bakshi, 2004). Goods and services that contain the least energy but required the most work to create have the largest transformity. These include human services and information as the energy of the information is that of the information carrier, i.e. computers, paper or human mind (Odum, 1996).

Transformities are usually calculated by analyzing the production process for a resource or a particular item. The transformity of planetary products like the wind, rain and waves are determined by using global production processes. The transformity of a particular economic or ecological products and services is determined by analyzing the production processes of the economic and environmental subsystems. Then all energy inputs required for the production are documented and converted to solar emergy joule by multiplying by the appropriate transformity. Finally, to get the transformity of the product, all the solar emergy joules for the different steps in the production process are summed up and then divided by the available energy of the product (Brown and McClanahan, 1996).

The baseline for all transformity calculations is the total emergy input to the Earth. This is the sum of the emergy of the solar insolation, deep earth heat and tidal energy. These global emergy inputs are the driving force for all planetary activities. Most of the case studies that use Emergy Evaluation rely on and use transformities previously calculated. Thus, the availability of this data often determines the ease with which energy accounting studies can be performed (Hau and Bakshi, 2004). So far, 3 different baselines have been calculated and the main reason is new knowledge in calculating the planetary solar energy. This results in different transformities for the same flow between references but all the past baselines can be easily related through multiplication by an appropriate factor but the results of an Emergy Evaluation do not change by shifting the baseline (Campbell *et al*, 2005).

Macroeconomic dollar: In Emergy Evaluation, macroeconomic dollar is the money that circulates in the economy as a result of an emergy flow. This value for an emergy flow or storage is obtained by dividing the emergy by the ratio of total emergy to gross national product (GNP) for the national economy (Brown and McClanahan, 1996).

3.3 Overview of Emergy Evaluation methodology

In short, Emergy Evaluation of a given system is a mass and energy flow analysis where flows are transformed to emergy using transformities. The general methodology for Emergy Evaluation is a “top-down” systems approach and includes the following 3 steps that are explained in the following sections (Campbell *et al*., 2005, Brown and McClanahan, 1996).

- Construction of overview system diagrams: This is done to put the system of interest into perspective, organize thinking and relationships between components and pathways of exchange and resource flow.
- Construction of Emergy Evaluation tables: Pathways crossing the system boundaries and relevant pathways inside the boundaries are put into an Emergy Evaluation table and calculations compiled to evaluate the pathways. Raw data and conversion factors are collected to complete the table. Conversion factors, like energy contents and transformities are needed to change the raw data into emergy units.
- Calculations of emergy indices and ratios from subsets of the data: These indices relate emergy flows of the economy with those of the environment and predict economic viability, carrying capacity and can be used in policy making.

3.3.1 System diagrams

The diagrams represent all relevant interactions between human and natural components of the system of interest. Usually a detailed graph is first constructed and later an aggregated one to obtain the simplest possible system that can still answers the original research question (Campbell *et al et al*., 2005). Figure 5 is a summary diagram that illustrates the use of nonrenewable and renewable emergies in a regional economy. The larger rectangle represents the system boundary and surrounds the components of the system, storages, processes and flows. Different flows, both within and crossing the boundaries support the system. R is the renewable energy sources that support the economy; N is the indigenous nonrenewable resources (N_0 from rural sources, N_1 is from urban sources and N_2 is exported without use); F is imported fuels and minerals; G is imported goods; I is the dollars paid for imports; P_2I is imported human services; E is dollars received for exports; P_1E is exported human services; B is exported goods, X is the Gross National Product of the nation, here USD; P_2 is the emergy to dollar ratio of the trading partner and P_1 is the emergy to dollar ratio of the nation (Haden, 2003).

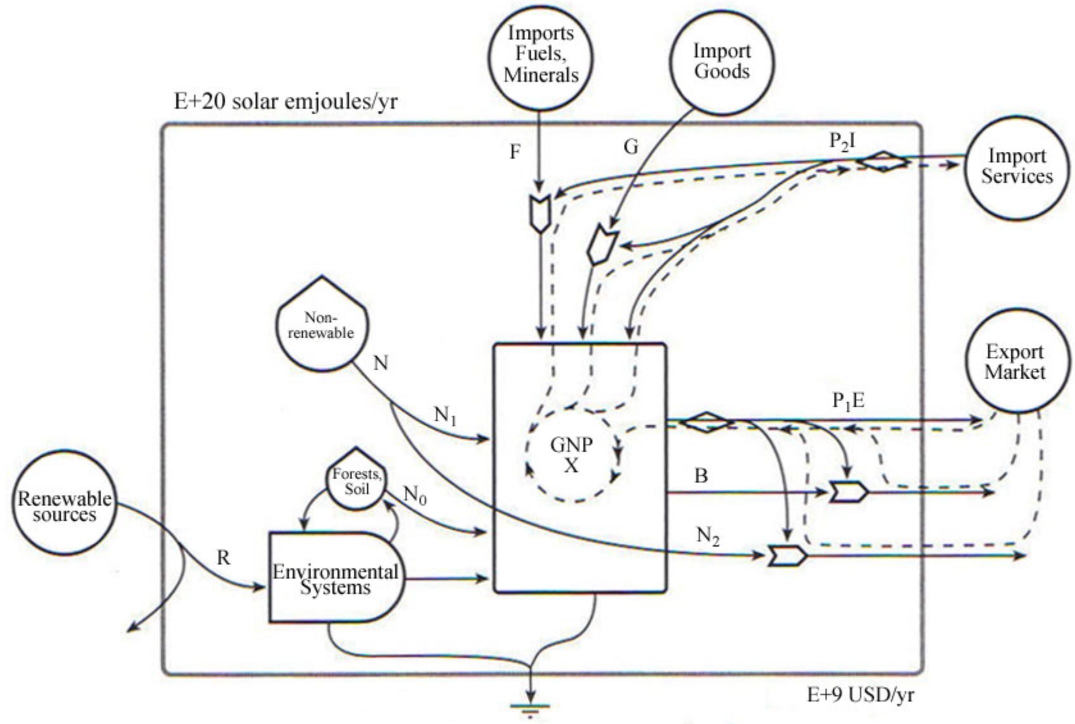


Figure 5. Summary emergy flow diagram for a national economy (Haden, 2003:30). The letters refer to emergy flows and are explained in the text. Symbols are explained in the Appendix.

3.3.2 Emergy Evaluation tables and data sources

Emergy Evaluation tables provide a template for the calculation of the emergy values for energy sources and flows. In these tables, raw data on flows and storage reserves are converted to energy and then to emergy units and emdollars to aid in comparisons. The Emergy Evaluation tables have six columns and various numbers of rows, depending on the system (figure 3). Each row represents an outflow or inflow pathway of the system of interest, evaluated as fluxes in units per year. The original information is usually reported as annual flows of mass and/or dollars and need to be converted into energy and emergy. The energy density of many objects has been tabulated so in many cases mass can be easily converted to energy. When the energy density is not available, the mass it multiplied with a specific emergy, expressed in sej/g. To convert money flows into the average emergy in the human services associated with the good or service purchased, the amount is multiplied by the appropriate emergy to dollar ratio (Campbell *et al*., 2005).

Table 1. Outline of an emergy table

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Note	Item	Raw units J, g, $	Solar emergy/unit sej/J, sej/g, sej/$	Solar emergy sej, sej/yr	EmDollar EmDollar/yr

The columns are defined as follows:

Column 1: Note. The line number is the number of the item evaluated and corresponds also to a footnote where raw data sources are cited and calculations shown.
Column 2: Item. The name of the item/flow is listed.

Column 3: Raw units: The actual units of the flow, usually evaluated as flux per year. Most often the units are joules/years but can be grams or money per year. Source, derivation and characteristics of this data are given in the footnotes.
Column 4: Solar emergy per unit. Here, transformities and specific emergies are listed. These numbers are usually derived from previous studies. Transformities used in this study are listed in the Appendix.
Column 5: Solar emergy is the product of the raw units in column 3 and the transformity/specific emergy in column 4.
Column 6: EmDollars are obtained by dividing the emergy in column 5 by the emergy-to-money ratio (calculated independently) for the economy of the nation in the selected year.

In the case study on Iceland the Emergy Evaluation tables include the following tabular accounts and what follows is the explanation on how each category is evaluated.

a) Renewable resources received/used within the system, and production based on renewable resources
b) Production and consumption of nonrenewable resources within the system,
c) Imports and exports to and from the system,

a) Evaluation of renewable resources
The planetary emergy inflows of solar radiation, deep heat of the earth and gravitational attraction of the moon and the sun are the basis for the regular replenishment of renewable resources. The renewable resources of the earth result from these primary planetary emergy inflows and their co-products that are generated in their interaction to the geobiosphere. These are the emergy from the sun, wind, rain, geological uplift, waves and tides (Campbell *et al*, 2005). When calculating the average energy supplied to a system from renewable resources, long-term averages of environmental variables should be used to prevent variations (Campbell *et al*, 2005).

b) Evaluation of nonrenewable resources
All raw materials that have been generated by environmental processes over a long time but used up by human activities at a rate faster than they are renewed are called nonrenewable resources. In a system, all storages that are used faster than they are replaced are defined as the nonrenewable emergy supporting the system (Campbell *et al*, 2005).

c) Evaluation of imports and exports
According to Campbell *et al* (2005), emergy is imported and exported in three different forms:

- emergy in materials that enter and leave the system
- emergy in the human service that is connected with the materials entering and leaving the system (such as collecting, refining, manufacturing, shipping and handling)
- emergy in services separate from the material flows (for example consulting and financial services).

Both the monetary value and the tonnage shipped of commodities need to be collected because goods have both energy and emergy value associated with their concentration in nature and creation. The contribution of human services in the economic value of good is reflected in the money paid for the good. By multiplying this monetary value by the national emergy to money ratio for the year of analysis gives an estimate of human services associated with the imported/exported material. The flows of energy or mass of material are multiplied by the appropriate transformity/specific emergy for the material and to determine the total emergy in the materials in goods, the emergy of all the different materials are summed (Campbell *et al*, 2005).

It is worth to point out that emergy in tourism is classified as exported emergy. This is because money that enters the system does not bring emergy into it but generates emergy flow instead. According to Campbell *et al* (2005) tourists receive value from their recreational experiences that are virtual emergy flows. These flows require unique emergy storages and flows to exist within the system for their creation. In the case of Iceland, these experiences would not be possible without the emergy in the unique recreational opportunities within the country.

