ENERGY ANALYSIS OVERVIEW OF DOMINICA*

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INTRODUCTION

Ecological Overview of Dominica

Dominica is the largest of the Windward Islands in the Lesser Antilles of the Carribean and has a land area of approximately 790 square kilometers (see Figure 9.1). Being the product of the fusion of three volcanoes, Dominica is the most mountainous island of the Lesser Antilles. The overwhelming influence of runoff and landslides of the mountainous interior dominates the narrow band of gentle slopes which gird the island's perimeter. The largest peak of the interior highlands is Morne Diablotin (1440 m). Rainfall is high in relation to other islands in the Carribean and most environments on earth, ranging from 2030 mm/year at the seaside capitol of Roseau to over 9000 mm/year in the cloud forests at the mountain summits. The mountains' blocking of the trade winds carrying moist tropical air causes a large runoff of high quality rainwater with great chemical potential energies supporting the work of weathering and forest growth.

As illustrated in Figure 9.1, the areal extent of urbanization is small in Dominica, limited to a few small towns on the coast. The major extent of human influence has been the conversion of rainforest on the relatively gentle slopes of the perimeter to agriculture. Some scrub ecosystems remain on the drier east coast.

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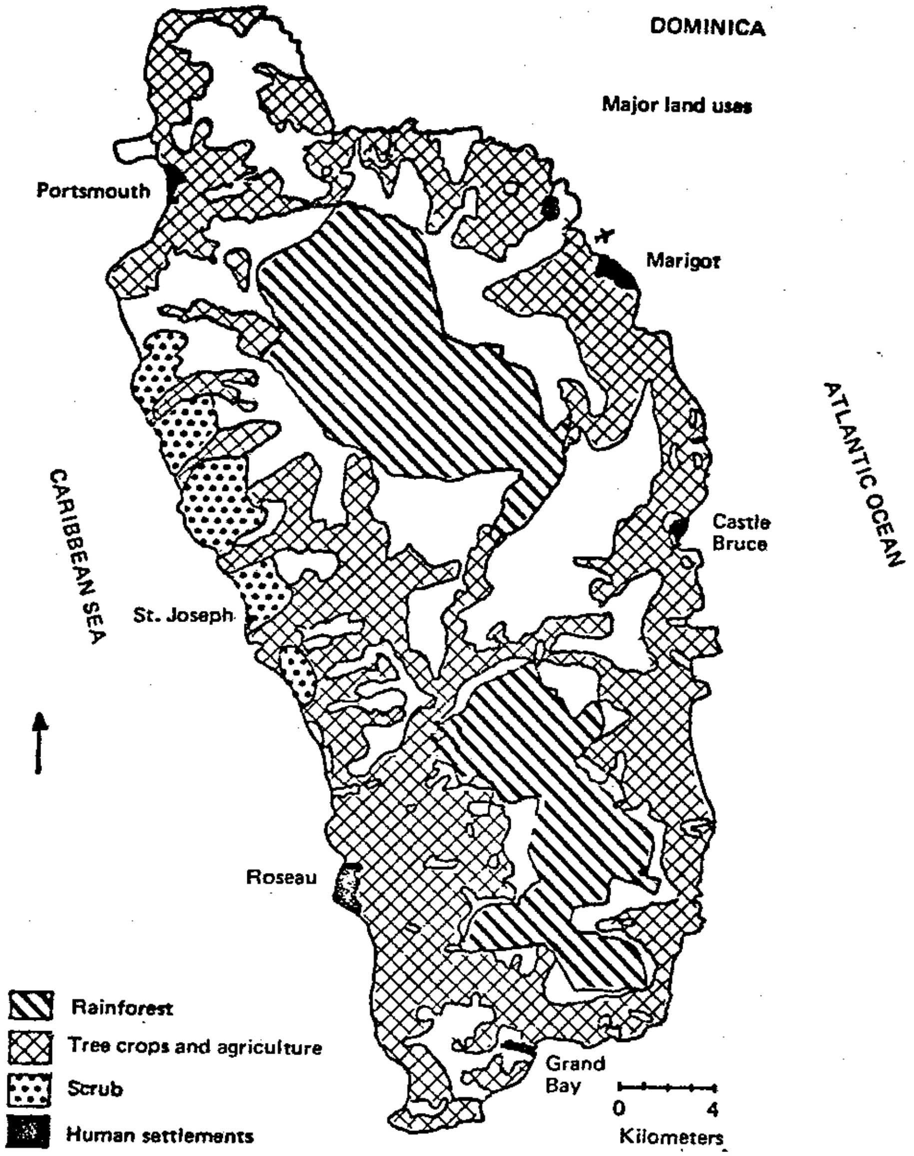

Figure 9.1. Land use map of Dominica adapted from United Nations (1975).

The dissipation of gravitational potential energy as rainwater flows down from the summits and shapes the landscape. However, much of this energy currently washes straight into the sea without being harnessed economically, such as for hydropower.

The interaction of high rainfall and volcanic soils has produced cloud forests on the peaks and rain forests on the upper slopes (Figure 9.1). Inaccessibility to markets and rugged topography have daunted many attempts to replace these forests with intensive agriculture. Most people have been supported by shifting cultivation in small plots utilizing rain forest soils and wood for short periods. The virgin rain forest has diminished from roughly two-thirds of the island's area to 1/3 at present.

Dominica is rich in other environmental input with high embodied energies, including sun, wind, waves, tides, rapid geologic uplift and thermal input from volcanic activity. Severe hurricanes pulse through the island on an irregular basis, several having swept the island in the late 1970's and early 1980's. The immediate effects of winds, floods and high tides are destructive to housing, roads and docks, but the long term effects of such storms may be to increase weathering, accelerate geological cycles and pulse natural ecosystems.

Except under the cloud cover of the summits, tropical solar input is relatively high in Dominica by world standards. The trade winds from the east and south-east with a long, uninterrupted fetch over the Atlantic Ocean, drive waves onto Dominica's eastern shore. The rocky shores of Dominica reflect a sizable portion of the wave energy back into the sea. The trade winds also bring moisture which condenses into rain at the cooler elevations and moderates the climate by dispersing heat. The steepness of Dominica's marine slopes allows little area on its oceanic shelves for the work of tidal energies.

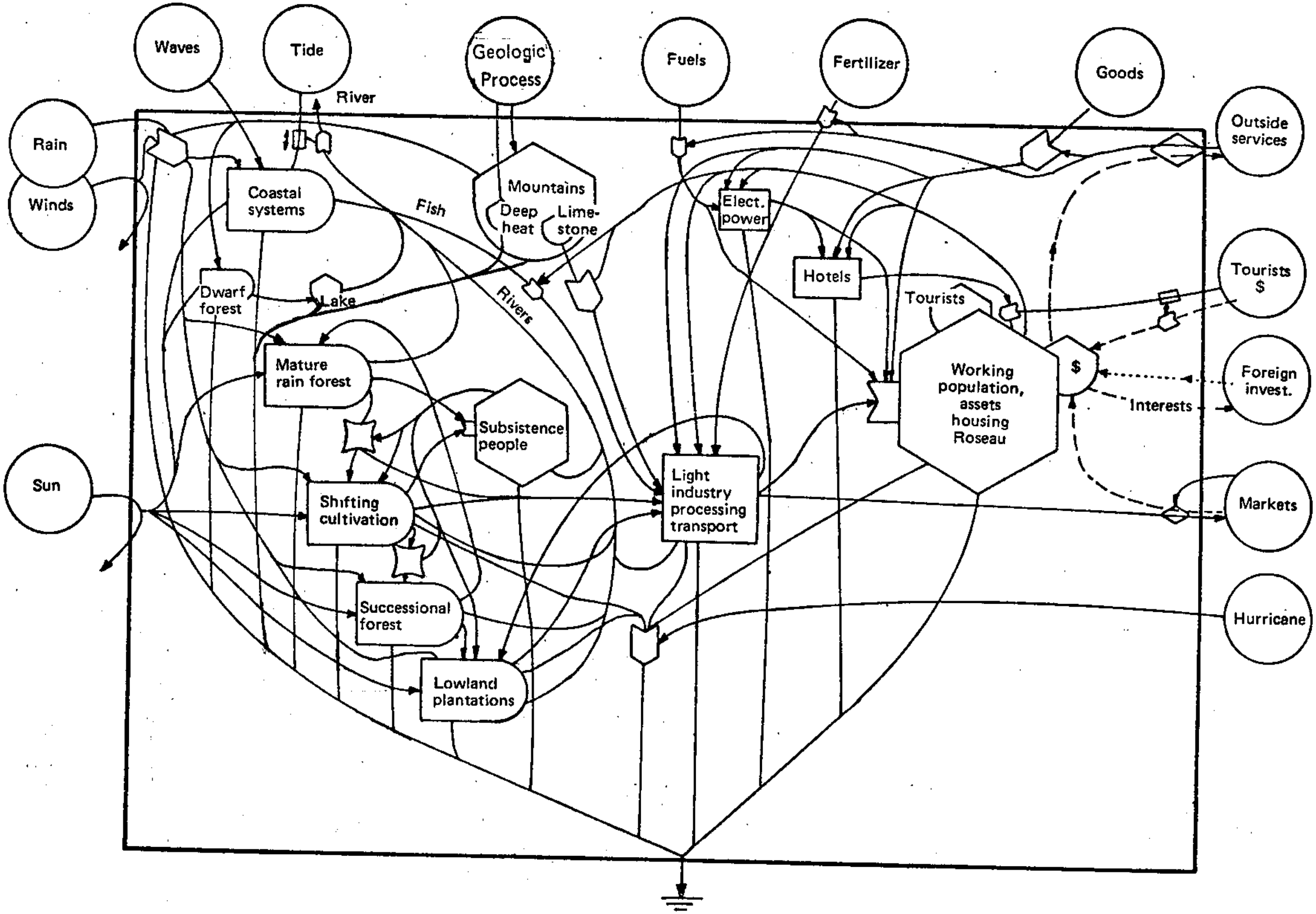

Figure 9.2. Energy diagram of the main compounds and processes of Dominica, West Indies.

Persistent hot springs from volcanic activity might support geothermal power generation.

Human Processes in Dominica

Human activity on Dominica centers on agriculture, primarily banana and coconut plantations and citrus cropping, and on modest development of light industry, such as processing oils and juice manufacture. More than 75% of Dominica's 100,000 agricultural acres are low-energy farms less than 10 acres in size. Fishing exists on a small scale, but is important as a local source of protein. Requirements for domestic power and light industry have been supplied by small-scale hydroelectric power generation facilities.

