THE APPROPRIATED CARRYING CAPACITY OF TOMATO PRODUCTION: COMPARING THE ECOLOGICAL FOOTPRINTS OF HYDROPONIC GREENHOUSE AND MECHANIZED FIELD OPERATIONS

By

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Abstract

Agribusiness advocates claim that modern agro-technology has led to higher per hectare yields. In particular, hydroponic greenhouse agriculture is advanced as a new and particularly productive approach to high output farming. This may contribute to the belief that agricultural land can be urbanized because human ingenuity is seemingly developing substitutes for the lost soil.

This thesis challenges this assumption by examining agricultural technology from an ecological perspective. It uses the concept of the ecological footprint (or appropriated carrying capacity) to compare the productivity of hydroponic agriculture with that of conventional open field operations. I assess and compare the biophysical inputs required by these operations to produce 1000 tonnes of tomatoes. These figures are then translated into corresponding land areas (in various categories) necessary to produce the required biophysical inputs. In contrast to common belief, hydroponic operations require 14 - 21 times more land than conventional open field operations to produce the same output (including the land directly occupied by the farms).

This case study demonstrates the merits of appropriated carrying capacity analysis for assessing progress toward sustainability. It shows that hydroponic agriculture is a prime example of apparent economic success which is, in fact, ecologically unsustainable. There is no reason for confidence that we can pave over our agricultural lands just yet! Finally, this study demonstrates that the apparent yields of hydroponic greenhouse agriculture are partially a reflection of underpriced resource inputs, a form of subsidy which is not sustainable.

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Chapter 1

Introduction

1.1 Problem Statement

Technological optimists believe that there are no practical constraints on food production (Simon 1981 pp. 67 - 69). For example, it is widely believed that industrialized hydroponic greenhouse farming can increase agricultural output (harvest) per hectare of land far beyond that of conventional field agriculture (see Defreitas 1992 p. 18 and Wall Street Journal, June 6, 1987 p. 20). This belief might be used to argue the superiority of industrial agriculture over traditional field cultivation and could be used to weaken arguments for conservation of our limited arable land. It is questionable, however, whether high-tech agriculture is actually more productive per unit of land than traditional field production. Hydroponic farming practice requires many energy and material inputs and the production of these inputs "appropriates" the production of additional land often in other parts of the world.

Turning to the present state of world agriculture and food security, we find a number of trends which make us apprehensive, including soil erosion, global climate changes and the explosion of human population. Rees states:

> Agriculture everywhere is increasingly constrained by ecological trends including loss of topsoil, excessive runoff, waterlogging and salting of soil by irrigation, falling water tables, farmland conversion, and now possibly climate change (Rees 1990a p. 110).

The problem of soil loss is critical as Pimentel et al. (1987) point out:

> Serious soil erosion is occurring in most of the world' major agricultural regions, ... Soil loss rates, generally ranging from 10 to 100 t/ha/yr on cultivated lands, are exceeding soil formation rates by at least tenfold (p. 277).

Due to severe soil loss, current world food production is threatened. According to Shah et al. (1985), "based on current worldwide soil loss, and projections for the period from 1975 to 2000, degradation of arable land will depress food production between 15 to 30 %" (cited in Pimentel et al. 1987 p. 278).

At the same time, human needs are growing rapidly. Rees and Brown warn us:

> If these data were adequate to aggregate for the world as a whole, it undoubtedly would show that sustainable world food output is now running well below consumption. The annual addition to world population, estimated at 88 million in 1988, is projected to reach 91 million in the early nineties. By the end of the decade, there will be nearly a billion more people to feed. In the two regions with the fastest population growth, Africa and Latin America, per capita grain production is falling. If action is not taken soon to reverse these declines, hunger and malnutrition will spread, and eventually food consumption for some will fall below the survival level (Brown 1988 pp. 7 - 8, cited in Rees 1990a p. 110).[1]

Despite the potential decline in global agricultural productivity and rising population, some may argue that high-tech agriculture will solve these problems and that therefore

[1] The current world population is 5.04 billion in 1987 (Teikoku Shoin Henshubu 1991). The United Nations (U.N.) estimate that the world population will reach 9.42 billion in 2025. Kuroda estimates that it will reach 10 billion in 2030 by using the U.N.'s estimate (Kuroda 1991). The U.N. estimate that the world population will be stabilized at 11 billion at the end of 21st century (Kuroda 1991). Sadik states that this figure may be 14 billion if the decline in birthrates is smaller than expected (1990, cited in Kuroda 1991). If these estimates are correct, 2 - 3 times more people have to be fed on this planet at the end of the 21st century.

we need not worry about the soil loss or the urbanization of arable land. The important question is, therefore, whether hydroponic greenhouses are really more productive than traditional field farming. More broadly, is high-tech agriculture really a clear-cut solution to this potential global crisis?

The correct answers to such questions are central to the survival of humankind. In particular, the issues addressed by this study are key for determining the future direction of agriculture, land-use, and development policies. The wisdom of humankind is now being tested. If we err, future generations will hold us to account for any resultant widespread hunger and malnutrition. We have to remember that once an environmental asset is degraded, its loss is essentially irreversible (see Inoue 1986).

1.2 Purpose

The primary purpose of this thesis is to investigate whether a heated hydroponic greenhouse can sustain higher productivity per unit area compared to traditional mechanized open field farming practice. The research is oriented to determining which system is actually more productive in an input-output framework on a land equivalent basis.

There are three sub-objectives.

1) to demonstrate the applicability of an ecological analytical framework to assess agricultural sustainability. I employ a new concept, Ecological Footprint (EF) or Appropriated Carrying Capacity (ACC) developed by Rees and Wackernagel at the University of British Columbia (UBC) in 1991 (Rees 1992, Rees and Wackernagel 1992) to show the true "ecological footprints" of agricultural practices.

2) to show an example of the conflicts between individual economic benefit and total social, ecological costs. These conflicts characterize the sustainability debate! (See Rees 1993c, Hara 1992).

3) to explore policy implications for sustainable agriculture and more generally for achieving a sustainable society.

1.3 Methods

In order to achieve the above purposes, I analyse and compare two hydroponic tomato greenhouses in Surrey, B.C. and two mechanized open field tomato farms in Spences Bridge and Cache Creek, B.C. I calculate their energy and material inputs and outputs using both the EF/ACC analysis and an economic analysis. Details are presented in Chapter 3.