3.3.3 The summary flow table

When the Emergy Evaluation tables are completed, the next step in an Emergy Evaluation is to combine the information from the tables into summary flow variables. The summary variables provide a macroscopic overview of emergy and dollar flows for the system. The information in this table provides the numbers needed for the calculations of emergy indices (Campbell *et al et al*, 2005). Emergy and money flows for the system are categorized with the following letters:

- R: Renewable energy inflow
- N: Nonrenewable energy sources and any renewable resources used faster than they are replaced.
- F: Fuels and minerals imported and/or used within the state.
- G: Imported goods excluding fuels and minerals
- I: Money paid for all imports
- P_2: Trade partner's emergy to dollar ratio
- P_2I: Total emergy of imported services
- B: Exported products
- E: Money received for all exports
- U: Total emergy use: $R+N+F+G+P_2I$
- X: The gross national product, GNP
- P_1: Country Emergy to dollar ratio, U/GNP, used in export
- P_1E: Total emergy of exported services

The calculations of all the summary flows are self explanatory except the renewable energy flow. It is a fundamental variable in the following calculations on indices and therefore the overall results. Even though the emergy in all renewable resources that are thought to be important inputs into the system are evaluated, not all of them can be included in the emergy base for system. That would lead to double counting of co-products of a single interconnected planetary system (Campbell *et al et al*, 2005). A simple way to determine how much solar emergy the basic earth system has contributed to a system and hence, to prevent this double counting, is to use the largest of the each planetary process (sun, earth heat, tide) and ignore the rest. Then it is assumed that the rest is already included in the largest one selected (Odum, 1996).

3.3.4 Calculations of Indices and ratios

The final step in an Emergy Evaluation for a system is to use information given in the summary flow table to calculate emergy indices that can aid in interpreting the results of the evaluation (Campbell *et al*., 2005, Haden, 2003). What follows is an explanation on the emergy indices used in this study.

The emergy/money ratio
This ratio connects economic activity to the emergy flows that support it. It is obtained by dividing the total emergy use of a country or a state by its gross economic product. The outcome is the average amount of emergy or real wealth that is purchased by spending a dollar in a certain place, or the purchasing power of a currency. Areas that have high emergy to dollar ratio are thought attractive to tourists and new businesses (Campbell *et al*, 2005).

The emergy to money ratio has another useful property that is the estimation of human services embedded in a product. Because money is only paid to people for their services this ratio can be used to estimate the average value of human services in a system. Thus, a money value of a product or service is multiplied by the emergy to dollar ratio to have the average emergy of human service embodied in the item. In this sense, country's emergy-to-money ratio is used to calculate the human service embedded in the export from that country and tourism. On the other hand, to obtain the emergy embedded in imported goods, the money value of imported goods should be multiplied with the emergy-to-money ratio of the trading partner (Campbell *et al*, 2005).

Ratio of imports to exports = The Emergy Exchange Ratio (EER)
This is the ratio of emergy received to the energy given in external trade. The trading partner that receives more emergy is receiving more real wealth and hence, greater economic stimulation because of the trade. The ratio of exports to imports reveals how much a system contributes emergy to or receives it from its trading partner (Campbell, 2005).

Ratio of purchased to free = The Investment Ratio
The ratio of solar emergy purchased from outside the system to the solar emergy supplied by the renewable and non-renewable energy sources from within is called The Investment Ratio because it is the ratio of invested emergy to resident. It shows the proportion of economic investment to the indigenous resources of a region and reflects the intensity of development (Campbell, 2005, Brown and McClanahan, 1996). Systems with a low investment ratio get high proportion of its emergy free from the environment and needs therefore to buy less (Odum, 1996).

Solar emergy used per unit area = empower density
This is the amount of emergy flow during specific time. Urban areas with industrial systems, commercial businesses and residential developments of high density have high level of incoming emergy flows and high empower density compared to rural areas (Haden, 2003).

Emergy Yield Ratio
Total emergy used within a system, both from local sources and imported, divided by the total imported emergy (fuel, goods and services) is called Emergy Yield Ratio. It is a measure of empower (emergy per time) contributed to the national economy from domestic sources (Haden, 2003).

Environmental Load Ratio
This is the ratio of the emergy used from non-renewable sources and imported in goods and services to the renewable emergy. What it shows is the quantity of emergy inputs to an economy that are not renewable or available locally and indicates the pressure on the local ecosystems from imported energy and materials. The higher the proportion of renewable emergy used by an economy, the lower the load ratio. On the other hand, economies that are highly dependent on outside emergy

sources have high load ratio. In general it is a measure of ecosystem stress due to economic activity (Haden, 2003).

Sustainability Index
This index is the emergy yield ratio divided by the environmental load ratio. It is assumed that the main goal of sustainability is to have as high yield ratio as possible but at the same time place as little load possible on the environment. If this index figure is high, it indicates that the emergy yielded by an economy is by a high degree from renewable sources and therefore more in harmony with the local environment (Haden, 2003).

Emergy Footprint Ratio
The traditional method of The Ecological Footprint shows the amount of resources consumed by a human population within a given area (Wackernagel, 1996). According to Haden (2003), an emergy based ecological footprint can be calculated by dividing the total emergy used by a system by the total renewable emergy flows supporting the same system. The number that results indicates how many times bigger the support area (receiving renewable emergy) of an economy would have to be to meet its emergy requirements locally.

3.4 Data sources for Iceland

In the following case study, the Emergy Evaluation on the Icelandic economy, data was collected from governmental sources, peer-reviewed articles and reports and specialists in the field of concern when data could not be found. Scientists and specialist at various governmental institutions provided data on renewable energy sources: The National Energy Authority (runoff rate, conduction to surface), Institute for Meteorological Research in Iceland (precipitation), The Icelandic Meteorological Office (wind speed), The National Land Survey of Iceland (average elevation), The Icelandic Maritime Administration (wave height) and The Icelandic Coast Guard, Hydrographic department (tidal range). Data on indigenous renewable production and all imports and exports was retrieved from the website of The National Statistical Institute of Iceland.

Most transformities used are from a recent, peer-reviewed USEPA report: Environmental Accounting of West Virginia, published in March 2005 (Campbell *et al*, 2005). It is of great convenience and accuracy for the outcome to have most of the transformities coming from the same source. All transformities and their sources are listed in the Appendix. The solar emergy baseline used in this report, as well as in this thesis, is 9,26E+24 sej/yr.

4. Results

Iceland's biophysical resource support base was evaluated to obtain the role of renewable energy in the national economy. The primary interest is in the pathways that cross the boundaries, both inputs and outputs, but the main focus is on the external flows that support the environmental system. Within the system, the internal interaction of interest is the extraction of natural resource storages for economic use, for example hydropower. First, the indigenous renewable and nonrenewable environmental sources are presented and then the imported and exported goods, fuels and their associated human services. Then Iceland's solar emergy support base is presented in a summary table and indices calculated that relate solar emergy use to economic activity, self-sufficiency and international exchange. The results are compared with other countries to place Iceland in perspective with the ecological-economic base of other countries and finally, the sustainability ranking of few countries according to Emergy Evaluation and Ecological footprint are compared.

4.1 Indigenous renewable and non-renewable environmental sources

The indigenous resource base of Iceland includes the renewable sources of sunlight, kinetic wind energy, geopotential and chemical energy of rainfall, geopotential and chemical energy of river flow, earth cycle, waves and tides. The only non-renewable emergy source is in the soil, lost in soil erosion. The major indigenous production systems are fisheries, the harnessing of hydro- and geothermal energy and livestock and agricultural production (table 2).

Emergy in precipitation (1,995 m/yr) was estimated to be the major renewable solar emergy source in Iceland. Together, the emergy in evapotranspired rain and the geopotential of runoff, sum up to 424 sej. The emergy absorbed through evapotranspiration is 187 sej compared to 237 sej for the geopotential in rain. The reason for this is the low evapotranspiration rate (20%) in the country due to limited vegetation. Rain is part of the hydrologic cycle that plays a special role in the organization of the geobiosphere. According to Odum (1996), rainwater carries the chemical potential energy of its purity relative to the seawater. It has been distilled from the salty sea by the energy of the sun and wind. The geopotential energy of rain falling on elevated lands carries the emergy of atmosphere, ocean and land. The emergy of these inputs, absorbed by the country, work together to produce vegetation and landforms (Odum, 1996).

The second largest inflow of renewable emergy was the earthcycle, 327E+20 sej that reflects the fact that Iceland is a volcanic active island. The geopotential and chemical potential energy of stream flow, estimated from data provided by The Icelandic Energy Authority was 219 and 401 sej/yr, respectively. If the energy of precipitation and streams are compared the total energy in precipitation is 15,1E+17 J and the total energy in streams is 16,1E+17 J, i.e. around 7% more energy is in streams compared to precipitation. As many of the biggest rivers in Iceland originate in glaciers, one can assume that this difference reflects the contribution from glaciers in river flow.

The indigenous renewable production systems ranged from 1,5E+20 sej (livestock production) to 148E+20 sej (fisheries). Fisheries accounted for almost 5x more than hydroelectricity production (32E+20 sej) that is the second largest in this category. It is interesting to see that when combined, livestock and agricultural production are only ≈ 60% of solar emergy from produced hydroelectricity. Also, a similar amount of emergy is lost in soil erosion as is produced in livestock industry.

Table 2. The solar emergy support for Iceland's indigenous resource base. All flows are based on annual contributions, using data from 2003.

Note	Item	Annual flows raw units/year (J,g)	Solar transformity (sej/unit)	Solar emergy (E+20 sej/year)	Macoeconomic value (E+5 USD, 2003)
RENEWABLE RESOURCES:					
1	Solar insolation	2,73E+20 J	1	2,7	2,8
2	Wind, kinetic energy	1,49E+19 J	1470	219,5	225,4
3	Rain, chemical potential energy	6,65E+17 J	28100	186,8	191,8
4	Rain, geopot energy of runoff	8,44E+17 J	28100	237,1	243,5
5	River, chemical pot.	8,01E+17 J	50100	401,5	412,2
6	River, geopotential	8,12E+17 J	27000	219,3	225,2
7	Waves energy	9,01E+17 J	30000	270,3	277,5
8	Tidal energy	6,53E+17 J	24300	158,6	162,8
9	Earth cycle	9,69E+17 J	33700	326,6	335,3
INDIGENOUS RENEWABLE PRODUCTION:					
10	Fisheries	7,53E+15 J	1,96E+6	147,7	151,6
11	Agricultural production	3,00E+16 J	6,30E+4	18,9	19,4
12	Livestock production	2,00E+14 J	7,36E+5	1,5	1,5
13	Hydroelectricity prod.	2,55E+16 J	1,25E+5	31,9	32,7
14	Geothermal energy	7,73E+16 J	3,10E+4	24,0	24,6
NONREWABLE SOURCES FROM WITHIN:					
15	Soil lost in soil erosion	1,70E+15 J	7,26E+4	1,2	1,3

Footnotes to table 2:

NB: Iceland's area = 103.000 km^2 (The Ministry of Foreign Affairs, 2005)
Continental shelf area = 109.000 km^2 at 200 m depth (World Resource Institute, 2005)