A small tourist trade is an important source of foreign exchange. The ruggedness of the terrain has made development of tourism infrastructure (airport, roads and protected harbor) difficult to establish and maintain. The lack of transportation facilities and sunny sites for hotels has certainly kept the flow of visitors to a low level. Tourism is hindered by the airport's relative inaccessibility from the main town and the sunnier beaches. The exceptional resource of beautiful, virgin rain forest has not yet caught the imagination of the international tourist as much as sunny beaches on other islands with less rain.

Dominica's interaction with the world is limited. Oscillating boom-and-bust, one crop agricultures with fluctuating prices has never permitted established, long lasting trade relations in any one area.

This paper is an energy analysis of main environmental and economic flows of the island system of Dominica. All significant flows and storages which occur on Dominica were measured in equivalent units of solar energy. The relative importances of various processes, banana and coconut plantations, were compared based on their energy use and contribution to the island economy. Energy based indices such as energy per person and imported/local energy ratios were used to compare Dominica with other national economies.

METHODS

Definitions

The following energy terms are used throughout this paper:

1) Energy Transformation Ratio (ETR): This solar based ratio is derived by dividing the total actual energies of a particular form (rain, tides, waves, for example) into the total sunlight energies falling on the earth during an equivalent length of time. This ratio expresses the amount of solar energy which is required to produce each joule of energy found in any kind of matter, living or non-living, or in any kind of force. Thus, as shown in Odum et al. (1983) Table 3.1, 1268 solar joules are needed to produce each joule of surface wind (kinesthetic) energy. An ETR thus describes the energy "efficiency" of a process and allows comparison with other processes. The ETR of aluminum is one thousand times that of steel (Odum et al. (1983) Table 3.1), so, broadly speaking, the steel making process is one thousand times more efficient in turning out a finished product than the aluminum making process. Such efficiencies can be used to compare various kinds of processes of one type, continuous-casting versus slab casting in the steel industry for example. However, different types of processes can also be compared. For instance, given a choice between aluminum and steel as construction materials, the lower efficiency of aluminum would have to be counterbalanced by superior durability or design capabilities to justify its choice over steel.

2) Embodied Energy: This term describes the amount of equivalent energy units of one type which were needed to create an object or process and are thus "embodied" in them. Following the example of the energy

transformation ratio for wind, 1268 solar joules are embodied in each joule of wind.

3) Energy Quality: This term reflects the fact that the more energy is embodied in an object or process the greater its effectiveness and flexibility in use. For example, electricity is a form of energy of higher quality than wind. Far more solar energy (15.9 E4 solar joules vs. 1268 solar joules) is required to produce one joule of electricity than one joule of wind. This one joule of electrical energy can do far more work than one joule of wind energy. And the diversity of forms of work or forms of energy (heat, mechanical or chemical) which electricity can produce far exceeds the capabilities of wind energy.

Procedure

The procedures employed for this paper's analysis are listed below. More detailed information about energy flow calculations and transformation ratios, their derivations and rationales for use in particular examples, is available in manual form (Odum et al., 1981) and (Odum et al., 1983).

Overview Diagram

Based on information about land use, regional economy and ecosystem principles an overview diagram of Dominica was created (see Figure 9.2) using energy symbols. The symbols used to describe an energy system (see Odum, 1983) form an energy language which gives a diagram several levels of information. These symbols reflect energy constraints, kinetic relationships, macroeconomic flows and causal influences for all the dominant processes in the system. All the major influences and energy flows recognized were included as follows:

Energy Sources in the Diagram

All energy sources (inputs) for island were listed in order of quality (Table 9.1). High quality energies are those with more embodied energy per unit of actual energy. Thus, more diffuse, natural energies such as sun, wind, rain, tides, geologic uplift, etc., are followed by more concentrated and flexible sources (in terms of use) such as fossil fuels and goods and services. This hierarchy is shown spatially in Figure 9.3 as the quality of the sources increases from left to right.

In addition to a table of dominant flows of energy across the boundaries of Dominica another table was created, Table 9.2, listing the major long term storages that contain embodied energy in Dominica. The following methods and calculations were used in creating these tables:

Actual Flow Energies

Using standard formulae of physics, chemistry and geology the actual energy flow or storage for each item in the tables was calculated in actual (heat equivalent) joules.

Energy Transformation Ratios

Energy transformation ratios taken primarily from Odum et al. (1983) were reported in the tables in solar equivalent joules. The formulations for energy transformation ratios can be found in the above reference. Many previous analyses have worked with fossil fuel (coal) equivalents as the common energy unit. However, since the sun is responsible for most of the forms of energy in question, solar equivalents are the common denominator here.

Embodied Energies

Embodied energies, reported in solar equivalent joules, were calculated by multiplying the actual joules by the transformation ratio associated with that element or process. The realtive importance of a storage or flow to human economies and nature is indicated by its total embodied energy.

The simultaneous generation by global atmospheric and oceanic systems of several types of natural energies creates the potential for overestimating natural inputs which drive the economy. The energies of rain, wind and beach waves are products, of varying intensity, of the same original solar energy which accumulated predominantly over the ocean. To avoid "double counting" of the original solar joules, each of the solar-derived inputs is evaluated separately. But the largest one is chosen as the representative natural input, and it includes the energy which generated the other natural inputs.

The embodied energies, when added to their appropriate pathways on an overview diagram (Figures 9.3 and 9.4), provided a perspective on the amounts and relative importance of various energy forms entering Dominica. Not all significant flows simply enter or leave the system as imports or exports. The drawdown of island resources (significant consumption of virgin timber and soils or depreciation of infrastructure) should be included in the embodied energy which supports the economy.

Aggregated Diagram

An aggregated diagram (Figure 9.3) reduces the number of systems described to an essential minimum. The merging of subsystems and their flows presents the clearest picture of the most crucial subsystems and their interactions. These merged flows and the dollars flows associated with them are listed in Table 9.3.

Summary Diagram

A summary diagram, Figure 9.4, was then created which presents two major inputs and the cumulative output of Dominica. Each of these two inputs comprises two compartments. The lower quality energy of "Renewable and Indigenous Resources" entering from the left is composed of: 1) renewable energy (chemical potential of rainfall), and 2) nonrenewable, indigenous resource use (clear-cut rainforest biomass and eroded topsoils). The higher quality energy entering from the top of the diagram, "Imported Resources," is composed of 1) imported fuels and goods, and 2) imported services. Important summary flows and ratios related to this diagram are listed in Table 9.4.

Overview Analysis

Other ratios and numbers useful in overview analysis were calculated based on the data in Table 9.3 and are listed in Table 9.4.

Items 1 through 6 in Table 9.4 are the sums of flows shown in Figure 9.3. Item 5 gives total energy consumption in Dominica for comparison with other nations.

Items 7 through 14 are ratios of aggregations of flows listed in Table 9.3. Item 7 is the sum of all used energies derived from local sources divided by total energy use. Item 8, Exports minus Imports, is a measure of the trade balance in net energy terms. Item 9, Export/Import ratio, is the embodied energy of all island outputs (products, re-exports and services (labor)) divided by the sum of all imports (fuel, fertilizer, goods and services). This ratio is analogous to a technical efficiency ratio, reflecting how effective the economy is in converting input to output. Item 10 is the fraction of energy use which is renewable on a local basis. This was calculated by dividing total yearly energy flow into the dominant natural energy flow. Item 11 indicates the importance of fossil fuels and other foreign sources in the total yearly energy flow of the island. This was calculated by dividing total energy flow into the sum of purchased energies. Item 12 indicates the flow. The embodied energy of imported services was calculated by multiplying Dominica's energy/$ ratio times the dollars paid for imports. This product was then divided by total energy flow (on an annual basis) in Dominica. Item 13 is a measure of the non-purchased (free) fraction of energy use, and was calculated by dividing total energy flow into the sum of rain and virgin rainforest biomass flows. Item 14 measures the importance of purchased energy sources relative to free energy sources by dividing the former by the latter.

Demographic Overview

Numbers useful in energy overview of Dominica's demography were calculated using embodied joules of one type and are listed in Tables 9.4, items 15 through 19.

Item 15, Use per Unit Area, is an indication of the density of energy use and was arrived at by dividing Dominica's area into total energy use, U.

Item 16, Per Capita Energy Use, was calculated by dividing the population into total energy use, U. This measure reflects the non-monetary inputs (natural services and energy flows) as well as human inputs (fuels, goods and services) which contribute to the standard of living.

Item 17, Renewable Carrying Capacity, is an estimate of Dominica's population at the current standard of living if the only energy inputs were natural, i.e., no subsidies or fossil fuel imports. This was calculated by dividing the total natural energy flow in Dominica by Item 16, Per Capita Energy Use.

Item 18, Developed Carrying Capacity, is an estiamte of Dominica's population at the current average standard of living of the United States. Thus, if Dominica interacted internationally to the same extent that the United States does (importing fuels and fertilizers and exporting raw and processed materials at U.S. rates) then it could support such a level of population. This was calculated by multiplying the "Renewable Carrying Capacity" by 8, the factor difference between renewable energy flows and total energy use in the United States.

Item 19, the "Ratio of Use to GNP," was calculated by dividing total energy use, U, by the total 1979 GNP.

Energy Dollar Ratio

An energy to dollar ratio was calculated which is based on the total energy consumption of the economy divided by the Gross National Product (GNP). The GNP represents total dollar flow through the final demand sector of the economy: exports, government, household consumption, maintenance and growth plus investment, financing and foreign aid. An algebraic approach to the energy/dollar ratio accompanies Table 9.3.

Subsystems Analysis

Two subsystems of Dominica were investigated: banana production and coconut oil processing. Footnoted calculations support summary diagrams of each subsystem.

a) Banana Industry Subsystem: Natural energy inputs to banana production were estimated by multiplying the rain energy per acre by the total acreage of banana production. The latter could be refined since the only data available was for 1975, and, due to the vagaries of international markets and hurricanes, year-to-year crop acreage can fluctuate substantially in Dominica. Labor energy input was estimted by multiplying gross tonnage of bananas by the price paid per ton by the energy/US $ ratio for Dominica. Goods and fossil fuels utilized for banana production were estiamted by multiplying the percentage that national banana sales are of the GDP by the energy transformation ratios of goods and fossil fuels, respectively.

b) Coconut Processing Industry Subsystem: The natural energies embodied in coconuts were calculated by multiplying the rain energy per acre, as determined in Footnote #3 to Table 9.1, by the total acreage devoted to coconut farming.