1.4 Significance of the Work

A comparative case study of hydroponic greenhouse and open field tomato production is worth pursuing for the following reasons.

(i) Relationship to Previous Research

There have been no previous comparative analyses of the ecological footprints of alternative agricultural technologies. There have been several studies to examine the energy requirements of field agriculture. For example, Odum (1971), Hannon (1973), Leach (1975, 1976), Udagawa (1975), Green (1978), Smil (1979), Fluck and Baird (1980), Pimentel (1979, 1980, 1984), Stanhill (1980, 1984), Rambo (1984a, 1984b), Stout (1984, 1990), Gever et al. (1987), Helsel (1987), Martinez-Alier (1987), Cleveland (1991) and others have worked extensively on such energy audits. However, little has been reported on the energetics of heated greenhouse crop production and I am aware of only one published study on greenhouse tomato growing (Stanhill 1980). Certainly there is no previous empirical research on the energetics of greenhouse tomato production in British Columbia, which includes both energy directly consumed and embodied energy of the input materials.[2]

One of the few studies on the energetics of greenhouse crop production is "The Energy Cost of Protected Cropping: A Comparison of Six Systems of Tomato Production" by Stanhill (1980). He compared energy inputs, both direct and embodied, to six different types of tomato production in California, Israel, and England, namely mechanized and labour-intensive open field operations without protective cover, open field operations protected by plastic net roofs and by low plastic tunnels, unheated greenhouse and heated greenhouse operations. One of the cases is a heated greenhouse in England.

(ii) Uniqueness of This Study

This research, however, is distinctive from Stanhill's. First, his analysis is entirely focused on energetics, while my research uses the concept of Appropriated Carrying Capacity (ACC), to estimate the total ecological footprints of the competing technologies. Putting it simply, I convert energy inputs and embodied energy into their land-equivalents.

Second, Stanhill's greenhouses were standard heated greenhouses, whereas my samples are hydroponic greenhouses, which use no soil as plant beds.

Third, his research data are taken from *The U.K. Tomato Manual*, while my research is based on detailed primary data collected for typical cases. The empirical aspect of the research deserves attention also.

In addition, this research compares the conclusions from both an ecological analysis and economic analysis, and tries to demonstrate conflicts between the two.

Finally, the geographical context is unique. There is no documented research on hydroponic greenhouses either in Canada or the United States in terms of either energy

[2]This was confirmed through the interview with Professor Anthony Lau, Department of Bio-Resources Engineering at the University of British Columbia held on October 2, 1992, one with Professor Len Staley of the same department held on April 21, 1993, and one with Mr. Gordon Monk, President of the Western Biotech Engineering held on April 21, 1993.

analysis or ecological footprints.

(iii) Why Tomatoes?

The tomato is one of the most prevalent vegetables grown in greenhouses. Stanhill calls tomatoes "the most important protected food crop" (1980, p. 145). In B.C., tomatoes account for 44 % of all vegetable greenhouse crops by sales volume in 1991. Tomatoes have the largest share, followed by green peppers (30 %), cucumbers (23 %) and lettuce (3 %) (B.C. Ministry of Agriculture, Fisheries and Food 1991b). Therefore, discussion of greenhouse tomato production is a significant contribution to the debate on greenhouses in general.

Secondly, tomatoes play a key role in the North American diet. According to Stevens (1972, p. 90), the tomato is the top ranking contributor to North American's nutrient intake. The tomato's relative nutrient value is not high, but the quantity of tomatoes consumed, including both fresh and processed, is large. In fact, a tomato's relative nutrient value per unit mass is only ranked 16th among 39 major fruits and vegetables in the U. S. in 1970 (p. 89), but its production mass ranked 3rd (6 million tonnes), after potatoes being the first (16 million tonnes) and oranges being the second (7 million tonnes) (p. 88). Therefore, any findings for tomato production are significant to North American agriculture.

Chapter 2

The Concept of Ecological Footprint/Appropriated Carrying Capacity

2.1 Natural Capital: A Key Word for Sustainability

The primary purpose of this research is to assess the sustainability of agriculture, recognizing that maintaining adequate stocks of natural capital is fundamental to ecological sustainability. Since "Natural Capital" is an important prerequisite for sustainability, I would like to clarify what the concept means. There are various interpretations. For example, Barbier identifies natural capital very narrowly as commercially available renewable and non-renewable resources (1992). However, I feel that non-traded natural resources (e.g. the atmosphere and the ozone layer) and nature's functions and services (e.g. the forest's carbon dioxide absorption function) are important components of natural capital and that thus, broader interpretation is essential. I therefore agree with the following definition by Rees, and Wackernagel and Rees:

> Natural capital is not just an inventory of resources; it includes those components of the ecosphere, and the structural relationships among them, whose integrity is essential for the continuous self-production of the system itself. Indeed, it is this highly evolved structural and functional integration that makes of the ecosphere the uniquely livable "environment" it is for the very organisms it comprises (Rees 1990b, 1993). Geoclimatic, hydrological, and ecological cycles do not simply transport and distribute nutrients and energy but are among the self-regulatory, homeostatic mechanisms that stabilize conditions on Earth for all contemporary life-forms, including humankind (Wackernagel and Rees 1992).

2.2 The Constancy of Capital Stock Criterion for Sustainability

There has been an increasing recognition among most ecological economists and some neoclassical economists that sustainability requires constant capital stocks which are at least adequate to produce sustainable flows (income) sufficient to support the human population at a satisfactory material standard (constant stocks below this level will not sustain us). Of course if population or consumption is growing, the stocks must increase to maintain "adequate" flows (Repetto 1986, Daly and Cobb 1989, Daly 1989, Pearce and Turner 1990, Rees 1993). In essence, adherence to this criterion would require that each generation leave the next generation an undiminished stock of productive assets. There are two interpretations of the constant capital stock idea (adapted by Rees 1993 from Pearce et al. 1989):

a) each generation should inherit an aggregate stock of manufactured and natural assets no less than the stock inherited by the previous generation. This corresponds to Daly and Cobb's (1989) conditions for "weak sustainability";

b) each generation should inherit a stock of natural assets alone no less than the stock of such assets inherited by the previous generation. This is a version of "strong sustainability" as defined by Daly and Cobb (1989).