RENEWABLE ENERGY

1. **Solar insolation**: Insolation = 3,0E+9 J/m^2 (Einarsson, M.A., 1984), Albedo (reflectivity) = 0,43 (Einarsson, M.A., 1984).
   Solar energy absorbed = (area including shelf)(average insolation)(1-Albedo)
   = (1,03E11m^2+1,09E11m^2)(3E+9 J/m^2)(1-0,43) = 2,73E+20 J.
2. **Wind, kinetic energy**: Gudrun Gisladottir at The Icelandic Meteorological Office provided data for wind speed at several locations. The average annual wind velocity used was calculated from data from 14 stations, 7 from lowland areas around the coastline (Reykjavík, Stykkishólmur, Akureyri, Teigarhorn, Stórhöfdi, Raufarhöfn and Ædey) and 7 from in the central highlands (Hveravellir, Grímsstadir á Fjöllum, Brú á Jökuldal, Sandbúdir, Eyjabakkar, Lónakvísl og Veidivatnahraun). All the numbers from the lowland stations are an average of 45 years but the highland numbers originate in an average of different number of years. Calculated average annual wind velocity over land = 6,3 m/s. (Gísladóttir, G., 2005). Geostrophic wind = 10,5 m/s, according to Campbell *et al* (2005) winds over land is about 0,6 of the geostrophic winds. Density of air = 1,3 kg/m^3 (The physics factbook, 2005). Drag coefficient for land = 0,002, Drag coefficient for water = 0,001 (Garratt, 1977).
   Wind energy (land) = (area)(air density)(drag coefficient)(geostrophic wind velocity)^3(sec/yr)
   = (1,03E11m^2)(1,3 kg/m^3)(0,002)(10,5m/s)^3(3,15E+7sec/yr) = 9,76E+18 J/yr
   Wind energy (shelf) = (area)(air density)(drag coefficient)(geostrophic wind velocity)^3(sec/yr)
   = (1,09E11m^2)(1,3 kg/m^3)(0,001)(10,5m/s)^3(3,15E+7sec/yr) = 5,16E+18 J/yr
   Wind, kinetic energy, total = 1,49E+19 J/yr
3. **Rain, chemical potential energy = evapotranspired rain on land + chemical potential of rain in shelf**. Ólafur Rögnvaldsson at Institute for Meteorological Research in Iceland provided data on annual preciptiation, data from 1990-2003. Average rainfall = 1,995m (Rögnvaldsson, O., 2005). Evapotranspiration = 20 % (Tómasson, H., 1982). The average rainfall on the continental shelf was estimated as 45% of average or 0,898 m/y (Brown and McClanahan, 1996). Gibbs free energy is the free energy of water relative to seawater (Odum, H.T., 1996). The chemical potential energy is the sum of the chemical potential energy in rain absorbed on land and on the continental shelf.
   Evapotranspired chemical potential energy in rain on land
   = (area of land)(rainfall on land)(% evapotranspiration)(density of water)(Gibbs no.)
   = (1,03E11m^2)(0,812m/y)(0,20)(1000kg/m3)(4970J/kg) = 8,31+16 J/y.

Chemical potential energy in rain on shelf = (area of shelf)(rainfall on shelf)(density of water)(Gibbs no.)
= (1,09E11m^2)(0,336m/y)(1000kg/m^3)(4970J/kg) = 1,82E+17 J/y.
Total energy = 2,79E+17 J/y.

4. **Rain, geopotential energy = Geopotential energy of rain on land elevated above sea level (physical energy of streams)**: Average rainfall (land) = 1,995 m/y (Rögnvaldsson, O., 2005). Average elevation = 510m, provided by Gudmundur Valsson at The National Land Survey of Iceland. The error in this number is estimated +/- 10 m. (Valsson, G., 2005). Average % runoff = 80% (Tómasson, H., 1982).
   Geopotential energy = (land area)(rainfall)(average elevation)(gravity)(density of water)(runoff)
   = (1,03E11m^2)(0,812m/y)(510m)(9,82m/s^2)(1000kg/m^3)(0,80) = 8,44+17 J/yr.
5. **Rivers, chemical potential energy**: average discharge of all rivers = 5150 m^3/s (Tómasson, H., 1982). Chemical potential energy in rivers = (discharge)(sec/yr)(density of water)(Gibbs no.)
   = (5150 m^3/s)(3,15E+7sec/yr)(1000kg/m^3)(4970J/kg) = 8,01E+17 J/yr.
6. **River, geopotential energy:** average discharge of all rivers = 5150 m^3/s (Tómasson, H., 1982), Average elevation = 510 m, provided by Gudmundur Valsson at The National Land Survey of Iceland. The error in this number is estimated +/- 10 m. (Valsson, G., 2005).
   Geopotential energy in rivers = (discharge)(sec/yr)(density of water)(average elevation)(gravity)
   = (5150 m^3/s)(3,15E+7sec/yr)(1000kg/m^3)(510m)(9,82m/s^2) = 8,12E+17 J/yr.
7. **Wave energy:** Shore length = 4970 km (The Ministry of Foreign Affairs, 2005). As the Icelandic shore is very indended (sculpted) it was decided to use shore length that is an estimate based on circumference of a circle using Iceland's land area. That gives 1138 km and it is the most reasonable estimate for the wave energy from the sea impinging on the Icelandic shore. Average wave height = 2,1m, data provided by Ingunn Jónsdóttir at The Icelandic Maritime Administration. Data from 10 wave measurement buoys around Iceland were used. (Jónsdóttir, I., 2005). Wave celerity = square root of gravity times the wave height for shallow water waves = 4,53 m/s. Density of sea water = 1025 kg/m3 (The physics factbook, 2005).
   Wave energy = (shore length)(1/8)(density)(gravity)(wave height)^2(celerity)(sec/yr)
   = (1138km)(1000m/km)(1/8)(1025kg/m3)(9,8m/s2)(2,1m)2(4,53m/s)(3,15E+7sec/yr) = 9,01E+17 J/yr.
8. **Tidal energy:** Average tidal range = 1,3m, data provided by Hilmar Helgason at the Icelandic Coast Guard, Hydrographic Department. The number used is the average in the year 2004 from 4 different places around the country: Reykjavík (2,1m), Ísafjördur (1,15m), Siglufjördur (0,7m) and Djúpivogur (1,2m). Tides per year = 706.
   Tidal energy = (shelf area)(0,5)(tides/yr)(average tidal range)^2(density of seawater)(gravity)
   = (1,09E11m^2)(0,5)(706)(1,3m)^2(1025kg/m^3)(9,8m/s^2) = 6,53E+17 J/yr
9. **Earth cycle**: Conduction to surface in Iceland = 131 Twh/yr (National Energy Authority, 2005). Annual conduction per km^2 = (131Twh*3,6E+15J/Twh)/1,03E+11m^2 = 4,58E+6 J/m^2*yr.
   Earth cycle, land = (Annual conduction per km^2)(area) = (4,58E+6 J/m^2*yr)(1,03E+11m^2) = 4,72E+17 J/yr
   Earth cycle, shelf = (Annual conduction per km^2)(area) = (4,58E+6 J/m^2*yr)(1,09E+11m^2) = 4,99E+17 J/yr
   Total = 9,69E+17 J

INDIGENOUS RENWABLE PRODUCTION

10. **Fisheries**: Average energy content = 4311 J/g (Energy/mass is taken from Campbell *et al*., 2003 and it correlates well with values from the website of The Public Health Institiute of Iceland. But as the number of fish species exported are many and the energy content lot listed on the website, it was decided to use the value from Campbell *et al*.). Total catch =1,75E+12 g (2003, data from the website of The National Statistical Institute of Iceland)
    Fisheries = (1,75E+12 g)(4311J/g) = 7,53E+15 J
11. **Agricultural production**: Production data for 2003 was taken from the website of The National Statistical Institute of Iceland. 2003 crop production = 1,62E+12 g (including 1,60E+12 g hay). Other main products are potatoes, corn and tomatoes. As hay is the dominant product the energy content of it was used for the whole production = 18901 J/g (Campbell *et al*, 2005).
    Agricultural production = (amount produced, mass)(energy/mass) = (1,62E+12g)(18901J/g) = 3,00E+16 J
12. **Livestock production**: Production data for 2003 was taken from the website of The National Statistical Institute of Iceland. Most energy per unit values used are from the website of The Public Health Institiute of Iceland. All calculations are: (annual production mass)(energy/mass). Sheep/lamb = (8,8E+9g)(9224J/g) = 8,1E+13 J, horses = (9,1E+8)(7180J/g) = 6,5E+12 J, cows = (83,6E+9g)(6490J/g) = 2,3E+13 J, pigs = (6,2E+9g)(7920J/g) = 4,9E+13 J, chicken = (5,7E+9g)(6630J/g) = 3,8E+13 J.
    Total livestock production = 2,00E+14 J
13. **Hydroelectricity**: Data from The National Energy Authority in Iceland.
    Hydroelectricity = (7084 Gwh)(1E+6 kWh/Gwh)(3,6E+6 J/kWh) = 2,55E+16 J
14. **Geothermal energy use**: Gross consumption 2003 = 7,73E+16 J (The National Energy Authority, 2005)

NONRENEWABLE SOURCES FROM WITHIN

15. **Top soil**: Total national stock of soil organic carbon in Iceland = 2,1E+9 t and annual current erosion 75E+3 t/y (Óskarsson *et al*, 2004). Energy density in pastureland = 22604 J/g (Campbell *et al*, 2005).
    Top soil: (75E+3 t)(22604 J/g)(1E+6g/t) = 1,70E+15 J

4.2 Imported and exported goods, fuels and human services

Human services associated with the production, refinement and delivery of imports accounted for about 28E+20 sej, which makes it the largest factor in imports. Fuels contributed 24E+20 sej; hence, human services and fuels contributed about half of the imports in 2003 (table 3).

There are four main categories of exported emergy in Iceland in 2003; marine products (114E+20 sej), human services associated with the production, refinement and delivery of exports (89E+20 sej/year), metals (66E+20 sej) and tourism (49E+20 sej). Of all metals exported, 57% was Aluminium and 26% Ferrosilica (FeSi). The high proportion of marine products reveal the high dependency of Iceland's economy on the renewable resource of the fish in the sea around the island. According to Doherty *et al* (2002), a high figure for exported human service is in part a result of taxes and high wages paid for labor, but also an indicative of high quality products made in the country.

Table 3. Iceland's foreign trade of emergy. All flows are based on annual contributions, using data from 2003.