The embodied energies of labor for coconut, copra, coconut oil and soap processing were calculated by multiplying the gross production tonnage by the US price per ton by Dominica's energy/US $ ratio. Coconut oil's purity and usefulness increase as the water content decreases. The energy needed to dehydrate molecules not chemically bonded to water is 0.54 kcal per gram. Multiplying this factor by the gross tonnage by a factor of 1.67, to account for volume reduction, by the energy transformation ratio for fossil fuels (Odum et al., 1983) gives the embodied energy of process heat. Summation of the previous 3 values gives the energy embodied in coconut oil. Energy requirements for pressing oil out of copra were not determined due to scarcity of data.

Toilet and Laundry Soap: Dividing total natural energy falling on coconut plantations by total coconut oil production gave the solar embodied energy/metric ton. Subtracting export oil from total oil production gave a figure for the remaining coconut oil serving as base material for soap production. Multiplying this remainder by the embodied energy per ton yielded the solar energy embodied in soap oils.

The energy embodied in the labor of handling and processing soap was determined by multiplying gross soap production tonnage by the price paid by Dominica's energy/US $ ratio.

The energy embodied in fossil fuels for the industrial manufacture of soaps was determined using US standards. Total US soap production heat energy divided by total US soap production gave an energy per weight ratio. Multiplying this ratio by Dominica's total soap tonnage produced by the energy transformation ratio for fossil fuels (Odum et al., 1983) yielded total energy of fossil fuels embodied in soaps if Dominica's manufacturing standards are of the same energy intensity as the US. It is conceivable that Dominica's standards are somewhat lower.

RESULTS

The complex energy relationships in the system of Dominica are shown in Figure 9.2, an energy diagram including significant outside energy sources, storages and energy uses in the land and industries and the predominantly human systems of Dominica. Energy flows are listed in Tables 9.1, and energy storages are listed in Tables 9.2.

In Table 9.1, tropical solar direct radiation is high by world standards, but is dwarfed by the more indirect solar equivalents in inputs of rain and waves. In particular, the chemical potential of pure rain water was approximately 31 times the embodied energy of direct sunlight.

The energy flow of rock uplift was of similar magnitude owing to the high degree of geological activity in this orographic region. The entire arc of the Lesser Antilles archipelago overlies the subduction zone where the Atlantic Plate dives westward under the Caribbean basin.

Since rainwater's purity is the largest of the inputs from the solar driven biosphere, it was used to represent natural flows. It includes all other environmental flows which are byproducts.

Much of the geopotential energy of rain runs off in streams concentrated further by the island mountain topography.

Table 9.2 lists the important energy storages of Dominica.

Table 9.1. Energy flows in Dominica in 1979.

Foot-note	Types of Energy	Actual Energy J/y	Energy Trans. Ratio SEJ/J	Embodied solar energy E18 SEJ/y
1.	Direct Sunlight	5.65 E18	1	5.6
2.	Wind	1.33 E16	1268	16.9
3.	Rain-chem. pot.	1.13 E16	15,444	175.0
4.	Rain-geopotential	8.33 E15	8888	74.0
5.	Waves	1.82 E15	25,889	47.0
6.	Earth Cycle	3.75 E15	2.98 E4	111.0
7.	Bananas (export)	4.25 E13	4.54 E5	19.0
8.	Coconuts & products (export)	1.34 E14	2.09 E5	63.0
9.	Fruits & Veg.Juice (export)	-	-	6.4
10.	Internal use of rainforest	-	-	371 .0
11.	Imported services	(39.6 E6 US$)	(2.37 E12 SEJ/US$)	93.9
12.	Fuels imported			
	Liquid motor fuels	2.52 E14	6.6 E4	16.6
13.	Electricity	5.42 E10	15.9 E4	0.0009
14.	Tourism (3.16 E6 US$)	-	2.37 E12/US$	7.4
15.	Single Hurricane	2.28 E15	4.08 E4	92.0
16.	Hurricanes	2.28 E14	4.08 E4	9.2
*	Others	-	-	-

*Tides and fertilizer use were calculated and found negligible compared to other ideas. Preliminary calculations showed the embodied energy of imported goods was less than 9% of imported services.

Footnotes for Table 9.1.

1. Direct sunlight

Sunlight: 1.8 E6 kcal/m^2/y (Sellers, 1965) = 7.53 E9 J/m^2/y. Dominica's area: 289.5 miles square (World Bank, 1981) = 7.5 E8 m^2. Continental shelf: marine slopes descend so steeply steeply that very little shelf area exists. Marine maps showed 600 foot depths routinely within 400 yards of shore.

(Total area)(Average insolation)

(7.5 E8 m^2)(7.53 E9 J/m^2/y) = 5.65 E18 J/y

2. Wind

Eddy diffusion: 4.5 m^3/m^2/sec; vertical gradient: 3.2 E-3 m/s/m (Newell, 1972).

(1 m^2)(1000 m)(1.23 kg/m^3)(4.5 m^3/m^2/sec)(3.14 E7 sec/y)

(3.2 E-3 m/s/m)(7.5 E8 m^2) = 1.33 E15 J/y

3. Rain - Chemical potential

Precipitation: 3050 mm/y (United Nations, 1975).
(area)(average rainfall)(Gibbs free energy)(conversion factor)

(7.5 E8 m^2)(3.05 m)(4.94 J/g)(1 E6 g water/m^3) = 1.13 E16 J/y

4. Rain - Geopotential

Average elevation: 609 m (derived from averaging the elevational areas of a topographical map of Dominica). Runoff: 1.86 m (since the average evapotranspiration figure for Puerto Rican rainforest is 39% (Odum and Pigeon, 1970), then the runoff is 61% or (0.61)(3.05 m/y) = 1.86 m/y.
(area)(ave.elevation)(runoff)(density of water)(gravity).

(7.5 E8 m^2)(609 m)(1.86 m/y)(1 E3 kg/m^3)(9.8 m/s^2) =

= 8.33 E15 J/y

5. Waves

Wave velocity derived by multiplying (gravity)(depth at measurement point) and taking the square root of the product: (9.8 m/s^2)(4 m) = sq. rt. (39.2 m^2/s^2) = 6.26 m/s. Wave height: 4 feet = 1.22 m (Table 19 of Synoptic Meteorological Observations, U.S. Naval Weather Service Command). Straight shoreline length: 4.84 E4 m, taken from a line drawn on a map of Dominica perpendicular to prevailing trade winds which

Footnotes for Table 9.1. continued

generate waves.

(straight shoreline length)(1/8)(density)(gravity)(ht)^2 (velocity)

4.84 E4 m)(1/8)(1.025 E3 g/m^2)(9.8 m/s^2)(1.22 m)^2(6.26 m/s)

(3.15 E7 s/y) = 1.82 E15 J/y

6. Earth cycle

(heat flow in an active orographic area)(area)

= (5 E6 J/m^2/y)(7.5 E8 m^2) = 3.75 E9 J/y

7,8. Bananas, coconuts, coconut oil and derivative products. See subsystems analysis, Tables 9.5 and 9.6., Figures 9.4. and 9.5.

9. Fruits, vegetables and juices

Total acreage for fruit and vegetable cultivation: 3,400 acres (nited Nations, 1975). Natural energy/acre: 9.44 E14 SEJ/acre (footnote 3, Table 9.1.); Fossil fuel/hectare: 4.97 GJ/ha (Slesser, 1978, Table 8.1)

(3400 acres) (9.44 E14 SEJ/acre/y) = 3.2 E18 SEJ/y

(1.14 E6 US$)(2.37 E12 SEJ/US$) = 2.7 E18 SEJ/y

(1,376.5 ha)(4.97 GJ/ha)(6.6 E4 SEJ/J) = 4.52 E17 SEJ/y

Total embodied energy = 6.36 E18 J/g

10. Internal use of rainforest

See Item N_o in Table 9.3.

11. Imported Services

Total import dollars in 1979: 39.4 $ E6 US$ (World Bank, 1981).

(39.6 E6 US$)(2.37 E12 SEJ/US$) = 9.33 E19 SEJ/y

Footnotes for Table 9.1. continued

12. Fuels imported

Total volumes of gasoline, kerosene, diesel and fuel oils imported in 1979 are 1,197 E3 gal., 61 E3 gal., 432 E3 gal. and 79 E3 gallons respectively. (World Bank, 1981). Actual calorie conversion factors, from (Odum et al., 1983) are 36,225 kcal/gal., 34,030 kcal/gal., 34,030 kcal/gal. and 37,431 kcal/gal.

Actual energy calculations:

gasoline (1,197 E3 gal)(36,225 kcal/gal) = 4.34 E10 Kcal
kerosene (61 E3 gal)(34,030 kcal/gal) = 2.09 E9 Kcal
diesel (432 E3 gal)(34,030 kcal/gal) = 1.47 E10 Kcal
fuel oils (79 E3 gal)(37,431 kcal/gal) = 2.99 E9 Kcal

Total actual energies:

liquid motor oils = 6.02 E10 kcal)(4186 J/kcal) = 2.52 E14 J/y
fuel oils = 2.99 E9 kcal)(4186 J/kcal) = 1.25 E13 J/y

13. Electricity

Average electricity generation from 1978 to 1979: 15,048 KWH (World Bank, 1981)

(15,048 KWH/y)(3.6 E5 J/KWH) = 5.42 E10 J/y

14. Tourism

Total tourism income: 3.18 E6 US $/y (World Bank, 1981). Energy/$ ratio from the U.S.A. representing tourist origins.

(3.18 E6 US$)(2.37 E12 SEJ/US$) = 7.35 E18 SEJ/y

15. Hurricane

Energy per hurricane, 4.85 E5 kcal/m^2/day (Hughes, 1952). 3% kinetic energy; 10% energy dispersed to the surface, see Appendix A14. Passage time, 0.5 days.

(Energy per unit area)(hours exposed)(area)

(4.85 E5 kcal/m^{2}day)(0.03)(0.10)(0.5 day)(7.5 E8 m^2)

(4186 J/kcal) = 2.28 E15 J/hurricane passage

Footnotes for Table 9.1. continued

16. Hurricane per year

Values taken from footnote 15 divided by the interval between hurricanes, 10 years.

$$\frac{(2.28\ \text{E15 J/hurricane})}{(10\ \text{years})} = 2.28\ \text{E14 J/y}$$

Table 9.2. Embodied energy in storages in Dominica in 1979.