The first interpretation reflects the general assumption of neoclassical economics that natural and humanly created capitals are substitutes and that the former (e.g., forests) can rationally be liquidated through "development" as long as subsequent investment in the latter (e.g., machinery) provides an equivalent endowment to the next generation (Rees 1993). [1]

The second interpretation better represents the ecological principles than the first

[1] " 'Equivalent endowment' would be defined in terms of monetary value, wealth generation potential, jobs, and similar economic criteria. (It is worth noting that humankind has regrettably failed to achieve even the modest objectives of 'weak sustainability' in much of the world.)" (Rees 1993 p. 10)

one. Particularly, maintaining natural capital stocks recognizes the multifunctionality of biological resources everywhere, "including their role as life support systems" (Pearce et al. 1990). In this regard, "strong sustainability" recognizes that manufactured and natural capital are complements rather than substitutes in most production functions (Daly and Cobb 1989). For example, what can be substituted for the protective function of the ozone layer? Rees (1992) and Rees and Wackernagel (1992) and this study accept the "strong" definition based on biophysical assets alone.

To meet this constant capital stocks criterion, Rees (1990) suggests that for the foreseeable future, humankind must learn to live on the annual production (the "interest") generated by remaining stocks of natural capital.[2] The "interest" in this context can be equated with the "net primary production" of the ecosphere. Living on this "net primary production," i.e., on sustainable income flows rather than on capital becomes a precondition for sustainability.

EF/ACC is a tool for estimating, from a biophysical perspective, the amount of natural capital needed to sustain a given economy or industrial process. EF/ACC measures the constant natural capital stock required to support our economy in land equivalents. Details of EF/ACC will be discussed in the following sections.

[2]This concept is based on Hicksian (or sustainable) income, the level of consumption that can be maintained from one period to the next without reducing wealth (productive assets) (Rees 1993, see Hicks 1946 and Daly and Cobb 1989).

2.3 Definition of Ecological Footprint/Appropriated Carrying Capacity

Wackernagel and Rees define the Ecological Footprint (EF) or Appropriated Carrying Capacity (ACC) for a region as:

> the land (and water) area in various categories required exclusively by the people in this region
>
> a) to continuously provide all the resources they currently consume, and
>
> b) to continuously absorb all the waste they currently discharge.
>
> This land exists right now somewhere on the globe, although some appears to be borrowed from the past (e.g., fossil energy) and some is being permanently appropriated from the future (e.g., in the form of contamination, plant growth reduction through increased UV radiation, soil degradation, etc.). (Wackernagel and Rees 1992).

Accordingly, I define the Ecological Footprint (EF) / Appropriated Carrying Capacity (ACC) of agricultural operations (such as, hydroponic greenhouse, conventional mechanized farming, and so on) as follows:

> The sum of the occupied farmland and the land-equivalent of other inputs (energy, materials, etc.) required to produce a defined unit of crop per year, using defined agricultural technology.

2.4 Advantage of EF/ACC Analysis over Energy Analysis/Audit (EA)

(i) EF/ACC Analysis Looks at Natural Capital More Comprehensively

As mentioned, EF/ACC serves as a surrogate for several ecological dimensions of natural capital. Energy Analysis (EA), however, is unidimensional, focusing exclusively on energy. EA emphasises inputs of commercial energy, i. e., fossil fuels (Murota 1979

p. 141) and ignores the contribution of the functional integrity of ecosystems to economic processes. In other words, EA identifies fossil fuels as a limiting factor for the economy.

The EF/ACC analysis considers the bioproductivity of ecosystems (land equivalents) in addition to the structural and functional relationships among components of the ecosphere as limiting factors of economic activity. EF/ACC, therefore, raises concerns about changes in the ecological conditions, such as climate change, the depletion of the ozone layer, and so on that threaten ecosystems production. As these factors change, bioproductivity may change, and this would be reflected in EF/ACC computations. Hence, EF/ACC is an ecological aggregate indicator of sustainability.

(ii) Land as a Limited Resource

Energy Analysis (EA) focuses on fossil fuel consumption because of the limited and nonrenewable features of this currently predominant energy source. This might give the illusion to society that other energy forms such as solar energy might free us from scarcity of resources as long as means for energy conversion and storage are advanced and/or that human activity may be expanded limitlessly as far as we can utilize this abundant energy source. Rees points out the danger of this kind of logic by stating that even though energy is unlimitedly available, there are other factors which will limit our growth. He insists on the superiority of the EF/ACC analysis, a land-based analysis, and that everyone recognises that land is limited. Therefore the EF/ACC concept will not create the same illusion about our capacity to grow (Rees, public lecture held at the Department of Geography, the University of British Columbia, February 24 1993).

(iii) Ease of Visualising Land Area

A given area of land is easy to imagine. We use land area comparisons in our daily life. For example, Canada is 27 times larger than Japan. My room is half the size of my housemate's, etc. Energy, however, is hard to visualize because it is invisible by itself and there is no theoretical limit to its quantity. We may realize the existence and magnitude of energy indirectly by looking at the motion of an object, measuring its temperature and so on. In our daily conversation, however, formal units of energy such as "Joule" or "Giga joule" are seldom referred to. Although the term "calorie" is one exception, it is mainly used for dietary purposes.

For the above three reasons, I would conclude that it is advantageous for us to use the EF/ACC analysis rather than Energy Analysis (EA) for conducting more accurate research in examining the reality of the ecosphere.

2.5 Application of the Concept of Ecological Footprint/ Appropriated Carrying Capacity

The Ecological Footprint/Appropriated Carrying Capacity is a new concept with only a few empirical applications to date. Studies on the land implications of Canadian consumption patterns and rough analyses of other nations' have been in progress (Wackernagel et al. 1993). EF/ACC does not only serve as an effective decision-making tool toward sustainability but it also enables comparisons between municipalities, or more specifically, different types of possible development patterns etc. Since 1991, Rees and Wackernagel, through the Task Force on Planning Healthy and Sustainable Communities at the University of British Columbia, have been working with staff at the City of Richmond, B.C. to develop and clarify the concept. They have also been giving advice on technical aspects of its application, etc., and have involved their citizens in the planning process.

Chapter 3

Methods/Procedure

For this research, two hydroponic tomato greenhouse operations and two tomato field operations have been empirically examined both in terms of their Appropriated Carrying Capacity and their economic performance.