Note	Item	Annual flows raw units/year (J,g)	Solar transformity (sej/unit)	Solar emergy (10^{20} sej/year)	Macoeconomic value (E+5 USD, 2003)
IMPORTS:					
16	Marine products	1,75E+14 J	3,27E+6	5,7	5,9
17	Other agricultural prod.	2,09E+15 J	2,33E+5	4,9	5,0
18	Alcoholic beverages	6,00E+13 J	5,89E+4	0,04	0,04
19	Fuels	3,74E+16 J	6,47E+4	24,2	24,9
20	Metals (80% Bauxite)	6,20E+11 g	1,47E+7	0,09	0,09
21	Textiles	9.70E+09 g	7.18E+6	0,001	0,001
22	Transport equipments	3.50E+10 g	7.76E+9	2,7	2,8
23	Machinery	1.80E+11 g	7.76E+9	14,0	14,3
24	Fertilizers	3.80E+11 g	2.99E+9	11,4	11,7
25	Plastic and rubber	2.90E+10 g	2.71E+9	0,8	0,8
26	Wood products	1.30E+11 g	1.49E+9	1,9	2,0
27	Animal feed and products of animal origin	2.05E+11 g	1.22E+6	0,003	0,003
28	Non metallic mineral prod.	9.30E+10 g	3.09E+9	2,9	3,0
29	Misc. manufact prod	4.50E+10 g	1.61E+9	0,7	0,7
30	Chemicals	5.29E+10 g	9.90E+9	5,2	5,4
31	Imported service	1.41E+09 g	2.00E+12	28,3	29,0

EXPORTS:

32	Marine products	3.49E+15 J	3.27E+6	114,2	117,2
33	Livestock (lambmeat)	4.80E+13 J	3.27E+6	1,6	1,6
34	Other agricultural prod.	1.73E+14 J	2.33E+5	0,4	0,4
35	Alcoholic beverages	1.74E+12 J	5.89E+4	0,001	0,001
36	Metals (57% Al, 26% FeSi)	5.40E+11 g	1.23E+10	66,4	68,2
37	Textiles	7.10E+08 g	7.18E+6	0,0001	0,0001
38	Minerals (97% pumice)	4.20E+10 g	5.50E+6	0,002	0,002
39	Transport equipments	9.60E+09 g	7.76E+9	0,7	0,8
40	Machinery	6.80E+09 g	7.76E+9	0,5	0,5
41	Plastic and rubber	1.50E+10 g	2.71E+9	0,4	0,4
42	Wood products	1.10E+11 g	1.49E+9	1,6	1,7
43	Tourism	4.66E+08 g	1,03E+13	48,5	49,8
44	Exported services	8.53E+08 g	1,03E+13	88,8	91,1

Footnotes to table 3:
IMPORTED FUELS, GOODS AND SERVICES
All data was retrieved from the homepage of The National Statistical Institute of Iceland in September 2005 (see table in Appendix). Goods are classified by SITC (Standard International Trade Classification). The units are tons that were converted into joules when possible. Most energy per unit values used are from the website of The Public Health Institute of Iceland.

16. **Marine products**: Amount imported (84% crustaceans and mollusks) = 5,32E+10 g/y. Energy per mass (an average for crustaceans) = 3300J/g. Marine products = (5,32E+10 g/y)(3300J/g) = 1,8E+14 J
17. **Other agricultural products** (milk and dairy products included): (1,7E+11 g/y)(13544 J/g) = 2,3E+15 J/y
18. **Alcoholic beverages**: (1,0E+10 g/y)(6000 J/g) = 6E+13 J
19. **Fuels (84% petroleum)**: Energy density of petroleum = 4,3E+7 J/kg (The physics factbook, 2005) Fuels = (8,7E+8 kg/y)(4,3E+7 J/kg) = 3,74E+16 J
31. **Imported Human Services**: Costs of imported human service embedded in goods = 113.039 million ISK (Statistical Series, 2004) or 1,13E+11ISK/(80 ISK/USD, 2003) = 1,47E+9 USD.

EXPORTED FUELS, GOODS AND SERVICES
All data was retrieved from the homepage of The National Statistical Institute of Iceland in September 2005 (see table in Appendix). Goods are classified by SI classification, which is an Icelandic classification only used for exports. This methods shows the weight of marine products. The units are tons that were converted into joules when possible. Most energy per unit values used are from the website of The Public Health Instituite of Iceland.

32. **Marine products**: Average energy content = 4311 J/g (Energy/mass is taken from Campbell *et al*., (2003) and it correlates well with values from the website of The Public Health Instituite of Iceland. But as the number of fish species exported are many and the energy content not listed on the website, it was decided to use the value from Campbell *et al*.). Total exported = 8,1E+11 g/y (2003, data from the website of The National Statistical Institute of Iceland). Marine products = (8,1E+11 g/y)(4311 J/g) = 3,5E+15 J/y
33. **Livestock**: Amount exported (72% from sheep) = 5,2E+9 g/y. Energy/mass = 9224 J/g (for lambmeat) Livestock = (5,2E+9 g/y)(9224 J/g) = 4,8E+13 J/y
34. **Other agricultural products**: (1,3E+10 g/y)(13544 J/g) = 1,7E+14 J/y
35. **Alcoholic beverages**: (2,9E+8 J/y)(6000 J/g) = 1,7E+12 J/y
36. **Tourism**: Money received for tourism was 37285 million ISK or 3,73E+10 IDK/(80 ISK/USD, 2003) = 4,66E+8 USD.
37. **Exported human services**: Money received for exported human service embedded in goods = 105.231 million ISK (Statistical Series, 2004) or 1,05E+11 ISK/(80 ISK/USD, 2003) = 1,31E+9 USD.

4.3 Summary flow and overview indices of Iceland's solar emergy and economic base

A summary of annual flows for Iceland is given in table 3. It provides an overview of the emergy and dollar flows across the system's boundaries and highlights the natural and economic sources of the flows. The incoming solar emergy to Iceland from external, independent sources, called the renewable emergy base, R, is the sum of inputs of free, renewable sources. According to Odum (1996), only the highest of all the planetary processes (sun, earth heat and tide) should be included in this renewable emergy base. Earth heat and tide contain only one item each but various items originate from the sun (sun, wind, wave and rain). Here, the estimated emergy in geopotential and chemical rain was the highest and therefore used in the base. Hence, the renewable emergy base for 2003, containing earthcycle, tidal emergy and chemical and geopotential emergy from rain is 9,09E+22 sej.

The total emergy used within the system was estimated to be the sum of renewable and non-renewable environmental sources and the solar emergy contribution from imports. This number, U (total emergy used), for the combined ecological-economic system in Iceland in 2003 was 1060E+20 sej. The gross national product (GNP) in 2003 was 810.844 million ISK (10,5 billion USD; 80 ISK/USD 2003 exchange rate). By dividing the solar emergy used (U) with the national economic product (X), the average amount of resources supporting the circulating currency was calculated as 1,04E+13 sej/USD. According to Doherty *et al*, (2002) this ratio is considered an estimate of the buying power a country´s currency using solar emergy as the measure of resources supporting the currency.

To be able to calculate the human services embedded in all imports, not only human service embedded in goods (table 2) a specific emergy is needed to multiply with the value of imports. This specific emergy is the emergy-to-money ratio of the trading partners. According to The Statistical Institute of Iceland, 87% of all imports to Iceland comes from Europe, USA and Japan. According to Doherty *et al*, (2002), average solar emergy per international dollar of 2E+12 sej/USD has been calculated for these countries and was used to calculate the solar emergy in imported human service.

As was pointed out in the methods chapter, emergy in imports and exports are measured in the mass or energy flow of goods, human services embedded in the goods and human services separate from material flow. In the case of Iceland, the money value of human services embedded in goods in import and export are given in data from The Statistical Institute of Iceland. As seen in table 3 the solar emergy for imported services embedded in goods was 28E+20 sej. On the other hand, the total human services imported, P_2I, found by multiplying the total money value of imports with the emergy to money ratio of the trading partners (2E+12 sej/year) is 77,9E+20 sej. This reveals the fact that 50E+20 sej of human services are imported separate from the material flows (for example consulting and financial services). Exported human services are calculated in a similar way, but instead of using the emergy-to-money ratio for the trading partners, the same ratio for Iceland is used to calculate the solar emergy value of human services in exports. The total exported human service, P_1E, was 374E+20 sej but services embedded in goods was 89E+20 sej. The exported human services separate from the material flows was therefore 285E+20 sej. Figure 6 is an overview diagram of the Icelandic economy in 2003, showing all major resource flows.

Table 4. Summary of major solar emergy flows and market economic monetary flows for Iceland, 2003.

Variable	Item	Solar emergy (10^{20} sej/year)	Market value (10^{9} USD, 2003)	sej/USD
R	Renewable sources	909		
	Rain, evapotranspired chemical potential	186,8		
	Rain, geopotential of runoff	237,1		
	Earthcycle	326,6		
	Tides	158,6		
N	Nonrenewable sources within Iceland	1,2		
F	Imported fuels (fossil fuels)	24,2		
G	Imported goods, minerals, fertilizers	50,3		
I	Dollars paid for all imports		3,9	
P_2	Trade partner´s solar emergy/USD index			2.0E+12
P_2I	Solar emergy value of service in imports	77,9		
B	Emergy of exported goods (without services)	235		
E	Dollars received for exports		3,6	
U	Total emergy use: R+N+F+G+P_2I	1060		
X	Gross National Product, USD		10,1	
P_1	Iceland´s emergy to dollar ratio, U/X			1.0E+13
P_1E	Solar emergy value of service in exports	377		

Footnotes to table 4: Calculation of Summary flows
R: According to Odum, the way to avoid double counting when determining how much solar emergy the basic earth systems (planetary processes) have contributed, the largest of each is used and the rest ignored. Here, emergy in incoming rain (from the sun; hydrologic cycle), earth cycle (from earth heat) and tidal energy (tides) are selected.
N: The only nonrenewable resource used from within the country is topsoil.
F: As there are no minerals or metals found in Iceland in sufficient quantities to make mining feasible with existing technology, the only item in this category is the emergy of imported fuels.
G: Total imported emergy minus imported fuels and service.
I: According to National Accounts, all imports in 2003 amounted to 311.520 millions ISK. An average currency in 2003 of 80 ISK/USD is used that gives 3,89E+9 USD.
P_2: Trading partner’s emergy/dollar ratio = 2E+12 sej/$ (Doherty, 2002). This ratio is the specific emergy used for calculating the emergy in the human service in tourism and imported service.
P_2I: The total emergy in imported services is calculated by multiplying the world’s emergy to money ratio (P2) and dollars paid for import (I). This is the total emergy, i.e. both the emergy connected with and separate from material flow.
B: Total exported emergy of goods (without services)
E: According to National Accounts exported goods and services amounted to 287.811 millions ISK. An average currency in 2003 of 80 ISK/USD is used that gives 3,6E+9 USD.
U: The total emergy used is found by adding together 1) the incoming renewable emergy, R, 2) the nonrenewable emergy used from within the country, N, 3) the emergy in imported fuels 4) and goods, 5) and the total emergy of imported services, P_2I.
X: According to National Accounts the gross national product in the Icelandic economy in 2003 was 810.844 million ISK. An average currency in 2003 of 80 ISK/USD is used that gives 10,1E+9 USD.
P_1: This is Iceland’s emergy to money ratio, U/X (total emergy used)/(gross national product). It is used as the specific emergy in calculating the emergy of exported service.
P_1E: The total emergy in exported services is calculated by multiplying Iceland’s emergy to money ratio (P1) and dollars received for export (E). This is the total emergy, i.e. both the emergy connected with and separate from material flow.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Figure 6. Overview diagram of the Icelandic economy in 2003, showing all major resource flows.

Several emergy indices that compare distribution and utilization of the emergy in resources available to Iceland are presented in table 5. They show renewable and purchased solar emergy use, imports and exports and give insight to the solar emergy support basis of Iceland. Most of these indices are self explanatory or have been explained in the methods chapter.

Renewable solar emergy flows account for about 85,4 % of Iceland's solar emergy base (item 7). If nonrenewable sources are added the number is 84,6% that reveals the low input from this source (only soil loss). The proportion of purchased solar emergy (goods, services and human services) was 14,4% (item 8). The ratio of purchased to free solar emergy (Investment ratio) was 0,17.