Footnote	Type of energy	Actual energy J	Energy transformation ratio SEJ/J	Embodied solar energy E19 SEJ
1	Old rainforest	9.83 E16	3.49 E4	343.0
2	Secondary forest	5.23 E15	1.9 E4	9.9
3	Cropland	3.49 E16	1.9 E4	66.0
4	Soil	3.4 E17	6.26 E4	2129.0
5	Limestone	6.9 E14	2.29 E8	15824.0

Footnotes to Table 9.2.

1. Old tropical rainforest

Area, rainforest reserve plus national parks: 43,000 acres = 1.74 E8 m^2 (United Nations, 1975). Organic matter density: 332 T/ha, living biomass in vegetation, plus 7.6 T/ha, litter (Brown and Lugo, Biotropica, Vol. 14, No. 3, p. 172). Forest organic matter combustion value: 4.1 kcal/g (Odum et al., 1983, p. E10).

(329.6 T/ha)(1 E6g/T)(ha/1E4 m^2)(4.1 Kcal/g)(1.74 E8 m^2)(4186 J/Kcal
= 9.83 E16 J

2. **Secondary Forest**

Storages of organic matter (above and below ground biomass plus litter) not including soil. Area of secondary forest (regrowth of cut rainforest): 33,700 acres = 1.36 E8 m^2 (United Nations, 1975, p. 36). Dominica's secondary forest assumed to be quite similar to a Cadam tree plantation in Puerto Rico (Odum and Pigeon, 1970). Density and organic matter storage calculations were taken from the aforesaid plantation data as follows:

Ten tree crown diameters were averaged and the resultant average was halved to obtain the average radius. Multiplication by pi gave the average circular area under a tree

Footnotes for Table 9.2. continued

crown. Organic matter stored per tree: 30,718 g (Odum and Pigeon, 1970).

Average diameter = 13.9 ft = 4.24 m

average radius = 2.12 m

Tree crown area = (2.12 m)^2(3.1416) = 14.1 m^2

Organic matter stored in secondary forest

(30,718 g dry weight/14.1 m^2)(4.2 kcal/g)(1.36 E8 m^2)

(4186 J/kcal) = 5.23 E15 J

3. Cropland

Tree crop areas, including uncultivated areas and pockets on steep slopes: 26,000 acres and 62,180 acres respectively (United Nations, 1975, p. 45). Assuming that the uncultivated crop area has a biomass approximately half way between the mean and highest value of cultivated land, 7000 g/m^2 (Whittaker, 1975) and that cultivated tree crop land has a biomass value at the bottom of the same-range, 2178.6 g/m^2. Actual energy calculations for both types are:

Uncultivated crop area:

(62180 acres)(4046.8 m^2/acre)(7000 g/m^2)(4.2 kcal/g)

(4186 J/kcal) = 3.1 E16 J

Cultivated tree crop area:

(26,000 acres)(4046.8 m^2/acre)(2179 g/m^2)(4.2 kcal/g)

(4186 J/kcal) = 4.03 E15 J

Total actual energy for both types: = 3.49 E16 J

4. Soil

High quality organic soils are confined to the virgin forest, see footnote 1, Table 9.2. for area: 1.74 E8 m^2. Red-yellow clay loam was used as a representative soil because it's the closest approximation of Lesser Antilles soil types (Mason, 1922; Shillingford, 1972). Soil organic matter: 350 T/y (Brown and Lugo, Biotropica, Vol. 14, No. 8)

(350 T/ha)(1.74 E8 m^2)(1ha/4046.8 m^2)(2.26 E4 J/g)(1 E6 g/T)

= 3.4 E17 J

Footnotes for Table 9.2. continued

5. Limestone in old reefs and sea deposits (chemical potential)

Total volume of deposit: 5.0 E6 yd^3 = 3.82 E6 m^3 (United Nations, 1975, p. 83). Actual energy per weight: 611 J/g (See Table 2.1.). Density: 1.9 E6 g/m^3.

(Volume)(Density)(Actual energy/weight)

(3.82 E6 m^3)(1.9 E6 g/m^3)(611 J/g) = 4.43 E15 J

Limestone deposits represent many years of marine reef activity storing calcium carbonate. Energy storages involved in human activity such as secondary forest and cropland, are almost insignificant compared to natural storages, being several orders of magnitude smaller than those of soils or rainforests.

The increasing size and importance of storages as a function of the time required for building them is evident in Table 9.2. Human dominated subsystems, such as cropland or secondary forest, store far less energy than the rainforest since the latter has taken at least 500 to 1,000 years to build its structure of energy dense trees and soils. Biomass found in secondary forest has not concentrated much energy or grain structure in 10 to 30 years to have much value for combustion or furniture.

Aggregated overview

Further aggregating, Table 9.3. summarizes the flows that drive the economy directly and indirectly. These flows are also drawn in Figure 9.2. The main sources of work to the island's economy directly and indirectly are: water, imported fuels, imported goods and services and the drain of stored biomass in rainforests and soils.

Table 9.3. Summary flows for Dominica in Figure 9.3.

Letter in Figure	Item	Embodied solar energy E19 SEJ/y	Dollars E6 $/y
R	Renewable sources used, SEJ/yr (rain, chem.)	17.5	-
N	Nonrenewable sources flow within the country (SEJ/yr):		-
			-
	- N_o dispersed rural source (SEJ/yr)	37.1	-
	- N_1 concentrated use (SEJ/yr)	-	-
	- N_2 exported without use	-	-
F	Imported minerals and fuels (SEJ/yr)	1.66	-
G	Imported goods (SEJ/yr)	-	-
P_2I	Imported service (SEJ/yr)	9.34	-
I	Dollars paid for imports ($/yr)	-	39.6
E	Dollars paid for exports ($/yr)	-	9.4
P_1E	Exported services (SEJ/yr)	3.95	-
B	Exported products, transformed within the country (SEJ/yr)	9.14	-
X	Gross National Product ($/yr)	-	75.4
P_2	Ratio embodied energy to dollar of of imports (SEJ/$) (US)	2.37 E12 SEJ/US$	-
P_1	Ratio embodied energy to dollar of country and for its exports (SEJ/$)	8.7 E12 SEJ/US$	-

Footnotes for Table 9.3.

R Chemical potential energy of rain is the largest renewable energy source (footnote 3, Table 9.1): 1.75 E20 SEJ/y.

N_o Reduction of virgin forest in Dominica from 67% to 38% in 20 years (United Nations, 1975) corresponds to a 1.5% loss/y. Since regrowth of such high quality wood and soil biomass requires more than 150 years, they are nonrenewable resources within the time frame of the present economy.

Footnotes for Table 9.3. continued

Rural use of nonrenewable wood and soil, calculations:

(annual use %)(total embodied energy of virgin rain forest)

(0.015)(343 E19 SEJ) = 5.15 E19 SEJ/y

(annual use %)(total embodied energy of virgin rainforest soils)

(0.015/y)(2129 E19 SEJ) = 3.19 E20 SEJ/y

Total use of indigenous nonrenewable energy sources

= 3.71 E20 SEJ/y

N_1 There was little concentrated energy use.

N_2 Only 2% of the estimated 251 E6 board feet of virgin timber has been exported as lumber (United Nations, 1975), and the operations as of 1979 were negligible. Limestone deposits of 5 E6 cubic yards were similarly unexploited. Therefore, N_2, nonrenewable resource exports without internal use, were negligible.

F Total imported fuel embodied energies (footnote 12, Table 9.1): 1.66 E19 SEJ/y.

G Imported goods, according to preliminary calculations were only 8.5% of the embodied energy of imported services and thus were negligible.

P_2I Imported services: 9.3 E19 SEJ/y (footnote 11, Table 9.1).

I Dollars for imports: 34.6 E6 US$ (World Bank, 1981).

E Dollars from exports: 9.4 E6 US$ (World Bank, 1981).

P_1E Exported servies (P_1E):

(4.20 E12 SEJ/US $)(9.4 E6 US$) = 3.95 E19 SEJ/y

B Exported products: 9.14 E19 SEJ/y (see footnotes 7-9, Table 9.1).

Footnotes for Table 9.3. continued

X Gross National Product (X): 75.4 E6 US$. This is the sum of the gross domestic product (GDP): 45.4 E6 US$ (United Nations, 1975) plus export: 9.4 E6 US$ (World Bank, 1981) plus foreign aid: 12.6 E6 US$ (World Bank, 1981, p. 157) plus financing: 7.9 E6 US$ (World Bank, 1981, p. 11).

P_2 Ratio of the United States annual embodied energy flow to import dollars (P_2): 2.37 E12 SEJ/US$/y.

P_1 Ratio of Dominica's embodied energy flow to dollars of GNP:

$$P_1 = \text{Energy used/GNP} = \frac{R + N_o + N_1 + F + G + P_2 I}{75.4\text{ E6 US dollars}} =$$

$$= 8.7\text{ E12 SEJ/US\$}$$

Energy-Dollar ratio

The total energy used (Figure 9.3) was divided by the gross national product (GNP) in US dollars to obtain an energy/dollar ratio (P_1).

The Gross National Product (GNP) was estimated as the sum of the Gross Domestic Product (GDP) plus the money flows of exports, investments and foreign aid. The latter, foreign aid, was notably higher than normal in 1979 owing to special disaster relief for hurricane damage. Dominica's energy/dollar ratio is almost four times that of the U.S.A. Use of embodied energy storages of rainforest and soil was the large energy value generated by the work of subsistence farmers which was not recognized by dollar circulation figures.