3.1 Case Selection (Hydroponic Greenhouse Operations)

The greenhouses have been selected by five criteria:

- First, that the case is a typical B.C. operation. By typical, I mean in size of operation, method of production and direct productivity per hectare.
- Second, that the owner has the willingness and time to support my research. Co-operation from the greenhouse owner is essential for this kind of research.
- Third, that the owner has on file reasonable data and information about various inputs.
- Fourth, that the owner can isolate the data for the subject tomato operation from that for other crops. Many greenhouses diversify their operations in terms of kinds of crops. To make the research as simple as possible, I concentrated only on tomatoes of regular size, leaving out cherry tomatoes.
- Fifth, that the location is not too far from Vancouver, to make it accessible.

Mr. Jim Portree, a greenhouse specialist from the B.C. Ministry of Agriculture, Fisheries and Food stationed at Abbotsford Agriculture and Food Centre recommended two typical hydroponic greenhouse operations in Surrey: these are referred to as "Greenhouse A" and "Greenhouse B" in this thesis.[1] Both greenhouses met my five criteria.

3.2 Data Collection (Hydroponic Greenhouse Operations)

There are more than 50 different inputs to a greenhouse, including the land occupied, the greenhouse building, irrigation, ventilation, heating, drainage pipe, carts, trucks, sawdust and rockwool (a soil-substitute), ground cover, electricity, natural gas, fertilizers and liquid CO_2. Therefore the case studies required a large amount of data pertaining to a variety of areas. For each input, I collected seven pieces of information, namely: material, mass, energy intensity, expected life span, price, and distance and means of transportation.

This research relied on a variety of information sources including: the greenhouse owners, agricultural input suppliers, fertilizer producers, chemical engineers, utility companies, greenhouse builders, shipping industries, greenhouse specialists in the Bio-Resources Engineering Department of the University of British Colombia, municipal governments, car dealers, the B.C. Ministry of Agriculture, and UBC libraries.

I visited each greenhouse 4 or 5 times. Each time I spent from 2 to 8 hours in their office or at the site. Most of the time was spent measuring the mass (and/or volume) of building materials and equipments and obtaining data on mass (or volume) and cost of operational (variable) inputs.

In order to obtain the mass of building materials, I measured the length, width and thickness of all the parts and then estimated their mass from their computed volumes.

[1] "Greenhouse A" wished to remain anonymous because this study involves disclosure of financial information. "Greenhouse B" wished that their name be mentioned in the appendix.

Obtaining and calculating the energy intensity of materials was sometimes hard, because basic data was scarce and inconsistent. For inconsistent data, I estimated energy intensity by averaging the whole data set, or by using the most reasonable data.

3.3 Case Selection (Small-scale Field Operations)

My original plan for the research on field operations was to use the past literature, instead of carrying out empirical research. It turned out, however, that there was a lack of documented research on tomato field operations in B.C. I also felt that carrying out empirical studies on both groups would be more accurate, particularly if various case studies were compared.

I set the same criteria for the selection of field farmers as for the greenhouse selection. Carolyin Egri, a professor at Simon Fraser University, has done extensive research on the fertilizer and chemical pesticide use of B.C. farmers. She suggested one representative field tomato farmer, Mr. Wayne Rice, who operates his farm together with his two sons, Steve and Mike, in Spences Bridge near Kamloops, 370 km away from Vancouver. Their operation is called "HillTop Gardens Farm Limited." In this thesis, it is referred to as "HillTop Gardens." In a phone interview, Mr. Rice assured his support. Their data were readily available and separable.

He put me in contact with another farmer in Cache Creek, 50 km north of Spences Bridge. The latter's name is Mr. Ted Horsting, and his farm is called "Horsting Farms." His operation met the first four of my five criteria.

3.4 Data Collection (Small-scale Field Operations)

I visited the field farmers from January 26 to 28, 1993. The data collection procedure was similar to that for greenhouses, except less extensive. ("HillTop Gardens" had a very small greenhouse used as a nursery. But it took me only 30 minutes to measure the whole structure.) Both farmers use only 25 main inputs (see appendix C). These include the land occupied, irrigation, pesticide sprayer, tractor, ground cover, chemical fertilizers, herbicides, insecticides, nursery building and dirt (topsoil) (the last two are applicable only for "HillTop Gardens").

3.5 Data Processing

I computed the EF/ACC and economic performance for each operation with the aid of Lotus 1-2-3 version 2.2 and Excel for Windows version 4.0, personal computer spreadsheets.

Chapter 4

Basis of Calculations, Assumptions and Missing Data

4.1 Separation of Data

(i) Greenhouse A

This consists of two greenhouses on a site in Surrey: one is for tomatoes (2.56 ha) and the other for green peppers (1.70 ha). In some cases, they only had total figures for tomatoes and peppers. The assistant manager assured me that the ratio of various inputs such as fertilizers and labour was 6 : 4, which was the ratio of the growing area of each crop. Therefore, I used 60 % of the total whenever separate data was unavailable.

(ii) Greenhouse B

The owner had been specializing in tomato production until the end of 1992. He started diversifying crops in 1993. For tomato production he uses an old greenhouse (37 years old as of 1993) made of wood, and a new greenhouse (7 years old) with a steel and aluminium framework. I decided to examine only the new greenhouse, since the old one is obsolete and seems energy-inefficient, and because this type of old wooden greenhouse is no longer typical.

Fortunately, the owner was able to give me most of the data separately. When I had to divide total figures into two (e.g. fuel consumption for forklift and trucks, pallet jack and so on), I used a ratio of 75 : 25 (new greenhouse : old one) which is the same as the ratio of production.

(iii) HillTop Gardens

They grow not only tomatoes but also peaches, apples, nectarines, apricots, pears, cherries, melons, corns, cucumbers, squashes and pumpkins. They have facilities and equipment for common use for these vegetables and fruits; for example, aluminium irrigation pipe, which is 1000 meters long. The water used to irrigate the tomato field is about 7 % of the total water consumption for all the crops. Therefore, I attributed 7 % of the total irrigation pipe to tomato production.

Since they have 3 pick-up trucks and since the revenues from tomatoes are 20 % of their total revenues, I assessed that they used 0.6 ($= 3 \times 0.2$) pick-up trucks for tomato production.

80 % of the nursery greenhouse space is used for tomato propagation.

10 % of the workshop and nutrient storage is designated for tomato production.