The emergy exhange ratio (imports/exports) is 0,25, i.e. four times more solar emergy is exported than imported. When compared to the monetary external trade, the Icelandic economy has a deficit of 23709 million ISK or 2,9% of GNP because it received 287811 million ISK for all its exports and paid 311520 million ISK for all its imports.

The imported human services accounted for 7,4% of the total solar emergy use and for the exported human services this number is 35%. The empower density, or the solar emergy use per unit area was 1E+12 sej/m^2 and per capita use was 3,6E+17 sej/person. According to Brown and McClanahan (1996), the renewable emergy carrying capacity at present living standard (item 17) measures the long term, sustainable carrying capacity of Iceland's landscape when it comes to humans. This index is calculated by multiplying the population (290570 people) with the percentage of renewable emergy (R/U) and gives an estimate of how many people the renewable emergy base could sustain at present living standard. According to the method of calculating emergy carrying capacity (Brown and McClanahan, 1996) this renewable emergy carrying capacity for Iceland was 247660 people or about 85% of the populatin in 2003.

For evaluating the sustainability of the Icelandic economy, Environmental load ratio, Emergy yield ratio and a sustainability index was calcuated. The environmental load ratio (the economic/environment ratio) was 0,17 and the emergy yield ratio was 6,9. This results in a sustainability index of 41.

Table 5. Overview indices of annual solar emergy use, origin and economic relation for Iceland in 2003

	Name of Index	Derivation	Quantity
1	Renewable solar emergy flow	R	909E+20 sej/yr
2	Solar emergy flow from indigenous nonrenewable reserves	N	1,23E+20 sej/yr
3	Flow of imported solar emergy	$F+G+P_2I$	152E+20 sej/yr
4	Total solar emergy, U	$U = N+R+F+G+P_2I$	1060E+20 sej/yr
5	Economic component	U-R	154E+20 sej/yr
6	% solar emergy used from home sources	(R+N)/U	85,6 %
7	% solar emergy used locally, renewable (free)	R/U	85,4 %
8	% solar emergy used, purchased	$(F+G+P_2I)/U$	14,4 %
9	Total exported solar emergy	$B+P_1E$	612E+20 sej/yr
10	Trade contribution (imports-exports)	$(F+G+P_2I)-(B+P_1E)$	-456E+20 sej/yr
11	Emergy exchange ratio, EER (imports/exports)	$B+P_1E)/(F+G+P_2I)$	0,25
12	Investment ratio, IR (purchased/free)	$(F+G+P_2I)/(R+N)$	0,17
13	% imported human services	P_2I/U	7,4
14	% exported human services	P_1E/U	35,5
15	Solar emergy used per unit area (empower density)	U/area (103000 km^2)	1,0E+12 sej/m^2
16	Solar emergy used per person	U/ pop (290570)	3,6E+17 sej/person
17	Renewable carrying capacity at present living standard	(R/U)(population)	248263
18	Fuel use per person	Fuel/pop (290570)	0,0004
19	Economic/environment ratio, ELR	$(F+N+G+P_2I)/R$	0,17
20	Emergy yield ratio, EYR	$U/(F+G+P_2I)$	7
21	Sustainability Index, SI	EYR/ELR	41
22	Emergy footprint ratio	U/R	1,17

4.4 Iceland's emergy indices compared to other nations

To increase the relevance of the results, presented above, they were compared with Emergy Evaluation of other countries. What is compared in the following tables is

1) the proportion solar emergy from within country and foreign exchange,
2) solar emergy use per capita,
3) solar emergy per unit area (empower density),
4) solar emergy to money ratio,
5) the economic/environment ratio and
6) sustainability indexes.

Data for comparison was retrieved from 3 sources, giving the following countries/states evaluated in a given year: Campbell *et al*, 2005 (Alaska (1985)), Doherty *et al*, 2002 (Switzerland (1983), USA (1987), Sweden (1988), New Zealand (1983), Australia (1983), Papua New Guinea (1991)) and Haden, 2003 (Denmark (1999)).

Unlike other more developed countries that are only moderately self-sufficient, Iceland is very self sufficient when it comes to emergy, with 85% of solar emergy coming from within the country (table 6). Of the countries/states compared, only Australia, Alaska and Papua New Guinea had a higher degree of self-sufficiency. When it comes to the trade balance, Iceland ranks between Australia and Papua New Guinea, exporting four times more emergy than it imports.

Table 6. Iceland's solar emergy self-sufficiency and trade balance compared to other countries

Nation	% solar emergy from within [1)]	solar emergy imported [2)] / solar emergy exported
Switzerland	19	3,2
USA	77	2,2
Sweden	28	1,2
Denmark	36	1,1
New Zealand	60	0,8
Australia	92	0,4
Iceland	**85**	**0,25**
Papua New Guinea	96	0,13
Alaska	92	0,08

[1)] (N+R)/U
[2)] $(F+G+P_2I)/(B+P_1E)$

Solar emergy use in Iceland per capita is very high compared to the other countries (table 7). Only Alaska has a higher use per capita. As the total solar emergy used is not particularly high in Iceland, this high per capita use reflects the small population (290570 people) in Iceland compared to the other countries, i.e. a large resource base supporting a sparse population. According to Campbell *et al* (2005), a high ratio of emergy used per capita indicates a high standard of living and overall high quality of life.

Table 7. Iceland's solar emergy use, population and per capita use compared to other countries.

Nation	Solar emergy used [1] E+20	Population E+6	solar emergy use per person [2], E+15
Alaska	4440	0,50	910
Iceland	**1060**	**0,29**	**358**
Australia	8850	15	59
Denmark	3020	5,3	57
Papua New Guinea	1216	3,5	35
Sweden	2580	8,5	30
USA	66400	227	29
New Zealand	791	3,1	26
Switzerland	733	6,4	12

[1] $U = N+R+F+G+P_2I$
[2] Iceland's population (2003) = 290570.

If the total solar emergy used per unit area is shown (empower density), Iceland ranks similar to USA (table 8). Denmark ranks highest, reflecting a dense population and a relatively high solar emergy use. When considering that around 80% of Iceland is not inhabited, its high ranking may seem surprising. Empower density usually reflects the magnitude of economic development within a country/state. Iceland has experienced a period of economic growth that may explain this high ranking (The Statistical Institute of Iceland, 2005).

Table 8. Iceland's population density and empower density compared with other countries

Nation	Area ($E+10m^2$)	Population density[1] (people/km^2)	Solar empower density[2] ($E+11$ sej/m^2*yr)
Denmark	4,3	123	70
Switzerland	4,1	154	18
Iceland	**10,3**	**3**	**10**
USA	940	24,2	7
Sweden	41	21	6
Alaska	149	0,3	3,0
New Zealand	27	11	2,9
Papua New Guinea	46,2	8	2,6
Australia	768	2	1,4

[1] Population (290570 people) divided by national area
[2] Solar emergy used (U) divided by the national area

Previous studies on various countries have shown that rural countries have a higher emergy to money ratio than more urban and industrialized countries. According to Doherty *et al* (2002), this can be explained with both a small GNP and a large environmental base, supporting a large part of the economy without monetary evaluation. Therefore the currency in those countries represents more total resources. Iceland ranks third in this comparison even though it is highly developed (table 9). The former explanation fits well to the Icelandic case, having rather low GNP and 80% of the country inhabited. As explained in chapter 3, countries with a high emergy to money ratio can attract tourists and new businesses.

Table 9. Iceland's solar emergy use, gross national products and solar emergy to dollar ratio compared with other countries

Nation	Solar emergy used[1)] (E+20 sej/yr)	GNP[2)] (E+9 USD/yr)	Solar emergy use/dollar[3)] (E+12 sej/USD)
Papua New Guinea	1216	2,6	48
Alaska	4440	19,3	23
Iceland	**1060**	**10,1**	**10**
Australia	8850	139	6,4
New Zealand	791	26	3,0
USA	66400	2600	2,0
Denmark	3020	17,6	1,7
Sweden	2580	178	1,5
Switzerland	733	102	0,7

[1)] $U=N+R+F+G+P_2I$
[2)] Gross national product
[3)] Solar emergy supporting a unit of currency, here USD.

According to Doherty *et al* (2002) the economic to environment ratio gives an indication of how dependent an economy is on its economic activities. This ratio tends to be high for the more developed countries because they have an extensive part of their total resource base tied to economic activities and import more solar emergy than they export. Therefore, they are often less self-sufficient than the more rural, developing countries (Doherty, 2002). When the ratio of economic to environmental resources for Iceland is compared to other countries Iceland ranks low that indicates a low dependency of the Icelandic economy on external purchases (table 10). Due to a low contribution from non-renewable resources, the economic/environment ratio is the same as the Investment ratio (ratio of purchased to free, item 12 in table 5). According to Campbell *et al* (2005), low investment ratios are thought to attract investments and future development.

Table 10. Iceland's environmental and economic components of annual solar emergy use compared to other countries

Nation	Environmental component, R[1] (E+20 sej/yr)	Economic component, U-R[2] (E+20 sej/yr)	Economic/environment ratio
Denmark	257	2763	10,8
Switzerland	87	646	7,4
USA	8240	58160	7,1
Sweden	456	2124	4,7
Australia	4590	3960	1,1
New Zealand	438	353	0,8
Iceland	**909**	**154**	**0,17**
Papua New Guinea	1050	166	0,14
Alaska	4040	40	0,01

[1] R = input from renewable solar emergy sources.
[2] U-R = total solar emergy used minus the contribution from renewable sources

In table 11, sustainability indices for Iceland and other countries are compared. This table contains fewer countries than the ones above because the data on all the countries could not be found. As was explained in chapter 3 the emergy footprint ratio indicates how many times bigger the support area of an economy would have to be to meet its emergy requirements locally. As can be seen, Iceland needs to be 20% larger to meet its own emergy need. When compared to the neighboring countries, Sweden and Denmark, there is a big difference; those countries need to be six and twelve times bigger, respectively. The emergy yield ratio shows that almost seven times more emergy is used within the Icelandic economy than is imported to it. The load ratio, the ratio of imported plus nonrenewable emergy to the renewable emergy base, is low (0,17) that results in a sustainability index of 41. This high number reflects the fact that Iceland is a sparsely populated country, with a relatively small economy but abundant in renewable energy resources. This index is around 100x times bigger than for USA and Sweden. Alaska sticks out here, as in many of the other comparisons, with a sustainability index of 340. This can be explained on a similar note as for Iceland because Alaska has ten times smaller population density than Iceland but its renewable emergy base, R, is almost 5 times bigger.