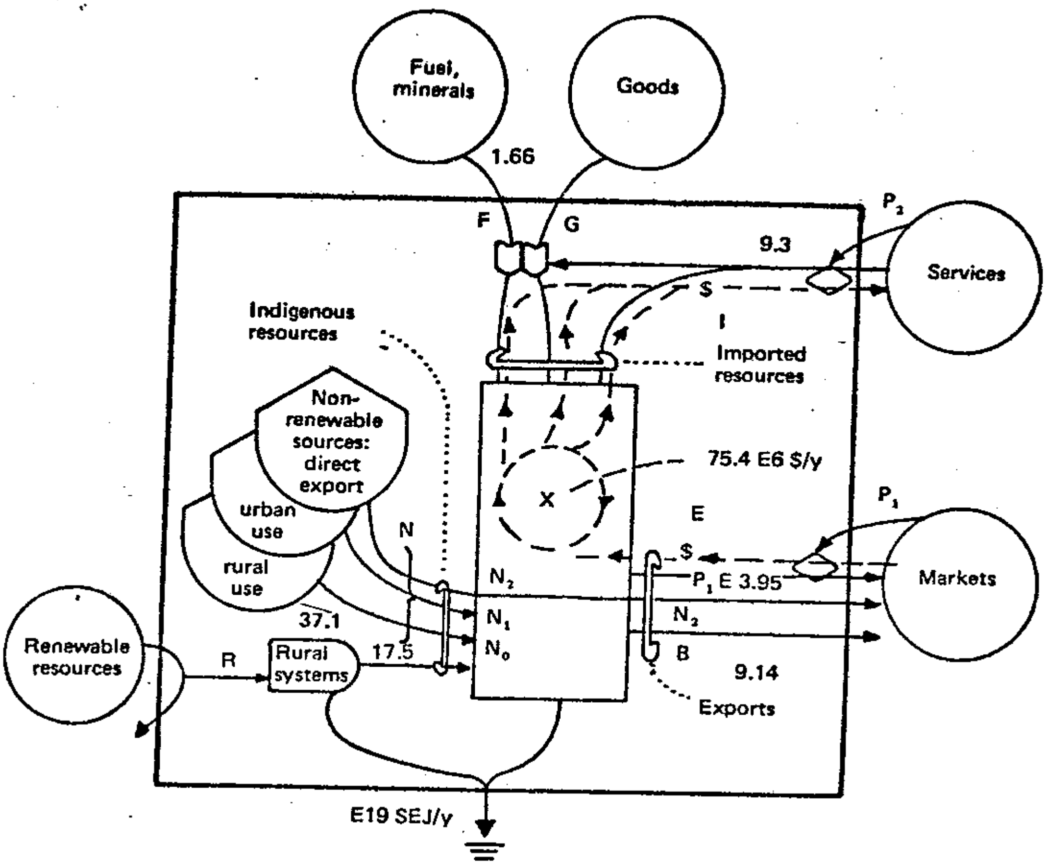

Figure 9.3. Summary diagram of the embodied energy flows of Dominica. An evaluation table is given as Table 9.3. Indices from these values are calculated in Table 9.4.

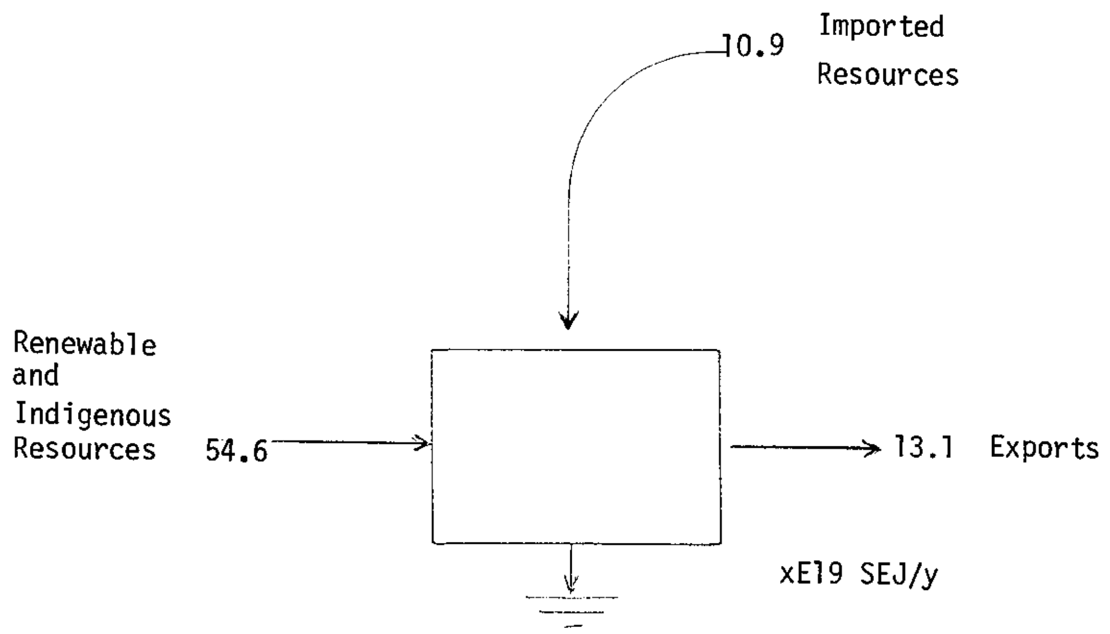

Figure 9.4 Summary diagram of the embodied energy flows of Dominica. Evaluations are given in Table 9.3 .

Energy Evaluation of the Trade Balance

International trade is included in Figure 9.2 and flows were evaluated in Figure 9.3. Export flow was mainly the sum of embodied energies in the two exporting subsystems, bananas and coconuts, plus those of fruits, vegetables and juices. The embodied energy of the import services was calculated based on an energy/dollar ratio (P_2) estimated for the various nations exporting to Dominica. The embodied energy of imported goods was found in preliminary analysis to be an insignificant fraction of imported services.

The balance of money payments showed a four-fold higher outflow than inflow. The difference is composed of investments, foreign aid and loans. However, the balance of embodied energy flows showed 1.5 times greater inflow than outflow.

National Overview Ratios

Table 9.4 lists various ratios calculated from data in Table 9.3 and Figure 9.4. These include ratios of outside to indigenous sources, export/import energies, fuel use/environmental energies, energy/person, energy/area and carrying capacities for the whole island. These ratios are useful both for predictions and international comparisons.

Subsystems

Two subsystems were analyzed as they were the most significant embodied energy exports from Dominica: 1) bananas, 2) coconuts and derivative products, copra, coconut oil and soap.

Table 9.4. Indices using embodied energy for overview of Dominica.

Item	Name of index and expression, see Figure 9.3		
1	Renewable embodied energy flow	R	1.75 E20 SEJ/y
2	Flow from indigenous non-renewable reserves	N	3.71 E20 SEJ/y
3	Flow of imported embodied energy	$F+G+P_2I$	1.10 E20 SEJ/y
4	Total embodied energy inflows	$R+N+F+G+P_2I$	6.56 E20 SEJ/y
5	Total embodied energy used, U	$U=N_o+N_1+R+F+G+P_2I$	6.56 E20 SEJ/y
6	Total exported embodied energy	$B+P_1E$	1.31 E20 SEJ/y
7	Fraction of embodied energy used derived from home sources	$(N_o+N_1+R)/U$	0.83
8	Exports minus imports	$(N_2+B+P_1E)-(F+G+P_2I$	2.09 E19 SEJ/y
9	Ratio of exports to imports	$(N_2+B+P_1E)/(F+G+P_2I)$	1.19
10	Fraction used, locally renewable	R/U	0.27
11	Fraction of use purchased	$(F+G+P_2I)/U$	0.17
12	Fraction used that is imported service	P_2I/U	0.14
13	Fraction of use that is free	$(R+N_o)/U$	0.83
14	Ratio of concentrated to rural	$(F+G+P_2I+N_1)/(R+N_o)$	0.20
15	Use per unit area (7.5 E8 m^2)	U/(area)	8.75 E11 SEJ/m^2
16	Use per capita (80,000 population)	U/(population)	8.2 E15 SEJ/per.
17	Renewable carrying capacity at present living standard	(R/U) (population)	21,600 people
18	Developed carrying capacity at same living standard	(R U) (population)	172,800 people
19	Ratio of use to GNP (energy-dollar ratio)	P_1 = U/(GNP)	8.70 E12 SEJ/$

Bananas

A subsystem diagram for bananas is given as Figure 9.5 and evaluations are in Table 9.5 for those bananas exported.

Bananas have dominated both agricultural land use and agricultural export revenues for decades in Dominica. The apparent small scale, low energy production system has required minor fossil fuel inputs when compared to service and the natural input of rain. However, subsistence farming consumes a large amount of embodied energy in the form of rain forest and soil biomass. Comparison of total embodied energy to total actual energy yielded an energy transformation ratio of 5.3 E5 SEJ/J. The embodied energy of exported bananas was 2.2 E19 SEJ/y or 24.7% of agricultural exports.

Coconuts and derivative products

A subsystem diagram for coconut agriculture and copra processing is given in Figure 9.6 and the evaluations are in Table 9.6.

Land use for coconut agriculture has been a fraction, about a third, of that for bananas. However, the investment in copra processing facilities and the annual use of large amounts of fossil fuel relative to other agricultural products makes coconut oil and products the highest embodied energy export. The large increases in embodied energy incurred with additional fossil fuel input, are evident in Figure 9.5. The differences in the embodied energies between coconuts, coconut oils and derivative soaps are ten and thirty-fold respectively. The

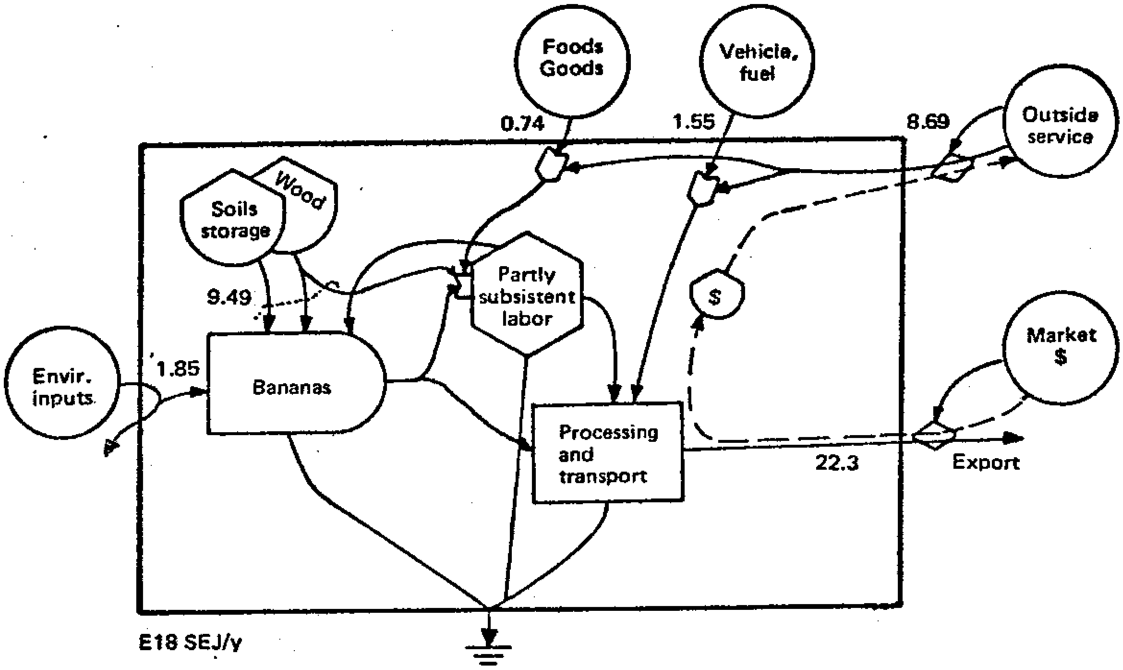

Figure 9.5. Energy flows in low energy banana plantings of Dominica.