(iv) Horsting Farms

Mr. Horsting grows tomatoes, potatoes, onions, apples, and other fruits. The tractor and the trucks are used for tomato production. Mr. Horsting attributes 10 % of the total use of these vehicles to tomato growing. Therefore I used 0.1 trucks in the mass calculation of these vehicles.

10 % of the workshop is used for tomatoes. The storage shed is used only for tomatoes. For storage, therefore, I employed the figure of 100 %.

For the irrigation pump, I used the figure of 13 %, since 13 % of the total water is used for tomatoes.

The irrigation piping in the tomato field is exclusively for tomatoes. Therefore I used 100 % for the pipes.

4.2 Energy Intensity

(i) Glass

For flat glass, Cole and Rousseau (1992) presented five different figures on energy intensity ranging from 10.2 mega joules per kilogram (later, abbreviated as MJ/kg) to 21.6 MJ/kg. Baird and Aun (1983) provide figures ranging from 8.42 MJ/kg to 29.3 MJ/kg. Brown et al. (1985) give a figure of 14.2 MJ/kg. For this study I use energy intensity of 14 MJ/kg.

(ii) Steel

I assume the energy intensity of steel to be 30 MJ/kg. Brown et al. (1985) provide a figure of 27.7 MJ/kg. Cole and Rousseau (1992) present energy intensity of steel of four countries. The average of these figures is 31.1 MJ/kg. The estimate of Fritsche et al. (1989) is 30 MJ/kg.

(iii) Aluminium

I employ the figure of 240 MJ/kg for aluminium energy intensity. Cole and Rousseau (1992) list five figures ranging from 145.0 to 261.7 MJ/kg. In their book, Baird and Aun (1983) provide eighteen figures ranging from 52.7 to 371 MJ/kg. Fritsche et al. (1989) present a figure of 250 MJ/kg.

(iv) Concrete

I employ 1.3 MJ/kg as concrete energy intensity. Cole and Rousseau (1992) present four figures ranging from 0.9 to 2.0 MJ/kg. Nine figures obtained by Baird and Aun (1983) range from 0.72 to 2.41 MJ/kg.

(v) Other Service Buildings

Embodied energy for service buildings such as the warehouse, workshop, boiler room, and office have been included in these calculations. Their exact geometric specifications were not collected at the site. Instead, I used a generic energy intensity figure in terms of the area occupied. Hannon et al. (1977) in Doering (1980) estimate energy intensity of 38 $\mathrm{Mcal/ft^2}$, which corresponds to:

$$
\begin{aligned}
38\ \mathrm{Mcal/ft^2} \times 4.19\ \mathrm{MJ/Mcal} &= 159.22\ \mathrm{MJ/ft^2} \\
159.22\ \mathrm{MJ/ft^2} \times 10.76\ \mathrm{ft^2/m^2} &= \underline{1713.2\ \mathrm{MJ/m^2}}
\end{aligned}
$$

(vi) Plastics

By ‘plastic’, I mean a ‘synthetic plastic’ which is a generic term for various kinds of polymers such as polyethylene, polystyrene, polyvinyl chloride and polypropylene. Wackernagel (1992) based on Brown et al. (1985) calculates a generic figure of 64 MJ/kg. Cole and Rousseau (1992) present five figures ranging from 49.3 to 122.8 MJ/kg. Baird and Aun (1983) provide eight figures stretching from 44 to 171 MJ/kg. I use the mean of figures of Cole and Rousseau, 85 MJ/kg, in this thesis.

(vii) Rockwool

Rockwool is used as nutrient holder, i.e., substitute for soil in hydroponic greenhouses. Wackernagel (1992) lists a figure of 28 MJ/kg for mineral wool. I use this figure.

(viii) Gypsum

On hot summer days, a white-wash made of gypsum powder is sprayed on the greenhouse glass to reduce brightness. Cole and Rousseau (1992) provide three figures ranging from 1.4 to 7.4 MJ/kg. Baird and Aun (1983) present five figures extending from 1.1 to 7.2 MJ/kg. For this thesis, I use 4.2 MJ/kg, which is employed by the UBC Task Force on Planning for Healthy and Sustainable Communities (Wackernagel 1992) and very close to the average of the five figures provided by Baird and Aun.

(ix) Gasoline and Diesel Oil

According to Doering (1980), gasoline energy intensity is 50.40 MJ/kg. From the same source, energy intensity of diesel oil is given as 44.4 MJ/kg.

(x) Propane Gas

According to Tuma, *Handbook of Physical Calculations* (1983), the energy content of propane gas is 48.95 MJ/kg.

(xi) Electricity

Electricity consumed by greenhouses and open field operation is supplied by B.C. Hydro, the electricity company of the Province of British Columbia. The greenhouse operations have electric generators for back-up because they need electricity 24 hours every day for irrigation motors, computers, and so on. The use of this generator, however, is minimal and thus insignificant. Therefore, I do not include this trivial portion of electricity generation in this study.

B.C. Hydro uses hydro-electric generation as well as thermal and geothermal power plants. For this research, however, I calculate land-equivalents for electricity, on the assumption that all the electric energy was generated by thermal power plants in order to avoid complexity of calculation. Otherwise, data is necessary as to how much land is required to generate one unit of electricity by hydro-power plants. For this we need to know not only the size of the reservoirs and energy requirement of the dam construction but also the area of the watershed of the river on which the dam is located, and the size of the region from which water evaporates to end up in the watershed; i.e. the size of the "natural solar collector." This is not an easy task, because a watershed is so large and complicated, and its use is not limited only to the water collecting function.

The United Nations Statistical Office and other international institutions assess a nation's energy requirement in a given year in terms of "Total Energy Requirements in Conventional Fuel Equivalent." To calculate this figure, primary electricity is valued on **a fossil-fuel-avoided basis** rather than an energy-output basis (World Resources Institute 1992 p. 324). Transforming thermal energy into electricity involves a loss in available energy. The efficiency of a thermal electric plant is defined as the ratio between final electricity produced and initial energy supplied. This rate varies widely from country to country and from plant to plant. The United Nations Statistical Office uses a standard factor of 0.3 (=30 %) efficiency to estimate the fossil fuel value of hydro, geothermal, wind, and nuclear electricity (World Resources Institute 1992 p. 324). For this research, I use this ratio of 0.3 (=30 %). This means that 1 kilowatt hour of thermal energy is equivalent to only 0.3 kilowatt hours of electric energy. In other words, in order to generate 1 kilowatt hour of electricity, 3.33 kilowatt hours of thermal energy are required. Therefore, for estimating the thermal energy equivalent, I multiplied the consumed electric energy by 3.33.