Table 11. Iceland's sustainability indices compared to other countries

Nation	EFR[1]	EYR[2]	ELR[3]	SI[4]
Alaska	1,1	34	0,1	340
Iceland	**1,2**	**7**	**0,17**	**41**
New Zealand	1,8	----	0,8	----
USA	10,2	4,1	9,2	0,4
Sweden	5,7	1,4	4,7	0,3
Denmark	11,8	1,6	10,8	0,14
West Virginia	33,5	1,4	32	0,04

[1] EFR = U/R = emergy footprint ratio
[2] EYR = $U/(F+G+P_2I)$ = emergy yield ratio
[3] ELR = $(F+N+G+P_2I)/R$ = environmental load ratio
[4] SI = EYR/ELR = sustainability index

4.5 Emergy Evaluation compared to Ecological Footprint

In the Introduction other tools for measuring sustainability were mentioned. According to Mayer *et al*, using tools from different disciplines in combination is thought more likely to give and an accurate assessment of sustainability. Therefore, it was decided to compare the results presented above with results previously published on the Ecological Footprint of nations. For years, countries have been ranked according to their impacts on the environment (ecological footprint) and the list published. On these lists are the calculated footprints of countries, i.e. the amount of biologically productive space worldwide that is in a constant production to support a citizen of each country (Wackernagel and Rees, 1996). Also listed is the available capacity of a productive area per capita for each country, including the sea (Mayer, 2004). If the footprint is divided with the capacity, it results in a unitless ratio that expresses the load on the nature within that country. For a sustainable use of resources, this ratio should be below or equal to 1. This Load Ratio was compared with Environmental Load Ratio and Emergy Footprint Ratio for 5 countries, Iceland, Sweden, Denmark, New Zealand and USA. The comparison can be viewed in table 12 where the countries are ranked according to their sustainability. According to the 3 different ratios, the countries end up in the same order in all cases except the Load Ratio ranks USA higher than Denmark, opposite to the other ratios.

Table 12. Emergy Evaluation versus Ecological Footprint

	Ecological Footprint[1])				
Country	*Footprint*	*Avail.capacity*	*Load Ratio*	ELR[2)]	EFR[3)]
Iceland	**7,4**	**21,7**	**0,3**	**0,2**	**1,2**
New Zealand	7,6	20,4	0,4	0,8	1,8
Sweden	5,9	7,0	0,8	4,7	5,7
Denmark	5,9	5,2	1,1	10,8	11,8
USA	10,3	6,7	1,5	9,2	10,2

[1)] Source: The Earthcouncil, 2005.
[2)] environmental load ratio
[3)] emergy footprint ratio

5. Discussion

5.1 Answering the research questions

The main research questions posed in the beginning can be summarized and answered as following:

1. *How much emergy is in the renewable natural resources in Iceland compared to economic activity?*
   As can be seen in table 1, the renewable natural resources are abundant and each category in the range of 200-400 sej/yr (excluding emergy from the sun). When added together, and thereby ignoring double counting, the renewable resources amount to over 2000 sej/yr. All exports accounted to 609E+20 sej/yr.

2. *What is the renewable emergy base for the Icelandic economy?*
   To avoid double counting, the only renewable natural resources calculated in the renewable emergy base are the emergy in rain (chemical and geopotential), earthcycle and tidal energy. Together, this makes the renewable emergy base 909 sej/yr

3. *How sustainable is the Icelandic economy in emergy terms and how do the results correlate with other methods that measure sustainability?*
   When looking at the solar emergy use per capita, Iceland ranks high compared to other nations. This reflects high standard of living and can hardly be thought as sustainable. When the abundant natural resources are taken into the account, Iceland's sustainability ranks very high, as it has high emergy yield ratio and low Environmental load ratio. Therefore, it depends on whether the total natural resources are considered or not, whether Iceland can be considered sustainable or not. The same trend occurs when the results of Ecological Footprint are evaluated.

4. *How is the emergy balance in Iceland compared to other countries?*
   Iceland has a net deficit of emergy but it is not exporting emergy in the form of unprocessed raw materials, but indeed processed marine products, refined metal that is imported, human services and emergy from tourism.

5.2 Interpreting the results

The results show that Iceland is rich in renewable resources. That has previously been shown but by creating a holistic view with the comparison of economic activity and environmental inputs a more accurate dimension of the Icelandic economy has been evaluated. The economy is greatly dependent on the local environment as is reflected in the fact that only about 14% of all emergy used within the country comes from purchased imports. The significance of emergy flowing in rain and earthcycle correlate well with the current knowledge as hydropower and geothermal energy are thought to be the main renewable resources within the country. Fisheries, that have been the foundation of the Icelandic economy for centuries amount to only about 16% of the renewable emergy base available for Iceland, and marine products constituted 19% of total exported emergy. When emergy in local renewable production of hydropower and geothermal energy is compared with the total renewable base for Iceland it can be observed that only 6% has been harnessed sofar. This puts the economy into another context.

According to Brown and Ulgiati (2001), a sustainable development is what can be supported by the renewable flows of emergy in a region in the long run. They further elaborate on criterias for sustainability by claiming that a development is not sustainable if more emergy leaves the economy than is received in exchange. These two criterias raise questions regarding the sustainability of the Icelandic economy. According to the results the total renewable base emergy in Iceland could sustain 85% of the population and therefore, Iceland can be said to be highly sustainable. Still, four times more emergy is exported than imported that contradicts this statement. To be able to evaluate this contradiction one must look more precisely on what is behind the numbers. As stated before, the Icelandic economy had a net emergy deficit, i.e it was exporting four times more emergy than it was importing. Knowing that emergy is defined as "a real wealth" this raised the question: Is Iceland loosing real wealth? To be able to interpret this, it is not enough to look at *how much* is exported but rather at *what* is being exported. As stated in chapter 4.2 the major categories of exported emergy are marine products, human services, metals and tourism. This means that the only major indigenous natural resource in exports is the fish in the sea around the island. The trade imbalance is not from exports of raw materials, but indeed relying on expertice of the nation (fisheries, human services) and the fact that Iceland posesses a landscape and culture that attracts tourists. According to the Icelandic Tourist Board, up to 80% of foreign tourists say that the main reason for their visit to Iceland is the pristine nature the country holds (The Icelandic Tourist Board, 2005).

Regarding the claim that Iceland can be considered 85% sustainable, it is true that the country is self-sufficient in electricity and district heating. On the other hand it is totally dependent on outside sources of food and fossil fuels because it does not posess any fossil fuel sources and only holds a small agricultural and livestock industry. This discussion of self sufficiency brings us to the exceptional situation in Iceland when it comes to energy: Imported oil is only used in transportation and the fishing fleet. This makes Iceland a perfect niche market for testing renewable fuels. Indeed, the Icelandic government made a clear policy statement towards a hydrogen economy in 1998 where the aim is to replace fossil fuels in the transport sector and fishing fleet with hydrogen, electrolyzed from water. As Iceland is rich in both sources, water and electricity this is thought to be a feasable option (Fridleifsson, 2004).

National economies have been broadly classified according to their imports and exports that has lead to the definition of consumer nations and producer nations. According to Brown and McClanhan (1996), consumer nation imports more emergy than it exports and vice versa, producer nation exports more than it imports. In addition, the producer nation is further classified according to what it is exporting; if the exports contain more than 50% processed goods the nation is classified as commodity producer, but if less than 50% is processed goods it is classified as resource producer. According to this classification, Iceland, with a net emergy loss and high proportion of processed goods, is a commodity producer. Classified as a producer, Iceland is grouped with many of the developing countries that are facing a net deficit of emergy in the form of exported raw materals, that are not processed locally and therefore do not increase their emergy value at home. As explained above the composition of exports in Iceland is mainly processed marine products, processed metals that are imported as raw materials (with low emergy) and human services and tourism. Therefore, it can be stated that Iceland, through its expertice is contributing real wealth (emergy) to the outer system, its trading partners.

High standard of living and overall high quality of life reflected in high emergy use per capita correlates well with current knowledge. Iceland is a welfare state with one of the highest energy consumption per capita in the world. Being an Icelander, the author knows that the living standards in Iceland are very high; Icelanders consume a lot, both goods and energy and their waste is great. This is reflected in the Ecological Footprint as well as high emergy/capita. But still, if the renewable sources within the country are added to the picture, the overall sustainability index of Iceland ranks it highest among the countries compared. Could it be that the great amount of natural resources and small population makes the outcome biased? This is something that needs to be considered in the discussion of sustainability because it seems that both the holistic picture of the economy and the impact of lifestyle on the environment, within it the economy, need to be considered, independently. Further studies, i.e. Emergy Evaluation on society will evaluate more exactly the sustainability of the nation. It was reassuring to see that Emergy Evaluation and Ecological Footprint ranked chosen countries the same way according to their sustainability. It increased the validity of the results to get a similar outcome with another evaluation method.

The Investment ratio and the economic/environment ratio indicate that Iceland can be considered a land of opportunities when it comes to investments and economic developments. This is manifested in the current situation where big foreign companies are bringing huge investments into the country in the form of Aluminium smelters. The tourist industry has gone through constant expansion the past decade (The Icelandic Tourist Board, 2005).

In light of the debate on construction or conservation in Iceland, explained in the Introduction, an interesting aspect of the foreign trade is the import and export of metals. The value of imported Bauxite, that is refined and transformed into Aluminium in Iceland, is only 0,09E+20 sej. Compared with exported Aluminium, with a value of 66.4 sej, the difference is manyfold. This originates in different transformities because much more energy goes into producing Aluminium than Bauxite. This fact reveals how large the renewable emergy base is for Iceland, being capable of importing raw material from outside sources, refine it locally with locally renewable energy sources and export it with a much higher value than was imported. However, one may argue that this picture is not complete because the environmental effects of hydropowerplant constructions and aluminium smelters are lacking and the lost emergy in pristine highlands are not fully accounted for. That is one of the limitations of the emergy method.

5.3 Limitations of the emergy method and recommendations

In this thesis, the evaluation of what to include in the renewable emergy base, R, turned out to be the most difficult part in the analysis. This subject is in fact an area of active research and therefore, people differ in their opinions. A method has not yet been developed that determines partial coefficients for the planetary processes and meanwhile estimation, where double counting is avoided, is acceptable. Several different bases were calculated, using different criteria to test the effect. It turned out that different criteria did not affect the result significantly. After consulting with a specialist within the emergy field, it was decided to use the approach presented in the thesis.

One may argue that the use of precalculated transformities is a source of inaccuracy. This is though the standard approach in the emergy field and as long as one makes sure that all transformities used are calculated according to the same solar emergy base, this is acceptable. According to Campbell *et al* (2005), the overall accuracy of Emergy Evaluation depends on the accuracy in the calculation of the various data collected. Because of the diversity in the amount and kind of information it is stated that the aim of the emergy analysts is to achieve estimates that are within 10% of the actual value of the value used.

According to Mayer *et al* (2004), the main positive aspect of Emergy Evaluation is the ability to convert many different resource flows into one common unit and assess sustainability of systems at multiple scales. The negative aspects, on the other hand, are considered the need for a detailed data on imports, exports and energy sources. This can be accepted even though the detailed data does not have to be a negative aspect. One may argue though that because of the detailed approach the method is not very transparent.

One limitation of the method is lack of information on emissions and pollution in general because that must affect the level of sustainability of the chosen system. Tonon *et al* (2006) realize this limitation and introduce an integrated assessment tool in a new article where thermodynamic, economic and environmental parameters are used and emission to the environment is also evaluated. This reflects the dynamic era of these studies where constant improvements are being made on the measuring tools that aim at creating a good tool to measure sustainability.