Table 9.5. Evaluation of banana agro-ecosystem of Dominica.

Footnote.	Item	Actual energy J/y	ETR SEJ/J	Embodied solar energy E18 SEJ/y
1	Rain transpired	1.20 E14	1.54 E4	1.85
2	Soil and wood used	2.72 E14	3.49 E4	9.49
3	Goods, food	-	-	0.74
4	Service, 3.66 E6 US$	-	2.37 E12/$	8.69
5	Fuel used	2.53 E13	6.6 E4	1.55
6	Exported bananas	4.25 E13	5.25 E5	22.3

Footnotes for Table 9.5

Low energy banana agro-ecosystems in Dominica

Since farms greater than 5 acres in size occupy 60% of all farm agreage, and total banana acreage was a dispersed 39,000 acres in 1970 (Marie, 1979), then subsistence farms are taken to be 15,600 acres (40% of the total). A 3 year cultivation rotation implies that 1/3 of this acreage is in use at any time, so (0.3)(15,600) = 5140 acres = 2.13 E3 hectares.

1. Solar equivalents of transpired rain

(rain transpired per area)(area)(Gibbs free energy per weight)

(3.05 m rain)(0.39 transpired)(5140 acres)(4.05 E3 m^2/A)

(4.94 J/g)(1 E6 g/m^3) = 1.20 E14 J/y

2. Soil and wood use

Grams/square meter calculations are taken from footnote 2, Table 9.2. A three year crop rotation means that in effect 1/3 of the 2,176 g/m^2, or 762.2 g/m^2, is consumed each year. Forest organic matter combustion value: 4.2 kcal/g (Odum et al., 1983).

(2.13 E3 ha)(762.2 g/m^2)(1 E4 m^2/ha)(4.2 kcal/g)

(4186 J/kcal) = 2.72 E14 J/y

Footnotes for Table 9.5. continued

3. Goods, food

Portions of national imports estimated from the proportion that banana sales is of total national sales (40% of national sales, so 0.4 x 9.2 E6 US $ = 3.6 E6 US $).

$$\frac{(3.6 \text{ E6 US \$})}{(39 \text{ E6 US \$})} (8.0 \text{ E18 SEJ/y}) = 7.39 \text{ E17 SEJ/y}$$

4. Services from sales

As indicated in Figure 9.3, money received for banana export may be used to evaluate the services external to the banana system. In 1978 37,016 t at 247.6 $US/t

(0.4)(3.7 E4 t)(2.476 E2 $/t) = $3.66 E6 (1978)

5. Fuels used

Fuel proportion that banana sales are of total sales

$$\frac{(3.6 \text{ E6 \$})}{(\$39 \text{ E6})} (2.52 \text{ E14 J/g}) = 2.35 \text{ E13 J/g}$$

6. Bananas exported

37,016 t in 1978 (World Bank,1981). Since subsistence farms occupy 40% of all farms, then 14,806 metric tons exported originated from subsistence farms. Fresh bananas with 1.040 kca./g in flesh; flesh is 2/3 of total banana (Liu, 1980).

(weight of bananas)(energy content)

(1.48 E4 t/y)(1 E6 g/t)(1.04 kcal/g)(0.66)(4186 J/kcal)

= 4.25 E13 J/y exported from banana plantings

Total embodied energy sum of inputs (Figure 9.3)

$$\frac{1.93 \text{ E19 SEJ/y}}{4.25 \text{ E13 J/y}} = 5.25 \text{ E5 SEJ/J}$$

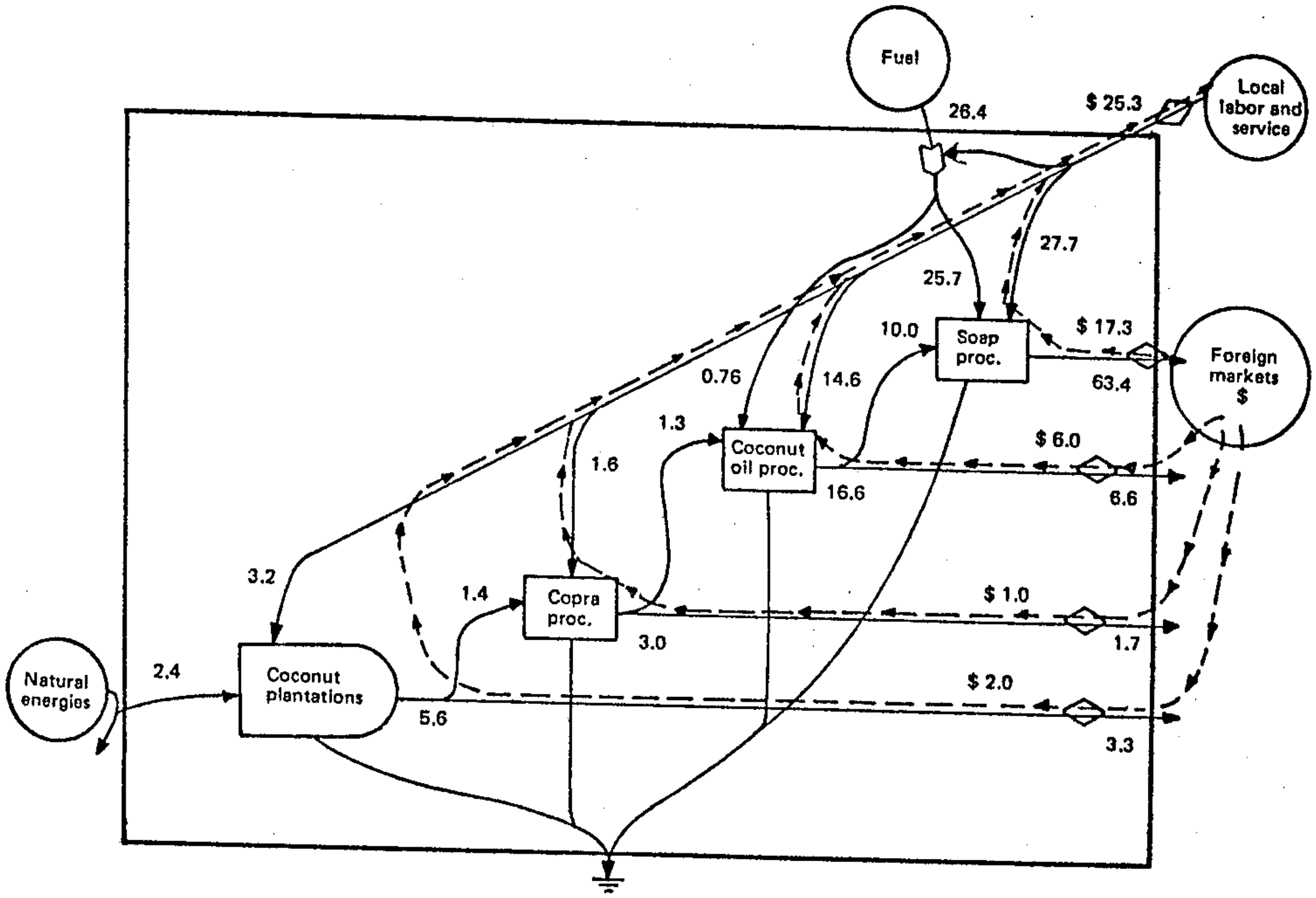

Figure 9.6. Summary diagram of coconuts and derivative products industry in Dominica in E18 SEJ/y and E5 U.S.

Table 9.6. Flows for evaluationg the embodied energy of coconuts and derivative products

Foot-note	Item	Actual energy J/y	Energy transforma. ratio SEJ/J or SEJ/$	Energy solar energy E18 SEJ/y
1	Natural energy	1.57 E4	1.54 E4	2.4
2	Labor handling coconuts, 3.7 E5 US$	-	1.6 E13 /$	5.9
3	Labor for copra 1.0 E5 US$	-	1.6 E13 /$	1.6
4	Labor handling oil 9.12 E5 US$	-	1.6 E13 /$	14.6
5	Fuel for oil dehydration	1.15 E13	6.6 E4	0.76
6	Labor for making soap, 1.73 E6 US$	-	1.6 E13 /$	27.7
7	Fuel for soap process	3.9 E14	6.6 E4	25.7
8	Coconut products			
	coconuts	1.8 E14	3.4 E4	3.4
	copra	4.4 E13	6.9 E4	3.0
	oil	1.4 E14	1.2 E5	16.6
	soap	8.85 E13	7.2 E5	63.4

Footnotes for Table 9.6.

1. Solar equivalents of transpired rain

   (3.0 meters rain)(0.39 transpired)(6,725 acres)(4.05 E3 m^2/A)

   (4.94 J/g)(1 E6 g/m^3) = 1.57 E14 J/y

2. Labor of harvesting and handling coconuts

   Production cost/acre: 187.89 EC$ = 69.59 US$ (J/ Marie, 1979).
   Yield/acre: 1.3 metric tons (United Nations, 1975); 1979 coconut export: 703 metric tons (World Bank, 1981).
   Total acreage = 703 metric tons/1.3 m.t./acre = 537 acres.

   (69.59 US$/acre)(537 acres) = 3.7 E5 US$.

3. Copra export revenues 1.05 E5 US$
   World Bank, (1981)(see Table 3.2).

Footnotes for Table 9.6 continued

4. Labor of handling oil

1979 coconut oil production (World Bank, 1981) = 396 E3 gal. = 1663 E3 liters x (0.8679 g/l) = 3.62 E3 m.t.
Total US purchases of coconut oil in 1979 divided into total price paid, yield a figure of 251.80 US$/metric ton.
Dominica's energy/dollar ratio: 1.6 E13 SEJ/US$ (Table 9.3).

(3.62 E3 metric tons oil)·(US $251.80/m.t.) = 9.12 E5 US$

5. Fossil fuel dehydrating coconut oil

Coconut oil is made more saleable by driving off any remaining water by raising the oil temperature to 110°C for several hours. 0.540 kcal/g is the dehydration energy of water molecules not chemically bonded (bonds of hydration) to the molecules of oil A multiplication factor of 1.4 was used to account for the sixty percent reduction during the dehydration process.