(xii) Chemical Fertilizers

(a) Chemical Fertilizers for Greenhouse Tomato Production

The energy requirements for the production of the following chemical fertilizers were reported in the literature:

- Potassium Chloride (muriate of potash) ··· 4.3 MJ/kg (Mudaher and Hignett 1982 p. 178)
- Ammonium Nitrate ··· 66.6 MJ/kg (Helsel 1987 p. 39)
- Magnesium Sulfate ··· 2.0 MJ/kg (Helsel 1987 p. 53)

The embodied energy data for the following chemical fertilizers could not be found. I estimated their embodied energy as:

- Potassium Sulfate ··· 3.5 MJ/kg
- Mono-Potassium Phosphate ··· 10.0 MJ/kg
- Potassium Nitrate ··· 14.2 MJ/kg
- Calcium Nitrate ··· 11.5 MJ/kg

- Phosphoric Acid ··· 17.5 MJ/kg
- Sodium Molybdate ··· 10.0 MJ/kg
- Iron Chelate ··· 15.0 MJ/kg
- Potassium Bicarbonate ··· 4.0 MJ/kg

The calculation details are explained in Appendix A.

(b) Chemical Fertilizers for Field Tomato Production

The following energy intensity for manufactured fertilizers was reported in the literature:

- Urea (46-0-0) ··· 36.6 MJ/kg (Mudahar and Hignett 1982 p. 178)

As the rest were not found in the literature, I assessed their embodied energy by myself. The calculation process is presented in Appendix A.

- All Purpose Fertilizer (20-20-20) ··· 19.3 MJ/kg
- Plant Starter (10-52-10) ··· 14.9 MJ/kg
- 12-5-0 ··· 9.3 MJ/kg
- 0-0-50 ··· 5.0 MJ/kg
- 0-0-60 ··· 6.0 MJ/kg
- Iron Sulfate ··· 6.3 MJ/kg
- Borate 40 ··· 4.0 MJ/kg

(xiii) Herbicides

The energy requirement for production of the following herbicide was reported in the literature:

- Trifluralin (Treflan 545 EC) ··· 150 MJ/kg (Helsel 1987 p. 168)

The following herbicides were not listed in the literature. I therefore use the average figure of all the herbicides listed on page 168 of the same book (Helsel 1987).

- Metribuzin (Sencor 500 F) ··· 264 MJ/kg
- Agribrom Powder ··· 264 MJ/kg

Pimentel et al. (1980) present a list of energy input figures for herbicides, insecticides and fungicides on page 46. The average figure for herbicides is 254 MJ/kg. This is very close to the figure which I use in this study, therefore, the employed figure is justifiable. In Appendix B, I present the lists of both Helsel and Pimentel et al. for herbicides, insecticides and fungicides.

(xiv) Insecticide

The following insecticide was listed in Helsel's book (1987 p. 168).

- Carbaryl ··· 153 MJ/kg

The following insecticides were not listed in the literature. I therefore use the average figure for all the insecticides listed on page 168 of the same book (Helsel 1987).

- Kelthane ··· 197 MJ/kg
- Lorsban ··· 197 MJ/kg
- Sulfotep103 ··· 197 MJ/kg

- Plant Fume 103 ··· 197 MJ/kg
- Vendex ··· 197 MJ/kg

The average figure using the list of Pimentel et al. (1980) is 185 MJ/kg. Therefore, the relevance of the employed figure is verified.

(xv) Fungicides

The following fungicides were not listed in the same literature. I, therefore, use the average figure of all the fungicides listed on page 168 of the same book (Helsel 1987).

- Monzate 200DF ··· 163 MJ/kg
- Roccal ··· 163 MJ/kg

The average figure of the list of Pimentel et al. (1980) is 97 MJ/kg. I employ Helsel's figure because the data is more recent.

(xvi) Seeds

It was not possible to find fossil energy requirement to produce tomato seeds *per se*. There is, however, one table which lists fossil energy requirement for production, processing and distribution of various kinds of seeds in David Pimentel ed. *Handbook of Energy Utilization in Agriculture* (1980 p. 32). From this table, I obtained an average of the energy costs of seed production of different kinds of vegetables and grains, which is 39.19 MJ/kg. This figure includes transportation energy requirements. In the same source, there is a table which lists a break-down of the energy requirement of alfalfa seed production, processing and distribution (Pimentel ed. 1980 p. 31). I calculated the % share of energy cost of transportation of the final products (i.e. seeds) to retail stores from the seed factory, which turned out to be 1.18 %. I deducted this portion from 39.19 MJ/kg, because I am adding the transportation energy requirements of the inputs to tomato production separately. Finally I assessed the fossil fuel energy embodied in tomato seeds to be 38.73 MJ/kg. (This figure does not include solar energy which tomatoes accumulate in their seeds through photosynthesis.)

(xvii) Liquid Carbon Dioxide for Greenhouse Operation

Plants take in carbon dioxide from the atmosphere and use it as one of the materials for photosynthesis. Greenhouse operations take advantage of additional carbon dioxide, which is the by-product of burning natural gas for heating of the greenhouse. From summer to early fall, greenhouses utilize liquid CO_2 to make up for the lower supply of by-product CO_2 and to keep up with the higher consumption rate of CO_2. For example, in 1992 Greenhouse A used liquid CO_2 from May to October when gas consumption was reduced to 70 % - 45 % of that of winter months, due to the higher temperature outside (consequently the inside carbon dioxide concentration level was lowered), while the potential photosynthesis rate was enhanced by higher light intensity.

Finding out the energy requirement for producing commercial liquid carbon dioxide was not simple. According to Mr. Bill Buchanan, a production supervisor at the Canadian Liquid Air Ltd. in Vancouver, they import raw gas which contains a high level of carbon dioxide from Washington State of the United States of America. This raw gas is a by-product of ammonia production. After compression, purification, and liquefaction, liquid CO_2 is available for distribution.