As stated in the Methods chapter, empower density, the solar emergy used per unit area, is highest within dense industrial/business areas and lowest within rural areas. That can be understood if one takes a city and its surrounding as an example. Then the highest emergy flow would be where the economical/business activity was highest because there the work done (by humans) was the highest. Moving towards the suburbs, the density would decrease and so the empower. According to this definition, the emergy value of a pristine highland in Iceland would be very low even though work has been done there for hundreds of years (by nature). But the issue is not that simple.

After reading through the emergy litterature, it is clear that more time is needed to specifically look at the emergy in the highlands. According to Odum (1996), if developmental plans on pristine landscapes are questioned, an Emergy Evaluation on different alternatives, where one alternative is doing nothing, can be done. Pristine areas may have high emergy value if they are habitats of endangerous species or posess unique geological landforms. One way to attract emergy flow to an untouched area without much development is to establish natureparks and ecotourism. There, it is important to maintain a low Investment Ratio (low level of development) because that attracts tourist but still the area would get a feedback from the economy. It can be speculated if it is possible to make equal wealth out of an untouched area in the long run if the same amount of money would be spent on nature park as is spent on the first development plan (such as hydropower plant).

5.4 Further studies

The primary Emergy Evaluation conducted in this thesis is the first level, the overview of the economy, in a complete Emergy Evaluation. It provides the basis for further evaluation where the window of research (system boundary) is decreased and more specific issues are addressed. To be able to add new information to the debate in Iceland over hydropowerplant constructions, the next level in Emergy Evaluation need to be performed. There, different alternatives can be considered, i.e. hydropowerplant and, for example, a nature park. In the Icelandic highlands, unique bio- and especially geodiversity need to be taken into account as the island is in constant molding. Odum (1996) points out that, in the case of hydropowerplants, the prior work of nature in developing suitable sites for the plants contains high emergy. A metaphore used to explains this is the thought of all the emergy that would be needed if bulldozers were to be used to build a mountain for catching the rain and then to shape the land that would be suitable for a dam.

6. Conclusions

According to the results, Iceland is very self sufficient and therefore sustainable but at the same time has a very high standard of living that hardly is a sign of sustainability. This inconsistency may be due to a small population and abundant renewable emergy sources that can bias the outcome, i.e. make the country look very sustainable. Iceland exports more emergy than it imports, but it is not in the form of raw materials but rather in the expertise of the nation in the form of processed marine products, human services and refined metals that are imported unprocessed and refined locally. The Emergy Evaluation, presented in this thesis is only the first step in a complete analysis. In the next step, the system boundaries need to be narrowed down and subsystem analysed. Future studies may include Emergy Evaluation on new alternatives to hydropowerplants.

The field of emergy research is active and the method is under constant improvements that aim at creating an even more accurate tool to measure sustainability of nations, in this respect Iceland. The Emergy method has been criticized for not being transparent and being to cumbersome but it may be argued that with all the details, a holistic picture is created with many of the different sides of the economic-environmental system. As sustainability is a transdisciplinary issue, it may indeed be necessary to perform a detailed analysis from the viewpoint of various disciplines to be able to measure sustainability in an accurate way.

7. References

Arnalds, O., Barkarson, B.H. 2003. Soil erosion and land use policy in Iceland in relation to sheep grazing and government subsidies. *Environmental Science & Policy* 6:105–113.

Brown, M.T. 2003. Prof. Howard T. Odum, 1924-2002. *Energy* 28:293-301.

Brown, M.T., Ulgiati, S. 2001. Emergy measures of carrying capacity to evaluate economic investments. *Population and Environment: A Journal of Interdisciplinary Studies* 22**(**5**):**471-501.

Brown, M.T., S. Ulgiati. 1999. Emergy evaluation of the biosphere and natural capital. *AMBIO* 28(6):468-493.

Brown, M.T., McClanahan, T.R. 1996. Emergy Analysis perspectives of Thailand and Mekong River dam proposals. *Ecological Modelling* 91:105-130.

Brown, M.T., Herendeen, R.A. 1996. Embodied energy analysis and Emergy Analysis: a comparative view. *Ecological Economics* 19:219-235.

Campbell, D.E., Brandt-Williams, S.L., Meisch, M.E.A. 2005. *Environmental accounting using emergy: Evaluation of the state of West Virginia*. Report. U.S Environmental Protection Agency, office of Research and development. EPA/600/R-05/006, AED-03-104.

Campbell, D., Meisch, M. Demos, T., Pomponio, J., Bradley, M.P. 2004. Keeping the books for environmental systems: an Emergy Analysis of West Virginia. *Environmental Monitoring and Assessment* 94:217-230.

Carter, N., 2001. *The politics of the environment: Ideas, activism, policy*. Cambridge University Press, UK. 361p.

Daly, H. E., 2005. Economics in a full world. *Scientific American*, september:78-85.

Doherty, S. J., Nilsson, P. O. and Odum, H.T. 2002. *Emergy Evaluation of forest production and industries in Sweden*. Report no. 1. Department of Bioenergy, Swedish University of Agricultural Sciences.

Einarsson, M.A., 1984. Climate of Iceland. In van Loon, H. (Editor), World Survey of climatology:15: climates of the oceans (p. 673-697). Amsterdam, Elsevier.

Felixson, T., 2004. Nature and limits to growth: The role of business in designing new path for development. Presented at the Nordic-Japan Environmental Conference, 11- 12 November 2004. Viewed 171105 at: http://landvernd.is/flokkar.asp?flokkur=1003

Fridleifsson, 2004. The feasibility of a transition to a hydrogen economy in Iceland – an overview. M.Sc. thesis. LUMES, Lund University, Sweden.

Garratt, J.R,, 1977. Review of drag coefficients over oceans and continents. *Monthly Weather Review*. 105:915-929.

Giannantoni, C., Lazzaretto, A., Macor, A. Mirandola, A., Stoppato, A., Tonon, S., Ulgiati, S. 2005. Multicriteria approach for the improvement of energy systems design. *Energy* 30:1989-2016.

Gisladottir, G., 2005. The Icelandic Meteorological Office. Personal communication, 300805.

Gudmundsson, M.F., 2003. The aluminium industry and export revenue volatility. *Monetary Bulletin, A Quarterly Publication of the Central Bank of Iceland.* 5(3), 42-48. Viewed at the homepage of the Central Bank of Iceland 171105 at: http://sedlabanki.is/uploads/files/MB033_5.pdf

Haden, A.C. 2003. *Emergy evaluation of Denmark and Danish Agriculture: Assessing the limits of agricultural systems to power society*. M.Sc. thesis. Department of Rural Development Studies (DRDS), Swedish University of Agricultural Sciences.

Hau, J.L., Bakshi, B.R. 2004. Promise and problems of Emergy Analysis. *Ecological Modelling* 178:215-225.

Helgason, H., 2005. The Icelandic Coast Guard, Hydrographic Department. Personal communication, 090905.

Hilmarsson, T., 2003. Energy and aluminium in Iceland. Presented on Platts Aluminium Symposium, Phoenix, Arizona. January 12-14, 2004. Viewed 171105 at: www.lv.is/files/2003_2_6_Platts.THi.doc

Jónsdóttir, I., 2005. The Icelandic Maritime Administration. Personal communication, 090905.

Landsvirkjun, 2005. Kárahnjúkar, Hydropower Project. Viewed 171105 at: http://www.karahnjukar.is/EN/article.asp?catID=351&artId=554

Lynas, M., 2004. Damned Nation. *The Ecologist* 33(10).

Mayer, A.L., Thurston, H.W., Pawlowski C.W. 2004. The multidisciplinary influence of common sustainability indices. *Frontiers in ecology and the environment* 2(8): 419-426.

Miller, G. T. 2004. *Living in the environment: principles, connections, and solutions. 13th edition*. Brooks/Cole. 757p.

Odum, H.T. 1996. *Environmental Accounting, Emergy and Environmental Decision Making*. J. Wiley & sons, New York, 370 pages. 369p.

Óskarsson *et al*, 2004. Organic carbon in Icelandic Andosols: geographical variation and impact of erosion. *Catena* 56:225-238.

Rögnvaldsson, O., Crochet, P., Ólafsson, H. 2004. Mapping of precipitation in Iceland using numerical simulations and statistical modeling. *Meteorologische Zeitschrift* 13(3):1-10.

Sverrisdóttir, V., 2004. Address delivered by the Minister of Industry and Commerce at the General Meeting of The National Energy Authority, March 24th 2004. Viewed on 171105 at: http://idnadarraduneyti.is/radherra/raedur-og-greinar/nr/1381.

The Ministry of Foreign Affairs, 2005. Iceland in figures. Viewed 171105 at: http://iceland.is

The National Energy Authority, 2005. The homepage of the National Energy Authoritry in Iceland. Viewed 171105 at: www.os.is

The National Statistical Institute of Iceland, 2005. Viewed in September and October, 2005 at: www.hagstofa.is

The Public Health Institute of Iceland, 2005. Viewed in September and October, 2005 at: http://www.manneldi.is/fraedsla/fraedsluefni/matur-mataraedi-holdafar/nr/265

The Earthcouncil, 2005. Ranking of the ecological Impact of Nations. Viewed 181105 at: http://www.ecouncil.ac.cr/rio/focus/report/english/footprint/

The Economist, 2005. Greening the books; Ecosystem services (no author mentioned). London: Sep 17th, 376(8444): 96.

The Icelandic Tourist Board, 2005. Viewed 171105 at: http://www.ferdamalarad.is/displayer.asp?cat_id=217

The physics factbook, 2005. An Encyclopedia of Scientific Essays. Viewed 181105 at: http://hypertextbook.com/facts/

Tómasson, H., 1982. Vattenkraft i Island och dess hydrologiska förutsätningar. The National Energy Authority, Iceland. Presented on the 7th Nordic hydrology conferences (nordiske hydrologiske konferanse, NHK-82), 28.-30. juni 1982.

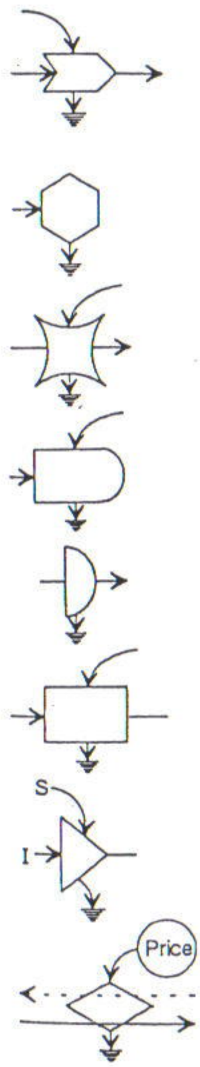
Valsson, G., 2005. The National Land Survey of Iceland. Personal communication, 310805.

Wackernagel, M., Rees. W., 1996. Our ecological footprint: Reducing human impact on the earth. New society publishers, Canada. 160p.