Process heat energies

= (3.62 E3 m.t.)(1 E6 g/m.t.)(.54 kcal/g)(1.4)(4186 J/kcal)

= 1.15 E13 J/y

6. Labor for production of soap

The World Bank (1981) in Table 3.2, p. 143 lists toilet and laundry soap export as 2,182 metric tons at a price of US$ 794.7/m.t. for a total of US$ 1,734,035 in export revenue.

7. Fuel for soap processing

Fuel use for soap processing on Dominica assumed to be similar to US production of soap is (30.1 kg/person)(230 E6 people) = 6.92 E9 kg and requires 2.95 E11 kcal. Fossil fuel use per kg = (2.95 E11 kcal)/(6.92 E9 kg) = 42.6 kcal/kg.

(42.6 kcal/kg)(4186 J/kcal)(1 E6 kg/T)(2182 T) = 3.9 E14 J/y

8. Coconuts and derivative products exported

Coconuts

1979 coconut export weight: 703 T (World Bank, 1981, p. 143)
Coconut production in 1979: 11,721 (World Bank, 1981, p. 174).
Coconut composition: 28% meat, 72% fiber (Encyclopedia Brittanica, 1974, p.472).

Footnotes for Table 9.6 continued

Actual energy calculations:

Fiber - (0.72)(11,721 T)(1 E6 g/T)(4 kcal/g)(4186 J/kcal)

= 1.4 E14 J

Meat - (0.28)(11,721 T)(0.5 water)(1. E6 g/T)(4.94 J/G)

= 8.1 E9 J

(0.28)(11,721 T)(0.3 oil)(1 E6 g/T)(8.816 kcal/g)(4186 J/kcal)

= 1.8 E14 J

Labor embodied energy: 5.9 E18 SEJ/y (Footnote 2, Table 9.6).
Natural embodied energy:

(540 acres)(3 m rain/y)(4.05 E3 m^2/A)(4.94 J/g)(1 E6 g/m^3)

= (1.26 E13 J)(1.54 E4 SEJ/J) = 1.95 E17 SEJ/y

Total embodied energy in coconuts: 6.1 E18 SEJ/y

Energy transformation ratio using solar equivalents of rain and labor used:

(3.4 E18 SEJ/y)/(1.8 E14 J/y) = . 3.4 E4 SEJ/J

Copra

1979 export: 574 T for 0.1 E6 US $; 1979 total copra production: 2704 T (World Bank, 1981, p. 143, 175). Average coconut ouputs worldwide: 4500 nuts/acre, 30 nuts/10 lbs. copra (Encyclopedia Brittanica, 1974, p. 472). Rain and transpiration data (see Footnote 3, Table 9.1). Embodied energy calculations:

Natural (2704 T)(1 E3 kg/T)(2.2 lbs./kg)(30 nuts/10 lbs. copra)

(1 acre/4500 nuts)(3 m rain)(0.39 transpired)

(4.05 E3 m^2/acre)(4.94 J/g)(1 E6 g/m^3)(1.54 E4 SEJ/J)

= 1.4 E18 SEJ/y

Labor (0.1 E6 US $)(1.6 E13 SEJ/US $)

= 1.6 E18 SEJ/y

Total embodied energy of copra: = 3.0 E18 SEJ/y

Energy of fatty acids in coconut oil: 9.4 kcal/g (Mitchell, 1979, p. 81).

Footnotes for Table 9.6 continued

Composition of copra: prepressed copra - water (5%), oil (70%), fiber (25%), post processed copra - protein (21.3%), oil (7%), fiber (71.7%)(Encyclopedia Brittanica, 1974). Actual energy of protein: 1520 kcal/kg (Mitchell, 1979). Actual energy of fiber: 4 kcal/g (Odum et al., 1983). Actual energy calculations:

Protein (0.21)(2704 T)(1 E3 kg/T)(1520 kcal/kg)(4186 J/kcal)

= 3.66 E12 J

Oil (0.07)(2704 T)(1 E6 g/T)(9.4 kcal/g)(4186 J/kcal)

= 7.45 E12 J

Fiber (0.72)(2704 T)(1 E6 g/T)(4 kcal/g)(4186 J/kcal

= 3.25 E13 J

Total actual energy of copra: = 4.35 E13 J

Energy transformation ratio using solar equivalents of rain and labor used:

(3.0 E18 SEJ/y)/(4.35 E13 J/y) = 6.9 E4 SEJ/J

Coconut Oil

Embodied energy of fuel used for oil processing: 7.6 E17 SEJ (see Footnote 5, Table 9.6). Embodied energy of labor: 1.46 E19 SEJ/y (see Footnote 4, Table 9.6). Dividing total copra oil content (0.7 x 2704 T = 1893 T oil) into total embodied energy of copra/y yields 1.6 E15 SEJ/T oil. Multiplying 800 T oil times the latter gives 1.28 E18 SEJ/y embodied energy of copra to oil industry. Total embodied energy:

(7.6 E17 SEJ) + (1.46 E19 SEJ/y) + (1.28 E18 SEJ/y) =

= 16.6 E18 SEJ/y

Total actual energy:

(3.62 E3 T)(1 E6 g/T)(9.4 kcal/g)(4186 J/kcal)

= 1.42 E14 J/y

Energy transformation ratio using the embodied energies of labor, fuel and oil derived from copra:

(16.6 E18 SEJ/y)/(1.42 E14 J/y) = 1.16 E5 SEJ/J

Footnotes for Table 9.6. continued

Soap

Embodied energy of fuel for soap processing: 25.7 E18 SEJ/y (see Footnote 7, Table 9.6). Embodied energy of labor for soap processing: 27.7 E18 SEJ/y (Footnote 6, Table 9.6). Embodied energy of coconut oil: 1.0 E19 SEJ/y (percentage of total oil production used for soap manufacture). Total embodied energy of soaps:

(1.0 E19 SEJ/y) + (25.7 E18 SEJ/y) + (27.7 E18 SEJ/y) =

= 63.4 E18 SEJ/y

Actual energy of lauric acid (predominant constituent of oils used to make soap): 8.816 kcal/g (Weast,1974). Total production of toilet and laundry soaps: 2398 T (World Bank, 1981, p. 175). Actual energy calculations:

(2398 T)(1 E6 g/T)(8.816 kcal/g)(4186 J/kcal) = 8.85 E13 J

Energy transformation ratio using the embodied energies of labor, fuels and coconut oil:

(63.4 E18 SEJ/y)/(8.85 E13 J/y) = 7.2 E5 SEJ/J

SEJ/y or 68% of agricultural imports.

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energy transformation ratio, 3.4 E4 SEJ/J, is 6% of that of bananas, which indicates that banana cultivation uses much more high quality energy(biomass of rainforest wood and soils) than coconut cultivation. The embodied energy of exported coconuts and derivative products was 7.5 E E19 SEJ/y or 68% of agricultural imports.

Fruits, Vegetables and Juices

The acreage devoted to the cultivation of fruits and vegetables compared to that for coconuts and bananas, was relatively minor. The embodied energy of fruit, vegetable and juice exports was 6.4 E18 SEJ/y or 7.0% of agricultural exports compared to 69% and 24% for coconut products and bananas respectively.

DISCUSSION

Main Basis for the Economy

The overview diagram in Figure 9.3 and the indices in Table 9.4, provide an overview of the basis of the economy of Dominica in energy terms. The main basis of the economy is the indigenous use of environmental energies, particularly the stored energies of rainforest woods and soils. By contrast the purchased embodied energies of imports are only 10% of the entire energy basis (item 11, Table 9.4).

The Monied Economy

The circulation of money in gross national product (Figure 9.3; Table 9.3) was about 69.6 million dollars per year, of which 39.6 million dollars per year was paid for imports (57%). Only 9.4 million dollars was received for exports (14%), the rest of the income coming from loans, investments, foreign aid , etc.

Dominica's trade balance might appear less dependent on foreign money sources in years other than 1979 when severe hurricane damange to export crops brought abnormal amounts of disaster relief and required special reinvestment in the capital assets of plantation and hotels and the power distribution network.

Previous Emphasis on Bananas

Part of the difficulty in developing the economy of Dominica arose when efforts to make the banana export industry were not very successful. Note the low energy bananas system in Figure 9.4 compared to that of Taiwan (Pimentel, 1978). Bananas are industrialized with more difficulty in Dominica's steep terrain, torrential rains, and poor transportation facilities as compared with economic competition from Ecuador and elsewhere. Earlier there were special trade prices with Great Britain and investment money went primarily into attempts to make the banana export industry competitive.

From the Second World War until Britain's joining of the European Common Market Dominica's banana export was supported by lower tariffs into the U.K. Despite this protection, more efficient producers (such as Ecuador) managed to hold export prices to a level which left Dominica's producers with little profit, 3 cents per pound (J. Marie, 1979). Joining the EEC in 1973 has forced the U.K. to dismantle the support structure and expose Dominica to open market pressures which may finally depress the banana industry to much lower levels. By 1980 banana output was at 70% of 1976 levels.

Present Self-Sufficiency

Since much of the economy is not accompanied by money, the evaluation based on energy provides a more favorable view of life in Dominica. On an energy basis 83% (Table 9.4, Item 7) of the economy is derived from home sources. The embodied energy of exports and imports is nearly balanced.

However, much of the environmental energy basis is being used in a nonrenewable way because of loss of soils and rainforest trees used faster than their regrowth. Almost 40% of Dominica's high quality storages in rainforest and soils have been drained in the last 20 years to maintain present economic activity. It appears that Dominica's energy basis for self-sufficiency is declining and dependence on external sources will increase ever faster. Exhaustion of natural storages deplete the basis for foreign investment and depress the economy. However, when export cropping in the highlands no longer pays, rainforests may have a chance to rebuild wood and soil storages for another cycle.

Economic Growth Potential

Economic development often proceeds with investments to draw resources of the environment into commerce ultimately increasing the input of fossil fuels and fuel based goods and services adding to the indigenous energy resources involved. This process is little developed in Dominica where the ratio of concentrated to rural energy is only 0.20. The ratio of electrical energy flow to total energy flow is only 0.0014% compared to values for New Zealand, 0.15; Spain, .22; and the USSR, 0.194.

Although the potential for attracting invested foreign embodied energy inputs is large, so far this process has been unsuccessful in generating exports that can compete well in international markets.

Embodied Energy-Dollar Ratio

The embodied energy-dollar ratio for Dominica is four times that of the United States, but 1/4 that of Liberia (Chapter 7). The ratio shows in another way how much of the system is outside the economy of circulating money. Anyone importing from Dominica to the United States obtains four times more embodied energy than is in the buying power of the dollar spent in the United States. Consequently, efforts to export raw products such as bananas, do not stimulate the home economy as much as complete processing which draws more dollars into the economy per embodied energy invested. Trade arrangements judged on the basis of dollar exchanges benefit the country with the lower energy dollar ratio.