It was not possible to find out the energy requirement for exactly the same processes as above. However, data were available for liquid CO_2 production using the flue gas from electricity power plants. By using an article by Hendricks et al. (1989), I obtained a figure that the recovery of carbon dioxide requires 5.72 MJ/kg. Among this, 4.75 MJ/kg is required for desorption of CO_2 and 0.97 MJ/kg for compression. In this study, I assume that the production of liquid CO_2 using by-product gas from ammonia production requires a similar amount of energy to that using flue gas from a power plant. Thus, I use a figure of 5.72 MJ/kg.

(xviii) Transportation

I considered three methods of transportation for both bringing inputs to farmland or greenhouses and for distributing tomatoes to consumers, namely: truck, rail and container ship. Energy requirement figures which I employ for these are: 3 MJ/tonne/km, 1 MJ/tonne/km, and 0.065 MJ/tonne/km, respectively.

Stout (1984) provides the following figures: 3 MJ/tonne/km for truck, and 1.2 MJ/tonne/km for rail. Similar figures are reported in Boustead et al. (1981). This book provides figures for various types of road vehicles, the average of which turned out to be 2.91 MJ/tonne/km. The same book provides a smaller figure for rail: 0.65 MJ for general rail freight per ton mile (which is 0.37 MJ/tonne/km). Here I employ 3 MJ/tonne/km for trucks and 1 MJ/tonne/km for rail.

Figures for sea transportation are more complicated and appeared to be confusing at first. In my opinion, this is because ships have a much wider range in size and type. I find that energy for freight shipment per tonne per kilometer varies drastically, probably depending on the size of the ships. Nevertheless, most literature does not provide this information. Wackernagel (1993, personal communication) uses 0.05 MJ/tonne/km. Boustead (1981) presents 0.14 MJ/ton/mile (which is 0.079 MJ/tonne/km). Stout (1984) provides far greater number, 1.2 MJ/tonne/km. Here I use 0.065 MJ/tonne/km.

4.3 Rate of Conversion from Energy to Land-Equivalent

I use the following relationship for this conversion: 1 hectare of land captures sunlight and accumulates an average of 80 GJ of energy in the form of biomass (finally processed to ethanol), i.e., the average net primary productivity of 1 ha of land is assumed to be 80 GJ per year. There are several studies for estimating this figure.[1] No study has documented higher yield than 80 MJ/ha/year. I employ this most optimistic figure for this study.

4.4 Renewable Inputs

(i) Sawdust and Wood

Greenhouse A uses sawdust in addition to rockwool as plant bed instead of soil. The kinds of trees used for this purpose are Hemlock and Fir trees, which are grown in B.C. forests (personal communication with the Cloverdale Fuels, Ltd in Surrey, B.C. February 18, 1993). HillTop Gardens uses wood (of unknown kind) for the framework of the nursery (I assumed the same kinds of tree are used). Every material except these renewable inputs was initially examined in terms of energy intensity or embodied energy per year, then converted to land-equivalent per year. However, I treated the renewable inputs differently. I obtained the mass of these inputs and then converted it directly to the land area necessary to grow these renewable resources.

I employed an average figure for B.C. mature forests[2], 1 ha of which produce 255 m^3 (cubic meters) of timber every 70 years (Environment Canada 1991 pp. 10 - 6, Table 10 - 1). This translates into a conversion rate of 3.6 cubic meters/ha/year. The average density of Hemlock and Fir is 0.42 tonne or 420 kg per m^3 (Tuma 1983). This gives us a rate of 1.53 tonne/ha/year or 1530 kg/ha/year.

[1] Wackernagel et al., 1993 lists results of similar researches.

[2] Mature forest means the stands or trees that are suited to harvesting are at or near rotation age (Environment Canada 1991 pp. 10 - 6)

4.5 Cost and Prices

(i) Costs of Land

Prices for the land used in greenhouse tomato production were based on figures from the Municipality of Surrey. Surrey provides average land prices for the Agricultural Land Reserve (ALR) and Suburban Residential Area (SRA) on which the respective greenhouses are located ($ 61,774/ha and $370,645/ha respectively) (personal communication with Mr. Fred Mathet, an appraisal specialist, February 19, 1993). I then used a financial formula within Excel for Windows, '=PMT', for calculating the annual payment for an amortized loan with 20 years of amortization.

According to Mr. Jim Portree, a greenhouse specialist from the B.C. Ministry of Agriculture, Food and Fisheries, financial institutions normally require farmers to possess equity of at least 30 % when they make contracts on long-term mortgage plans for purchasing land or greenhouse buildings (personal communication, March 9, 1993). Greenhouse A, however, claims that they borrowed only 30 % from the banks, and 70 % of the cost was paid from their savings. For the other three operations, I assume that the farmers borrowed 70 % of the total cost for purchasing land from the bank and that they paid 30 % of total cost from their own savings or by liquidating their own assets.

Mr. Portree states that the interest rate for this type of mortgage is almost the same as the prime rate. He suggests that I use the current prime rate which is 6.2 %. Thus, I assign 6.2 % to the interest rate of the mortgage plan.

I include the opportunity cost of the money spent for the land purchase. In other words, the money which was withdrawn from the farmers' accounts would have generated annual capital gains if the money had not been withdrawn. I assign 6.0 % for the interest rate of this opportunity cost, which is 0.2 % lower than current prime rate.

As far as the amortization period is concerned, I use the life expectancy of the greenhouse building; i.e. 20 years.

Thus, the formula for the annual mortgage payment of Greenhouse A for land within Excel for Windows reads:

$$
\begin{aligned}
&= \mathrm{PMT}(0.062 \times 0.3 + 0.06 \times 0.7, 20, 3.502 \times 61774) \quad \text{i.e.,} \\
&= \mathrm{PMT}(0.062[\text{prime rate}] \times 0.3[\text{amount borrowed}] \\
&\quad +0.06[\text{opportunity cost}] \times 0.7[\text{amount paid by owner}], \\
&\quad 20[\text{amortization period}], 3.502[\text{land area in ha}] \times 61774[\text{unit land price}])
\end{aligned}
$$

which gives us an annual payment of \$ 18,963.65, where the first parameter is the annual repayment rate, the second is the term of amortization, and the last is the purchase price of the land.

The Greenhouse B is located within the Suburban Residential Area. Its land value has been drastically increasing for the last 30 years. For this case, land value increase is also taken into account. In other words, I included annual capital gain through the increase of land value. It seems fair to include it because we include the opportunity cost of the capital (the negative side of the financial calculation) in this calculation and therefore it is natural to include the positive side). For the other three cases, the land value is assumed to be constant, for simplicity.