World Resource Institute, 2005. Earthtrends, The environmental information portal. Viewed 171105 at: earthtrends.wri.org/pdf_library/ country_profiles/coa_cou_352.pdf

Appendix

Symbols of the emergy system language (Odum, 1996:5)



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.

Switching action: A symbol that indicates one or more switching actions.

Producer: Unit that collects and transforms low-quality energy under control interactions of high-quality flows.

Self-limiting energy receiver: A unit that has a self-limiting output when input drives are high because there is a limiting constant quality of material reacting on a circular pathway within.

Box: Miscellaneous symbol to use for whatever unit or function is labeled.

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.

Transaction: A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source.

Sources of Transformities

1	Incident solar radiation	(by definition)	1
2	Wind, kinetic energy	Campbell et al, 2005:B-2	1470
3	Rain, chem pot evapotranspired	Campbell et al, 2005:B-2	28100
4	Rain, geopot runoff	Campbell et al, 2005:B-2	28100
5	River, chemical potential	Campbell et al, 2005:B-2	50100
6	River, geopotential	Campbell et al, 2005:B-2	27000
7	Wave energy	Campbell et al, 2005:B-2	30000
8	Tidal energy	Doherty, et al, 2002:37	24300
9	Earth cycle	Odum et al, 2000	33700
10	Fisheries	Campbell et al, 2005:B-2	1.96E+06
11	Agricultural production	Campbell et al, 2005:B-2	6.30E+04
12	Livestock production	Campbell et al, 2005:B-2	7.36E+05
13	Hydroelectricity	Campbell et al, 2005:B-2	1.25E+05
14	Geothermal energy	Campbell et al, 2005:B-2	3.10E+04
15	Erosion, topsoil	Campbell et al, 2005:B-2	7.26E+04
Items imported or exported			
16.32	Marine products	Campbell et al, 2005:C-22	3.27E+06
17.33	Other agric products	Campbell et al, 2005:B-2	2.33E+05
18.35	Alcoholic beverages	Campbell et al, 2005:B-2	5.89E+04
19	Fuels	Campbell et al, 2005:B-2	6.47E+04
20	Metals (Bauxite)	Campbell et al, 2005:B-3	1.47E+07
21.37	Textiles	Campbell et al, 2005:C-16	7.18E+06
22.39	Transport equipments	Campbell et al, 2005:C-16	7.76E+09
23.4	Machinery	Campbell et al, 2005:C-16	7.76E+09
24	Fertilizers	Campbell et al, 2005:C-16	2.99E+09
25.41	Plastic and rubber	Campbell et al, 2005:C-16	2.71E+09
26.42	Wood products	Campbell et al, 2005:C-16	1.49E+09
27	Animal feed and prod anim origin	Campbell et al, 2005:C-16	1.22E+06
28	Non metallic mineral prod	Campbell et al, 2005:C-16	3.09E+09
29	Misc manuf products	Campbell et al, 2005:C-16	1.61E+09
30	Chemicals	Campbell et al, 2005:C-16	9.90E+09
36	Metals (Aluminium)	Campbell et al, 2005:C-3	1.23E+10

All imports, data retrieved from the homepage of The Statistical Institute in Iceland.

Imports by groups of the SITC, Rev 3, 2003	
	Tonnes
Total	2869849
0 Food and live animals	223669,5
0 Live animals	5,1
1 Live animals	5,1
1 Meat and meat preparations	178,2
2 Dairy products and eggs	446,7
3 Fish, crustaceans, molluscs etc.	52908,9
4 Cereals and cereal preparations	90321,2
5 Vegetables and fruit	35648,4
6 Sugars, sugar prep. and honey	15088
7 Coffee, tea, cocoa, spices	4712,6
8 Animal feeds, excl. unmilled cereals	17498
9 Miscellaneous edible products	6862,4
	223669,5
1 Beverages and tobacco	12259,8
11 Beverages	11857,3
111 Non-alcoholic beverages n.e.s.	1633,8
112 Alcoholic bevarages	10223,6
12 Tobacco and tobacco manufactures	402,5
	12259,8
2 Crude materials, inedible	1102066
21 Hides, skins and furskins, raw	77,9
22 Oil seeds and oleaginous fruit	2986,2
23 Crude rubber, synth. and recycled	317,1
24 Cork and wood	53422,7
25 Pulp and waste paper	9,8
26 Textile fibres and their wastes	128,1
27 Crude fertilizers, crude minerals	343089,5
272 Fertilizers, crude, other than of 562	22,3
273 Stone, sand and gravel	45519,6
277 Natural abrasives; indust. diamonds	32
278 Other crude minerals	297515,6
28 Metalliferous ores, metal scrap	**520659,5**
281 Iron ore and concentrates	32282,6
282 Ferrous waste and scrap	0,4
285 Aluminium ores/conc. (incl.alumina)	488353,9
288 Non-ferrous waste/scrap n.e.s.	22,5
29 Crude animal and veget. materials	181375,1
	1102066
3 Mineral fuels; lubricants	**866381,1**
32 Coal, coke and briquettes	138557,7
321 Coal	85029,6
322 Briquettes, lignite and peat	701,3

325 Coke and semi-coke	52826,8
33 Petroleum, petroleum products	725434,4
333 Petroleum oils, crude	0,3
334 Petroleum products, refined	698640,3
335 Other petroleum products	26793,8
34 Gas, natural and manufactured	2389,1
342 Liquefied propane and butane	2386,7
343 Natural gas	0
344 Petroleum gases/gaseous hydrocarbons	2,4
345 Coal-/ producer gas and similar gases	0
	866381,2
4 Animal and vegetable oils, fats	6518,3
41 Animal oils and fats	1137,1
42 Fixed vegetable fats and oils	4064,5
43 Animal/vegetable fats/oils, processed	1316,7
	6518,3
5 Chemicals and related products	113440,4
51 Organic chemicals	4804,1
52 Inorganic chemicals	14882,4
53 Dyeing, tanning and col. materials	9682,3
54 Medicinal and pharmaceutical prod.	986,7
55 Oils, toilet and cleansing prep.	5993,2
56 Fertilizers, other than of 27	37232,2
57 Plastics in primary forms	15145
58 Plastic manufactures	8200,5
59 Chem. materials & products n.e.s.	16514
	113440,4
6 Manufactured goods	284529,6
61 Leather and dressed furskins	57,5
62 Rubber manufactures, n.e.s.	5476,6
63 Cork and wood manufactures	26839,6
64 Paper, paperboard, articles thereof	49788,5
65 Textile yarn etc., n.e.s.	6466,5
66 Non-metallic min. manufactures n.e.s.	93353,1
661 Lime, cement, constr. materials n.e.s.	60717,8
662 Clay and refractory constr. materials	9200,5
663 Mineral manufactures n.e.s.	13005,6
664 Glass	5242,7
665 Glassware	4577,1
666 Pottery	609,2
667 Pearls, precious/semi-precious stones	0,1
67 Iron and steel	58135,9
68 Non-ferrous metals	18528,8
69 Manufactures of metal n.e.s.	25883,1
	284529,6
7 Machinery and transp. equipment	215159,8
71 Power generating machinery	1301
72 Machinery for part. industries	15999,8
73 Metalworking machinery	1395,7

74 Gen. industr. machinery & equipm.	9495,3
75 Office machines and computers	1039,3
76 Telecom equipment etc.	1899,5
77 Elec. machinery, app. and appliances	148651,2
78 Road vehicles	27916,3
781 Motor cars, not for public-transport	15984,5
782 Lorries, vans and special-purpose cars	7268
783 Road motor vehicles, n.e.s.	887,9
784 Parts etc. for motor vehicles	1273,1
785 Motorcycles, cycles; invalid carriages	454,2
786 Trailers/semi-trailers; non-mech.vehicles	2048,7
79 Other transport equipment	7461,8
791 Railway and tramway vehicles	0
792 Aircraft and associated equipment	129,5
793 Ships, boats and floating structures	7332,3
	215159,9
8 Misc. manufactured articles	45197,7
81 Prefab. buildings; fixtures	12270,3
82 Furnit., mattr., cushions etc.	13515,9
83 Travel goods, handbags etc.	385,6
84 Apparel and clothing accessories	3290,2
85 Footwear	778,8
87 Prof., scient. & contr. instruments	889,3
88 Photogr. equip., opt. goods; watches	590,1
89 Misc. manufactured articles n.e.s.	13477,5
	45197,7
9 Other commodities	627,1
	2688479

All exports, data retrieved from the homepage of The Statistical Institute in Iceland.

Exports by commodities (SI classificaton) and branches of processing	
	2003
	Tonnes
Total	1453079
1 Marine products	808957,8
22 Livestock	464,8
220 Horses	464,5
224 Sheeps	0,3
229 Other livestock	0,1
23 Products of farm animals	4709,9
231 Products of horses	521,5
232 Products of bovine animals	191,6
233 Products of swine	252,6
234 Products of sheep	3713,1
235 Products of mink	25,6

236 Products of fox	3,5
239 Products of other farm animals	2
24 Milk and dairy products	786,1
25 Other products of land and sea	2774,3
29 Other agricultural products	214,7
3 Manufacturing products	520898,9
31 Food and beverages	6021,3
52 Non-alcoholic beverages	2854,6
53 Alcoholic beverages	289,8
319 Other food products	304
33 Animal feeds	8,5
34 Health care and toilet articles	575,4
35 Furs and textile articles	708,1
350 Tanned or dressed sheep skins	267,9
351 Other tanned or dressed furskins	131,5
355 Textile yarn, incl. wool tops	173,2
356 Textile articles	48,9
357 Clothing and footwear	83,8
359 Other leather, fur and textile articles	2,7
36 Mineral and chemical products	497056,4
360 Aluminium	286022,9
361 Ferro-silicon	129259,6
362 Diatomite	27969,4
363 Salt	1436,4
364 Rock wool	3050,4
365 Seaweed meal	57
366 Petroleum and petroleum products	28843,7
367 Cryolite	1374,7
369 Prepared additives for cements	19042,3
37 Fishing equipment	4219,1
370 Electronic weighing machinery	418,8
371 Fishing lines, cable, nets etc.	948,5
373 Fishtubs	1411,8
379 Fishing equipment	1440,1
38 Various manufacturing products	1982,7
381 Containers and wrappings	1410,3
382 Aluminium pans	193,5
383 Food processing machinery	379
39 Other manufacturing products	10327,3
391 Plastic and rubber manufactures	583,8
392 Miscellaneous articles of wood	317,4

393 Paper and print	1431,7
394 Metal and metal manufactures	734,4
399 Other products	7260
4 Other products	110767,2
41 Mineral substances	41611,1
410 Pumice stones	40530,8
412 Gravels and sand	996,2
419 Other mineral substances	84,2
Recovered products	56378,8
420 Metal scrap	42975
421 Plastics for recycling	11722,5
422 Paper for recycling	664,2
429 Other articles for recycling or waste	1017,1
43 Transport equipments	9557,9
430 Used ships	9363,2
431 Reconstruction of fishing vessels	1
432 Aircraft	0,6
433 Used or re-exported vehicles	193,2
49 Miscellaneous	3219,3

SI classification by commodities is an Icelandic classification only used for exports.