Energy Density

In Dominica, the embodied energy use/square meter is 8.8 E11 SEJ/m^2 (Table 9.4, Item 15). This ratio is about twice that of the U.S.A. and Liberia and reflects the enormous environmental energy flow per person contributed by the use of virgin forest and soil storages which was 56% of the total energy use in Dominica (Footnote 10, Table 9.1). On a per area basis, this flow dwarfs the fossil fuel energy use in the U.S.A. and the large natural energy flows in Liberia.

Energy per Person

Fuel use per person in Dominica, 2.08 E14 SEJ/y, is approximately 35% of the of the United States, 5.7 E14 SEJ/y. A more incisive measure of the energy standard of living might be total embodied energy per person (Item 16, Table 4). By this measure Dominica, 8.2 E15 SEJ/y, is 41% of the U.S.A., 2.0 E16 SEJ/y, and 31% of Liberia, 2.6 E16 SEJ/y.

Usually the resource inputs per person are indicated with fuel energy per person or other indices of commerce and industry. At least in an overall sense, Dominica's flows of renewable energies give them a comparable standard of living. The embodied energy in annual income (474 US$/y, World Bank, 1981), is only 55% of the total embodied energy use per person (7.58 E15 SEJ/1.39 E16 SEJ).

Carrying Capacity

The 1979 population was 82,699 people. The renewable carrying capacity or population level sustainable were Dominica to exist only on its renewable energy inputs (after rain forests are used) would be 21,600 people.

At the present rate of wood and soil use, the remaining rain forests will be used up in 60 years. During the period of time before, investments may be attracted and populations supported which will not be supportable later. Dominica is self-sufficient now, but on a declining resource. Changed land uses with land rotations and fertilizers may be needed to provide an alternative system to rain forest use.

The developed carrying capacity ratio in Table 9.4, indicates the carrying capacity if the economic development were that of the most industrialized nations, with eight times more embodied energy use than supplied from local renewable sources. For

Dominica with people at their present standard of living, the carrying capacity would be 172,800 people, much larger than the present population of 80,000. Unless it declines , the annual population growth rate, 1.6%/y (CIA,1977) will result in less energy per person if the economic developments that allow outside energy imports are not found.

Hydroelectric Potential

Part of balanced development is providing low cost electric supplies to all parts of a country. The interaction of high rain input and strong mountain uplift has created over three hundred rivers on Dominica. Many of these rivers have sufficient energy to drive turbines or machines on a fairly continuous basis without the necessity of maintaining a large water area uphill. Without the expense of building large dammed reservoirs, relatively inexpensive hydrpower could be established. Whether this energy drives mills directly or turbine dynamos for electricity will depend on the type of manufacturing capacity national policy pursues. Such a rurally available power source could provide the capacity to process agricultural products locally and thus bring more jobs and embodied energy to the local economy. Renewable hydropower may be available long after fossil fuels become too expensive. Developing such capacity will contribute to Dominica's immediate and future vitality.

Whereas geothermal energy is apparently available in hot spring areas of Dominica, the hydroelectric potentials require less special technology and are more renewable.

Renewable Forest Options

Tropical forest plantations develop useful light density roundwood products with a 20 year rotation especially if fertilizers are applied, although the products are inferior for many purposes as long as virgin forest wood is available.

Letting natural processes restore and regenerate soils and forests is the normal pattern on Dominica and elsewhere. In the shifting agricultural patterns, over 10 to 20 years are needed to develop appropriate soil conditions for another two or three years crop. This pattern may be improved with additional inputs, improved diversity of crops, fertilizers, etc.

For rugged watersheds and high lands with highest rainfalls, a longer rotation of 100 years may allow high quality timber at little cost, providing trees can receive protection and gene pools can be retained in clusters to provide seeding for fast forest regeneration.

Perhaps through import of exotics, plantations of high quality botanical products, pharmaceuticals, etc., not in competition with other areas, may increase the conversion of the large embodied energies of Dominica into means for economic development.

Developing a high diversity of tropical tree crops for local consumption could help local standards of living by routing the embodied environmental energies into human use.

Future

The unusual energy signature of Dominica provides a challenge to couple the economy of humans to the exceptional flows of water, uplifting lands, tropical growing conditions, and tropical seas. If more of the world's tourists can learn the fascination of seeing the best preserved rainforest island in the hemisphere, their funds may help to maintain the economic balance to help preserve some of the virgin forests. The future for Dominica is more promising than for some dry desert islands already over-populated.

BIBLIOGRAPHY

Anderson,J.W.(1980) *Bioenergetics of Autotrophs and Heterotrophs* .Edward Arnold pub.

Bailey,A.E.(1945) *Insuatrial Oil and Fat Products* .New York:Wiley-Interscience.

Bayley,Zuchetto,Shapiro,Man and Nessel(1977)"Energetics and Sytems Modeling: A Framework Study for Energy Evaluation of Alternative Transport Models".U.S. Army Engineers Report, IWR Contract Report 77-10. Fort Belvoir, Virginia.

Brady,N.C.(1974) *The Nature and Properties of Soils* .New York:MacMillan.

Brown,M.T.(19)"Energy Basis in Urban and Regional Hierarchies", PhD Dissertation for the Dept. of Environmental Engineering, College of Engineering, University of Florida, Gainesville, Florida.

Brown,S.,Lugo,A.(1982)"The Storage and Production of Organic Matter in Tropical Forests and their Role in the Global Carbon Cycle" Biotropica,Vol.14,No.3:pp.161-187.

Burnett,M.S.(1978)"Energy Analysis of Intermediate Technology Agricultural Systems", MS Thesis for the Dept. of Environmental Engineering,College of Engineering,University of Florida, Gainesville, Florida.

C.I.A.(1977) *National Basic Intelligence Factbook* , Office of Geographic and Cartographic Research, Central Intelligence Agency, Washington,D.C.

Encyclopedia Brittanica(1973) Vol.13 Chicago:W.Bentson.

FAO(1979) *1978 Fertilizer Yearbook* Rome:Food and Agriculture Organization of the United Nations.

Fluck,R.C.and C.D.Baird(1980) *Agricultural Energetics* Westport, Connecticut:AVI Pub. Co..

Gross,M.(1972) Oceanography - A View of the Earth Englewood Cliffs,N.J.: Prentice-Hall.

Hughes,L.A.(1952)"On the Low Level Wind Structure of Tropical Storms",J. of Meteorology,Vol.9:422-428.

Lackey,R.,Nielsen,L.(1980) Fisheries Management New York:Halstead Press.

Lugo,A.and Brown,S.(1981)"Tropical Forests of the Carribean", Ambio, Vol.10, No. 6,pp.318-325.

Marie,J.M.(1979) Agricultural Diversification in a Small Economy-The Case for Dominica , Occasional Paper No. 10. Cave Hill, Barbados: Institute of Social and Economic Research, University of the West Indies.

Mason,T.G.(1922)"The Elal Signifigance of Soil Shrinkage", West Indian Bulletin,Vol. 19,No. 1.

Mitchel,R.(1979) The Analysis of Indian Agro-Ecosystems ,Interprint, New Dehli, India.

Newell et al.(1977) The General Circulation of the Tropical Atmosphere Vol.1 .Cambridge,Mass:MIT Press.

Odum,E.,Gaeme Scott, and H.T. Odum(1980) Energy System for New Zealand Christchurch, New Zealand:Joint Centre for Environmental Sciences, University of Canterbury.

Odum,H.T.(1983) Systems Ecology New York:J. Wiley.

Odum,H.T.(1983)"Energy Analysis of the Environmental Role in Agriculture"(in press).

Odum,H.T.et al.(1983) A Manual for Using Energy Anatis for Plant Siting -Report to the Nuclear Regulatory Commision, Contract NRC-04-77-123. Springfield,VA: National Technical Information Service.

Odum,H.T.,Odum,E.(1981) Energy Basis For Man and Nature ,McGraw-Hill Book Company,N.Y..

Odum,H.T.,Pigeon,R.F.(1970) A Tropical Rain Forest -A Study of Irradiation and Ecology at El Verde,Puerto Rico. Division of Technical Information, U.S. Atomic Energy Commision.

Pimentel,D.and M. Pimentel(1979) Food,Energy and Society New York:Hallstead Press.

Pimentel,D.ed.(1980) Handbook of Energy Utilization in Agriculture Boca Raton:CRC Press.

Riehl(1979) Climate and Weather in the Tropics New York:Academic Press.

Sclater,J.G.,G.Taupart and D.Galson(1980)"The Heat Flow Through the Oceanioc and Continental Crust and the Heat Loss of the Earth" Rev. of Geophysics and Space Physics 18:269-311.

Sellers(1965) Physical Climatology Chicago:University of Chicago Press.

Shillignford,J.D.(1972) The Major Agricultural Land Types in Dominica,W.I. and Their Potential For Development ,Cornell University Press, Ithaca,N.Y.

Slesser,M. and C.Lewis(1979) Biological Energy Sources New York: Halsted Press, J. Wiley and Sons.

Slesser,M.(1978) Energy in the Economy ,St. Martins Press,N.Y.

Snoeyink,V.L..,Jenkins,D.(1980) Water Chemistry New York:Wiley & Sons.

Strathan(1977) Earth Surface Sediment Transport Fairlawn,N.J.:Oxford University Press.

Todd,D.K. ed.(1970) The Water Encyclopedia .Port Washington,N.Y.: Water Information Center.

United Nations(1975) Dominica National Structure Plan New York:Office of Technical Cooperation of the United Nations.

United Nations(1977) 1977 Statistical Yearbookk , Dept. of International Economic and Social Affairs, Statistical Office.

United Nations(1981) 1980 Yearbook of International Trade Statistics Vol I and II. New York:United Nations.

U.S. Bureau of Census(1977) Census of Manufacturers . Washington,D.C.:U.S. Government Printing Office.

Weast,R. ed.(1974) Handbook of Chemistry andPhysics Cleveland,Ohio: CRC Press.

Whetten,J.T.(1962)"Geology of St. CroixU.S. Virgin Islands" PhD Dissertation,Princeton University, Princeton, New Jersey.

Whittaker,R.H.(1975) Communities and Ecosystems .New York:MacMillan.

World Bank(1981a) Economic Memorandum on Dominica , Report No.3368-DOM.Washington,D.C.:Latin American and Carribean Regional Office, World Bank.

World Bank(1981b) World Development Report 1981 , Oxford University Press.