For land prices of tomato fields in Spences Bridge and Cache Creek, I used a selling price of 80 acres of land in Spences Bridge which one of the farmers advertises now at \$ 5,560/ha.

According to the B.C. Ministry of Agriculture, Food and Fisheries, no government subsidies have been available to greenhouse owners or field farmers for the purchase of major inputs, including land and greenhouse buildings. (personal communication with Mr. Ted Van der Gulik and Mr. Jim Portree March 9, 1993).

(ii) Other Fixed Costs

I used the same formula '=PMT' for computing the annual payment for other fixed facilities and equipment. Prices of these are obtained from copies of contracts, price lists in catalogues, and by interviewing sales persons or technical specialists of suppliers, builders and related industries.

As for the interest rate, I employ the same rate as for land, i.e., 6.2 %. As far as the amortization period is concerned, I use the same period as the life expectancy of the item. That is to say, I assume that the redemption will be over at the same time as the facility or the equipment is worn out and no longer usable.

(iii) Costs of Variable Inputs

By variable inputs, I mean

a) equipment which has to be replaced in one year or less and

b) various inputs which have to be supplied all the time.

For example, a) includes rockwool, ground covers etc. and b) encompasses natural gas, electricity, fertilizers, pesticides, and human labour.

Costs of variable inputs were also gained from the financial records of greenhouses, contracts, catalogues, and personal communications with suppliers and related industrial sectors.

Mr. Portree states that sometimes farmers or greenhouse owners borrow money for these inputs which have to be supplied long before the harvest starts (personal communication, March 9, 1993). He adds that the borrowing rate is about 1 % higher than the prime rate for this kind of short-term loan. Therefore, I used the same formula for some variable costs as the fixed cost with an interest rate of 7.2 % wherever this treatment is relevant. For example, ground cover, biological pest control, and seeds are treated as above. Otherwise, variable costs are considered to be paid at once directly from the farmers' accounts.

(iv) Tomato Price

For the farmgate price of the greenhouse tomatoes, I used an average for the prices of tomatoes over the last seven years, i.e., \$ 1.375/kg, because the price in 1992 (which is \$ 0.93/kg) was atypical (personal communication with Mr. Jim Portree, March 9, 1993). The price for the two greenhouse operations is the same, because they ship to the same cooperative.

The open field farmers, HillTop Gardens and Horsting, charge quite different prices: the former \$ 0.93 and the latter \$ 0.40. The former sells all their tomatoes at the vegetable stand along the major highway, while Mr. Horsting sells tomatoes at his farm and to some local supermarkets. This is a major cause of the price difference.

4.6 Other Assumptions and Missing Data

(i) Shortcut Calculation for Greenhouse Building Mass

I ascertained the dimensions and mass of the greenhouse buildings by measuring each part. I found that the two greenhouses are almost identical. Therefore, I made a refined calculation on one greenhouse as a whole, using the mass and embodied energy of different materials. Then I extrapolated these results to obtain mass and embodied energy for the other greenhouse with careful consideration. I used different extrapolation rates for the walls than for the rest of the greenhouse, as the area of the walls is proportional to the square root of the greenhouse area. The remaining portion is directly proportional to the area of the greenhouse assuming that the greenhouse land areas are 'similar' to each other in shape in geometric terms.

(ii) Electric Cables and Other Electric Equipments

I assumed these to be insignificant.

(iii) Labour

Energy for human-labour is not included in order to simplify this research. According to Stanhill (1980), the share of labour energy in total energy requirements is 0.4 % for extensively mechanized open field tomato production, and 0.05 % for heated greenhouse tomato operations. Even for labour-intensive open field tomato operations it is only 1.8 %. However, labour costs are included in the economic analysis.

(iv) Life Expectancy

The life expectancy of facilities and equipment were assessed by interviewing greenhouse owners or farmers, and sometimes technical staff and sales persons from suppliers. For the specific data, see the spreadsheets in Appendix C.

As far as greenhouse buildings are concerned, these could last more than 20 years from a structural point of view. But the managers feel that due to rapid technological change, they have to replace the buildings after 20 years or so. Besides, the light transmission of glass declines with time (personal communication with Professor Art Bomke, April 20, 1993). Thus I assessed the life expectancy of greenhouse buildings to be 20 years.

(v) Biological Pest Control

The energy requirements for producing biological pest control were not possible to find out.

4.7 Transportation: Means and Distance

(i) All Materials and Inputs *Except* Greenhouse Building Materials and Rockwool

I assumed that all the materials, equipment, and variable inputs except greenhouse building parts were transported 71 % by rail and 29 % by trucks. This ratio of 71 % and 29 % is based on actual tonne-kilometers/year of rail and truck transport in Canada.

Combination of trains and trucks (71 % and 29 % respectively) gives us a combined energy requirement for transportation per tonne per km, i.e., 1.58 MJ/tonne/km. (As mentioned in the previous section of Energy Intensity, I used 1.0 MJ/tonne/km for rails, and 3.0 MJ/tonne/km for trucks.) The calculation is:

$$1 \times 0.71 + 3 \times 0.29 = 1.58\text{MJ/tonne/km}.$$

I used a mean distance of pesticide transportation in the U. S. which is 640 km for all the commodities except greenhouse materials. This figure is obtained from Pimentel (1980), p. 47.

(ii) Greenhouse Building Materials and Parts

Greenhouse building materials and parts are transported by container ships from Rotterdam, Holland to Vancouver through the Panama Canal, according to a greenhouse import company in Vancouver.[3] The distance between the two ports is 16,390 km, according to Mr. Drace Acres, Manager of the Vancouver Port Corporation (personal communication, February 16, 1993). The energy requirement for container ships is 0.065 MJ/tonne/km as mentioned in previous section of this chapter. Concrete blocks for the post foundation are from Holland. Therefore, I included these blocks in this category. (The concrete building foundations are local. Thus I included it in the previous category.)

(iii) Rockwool Blocks

Rockwool is part of the plant bed, a substitute for soil. These blocks are imported from Japan by ship. The distance between Tokyo and Vancouver is 7736 km.[4]

(iv) Sawdust

Sawdust for plants beds is shipped from local sawmills to greenhouses via a sawdust supplier, according to Cloverdale Fuels, Ltd., a company which supplies sawdust to local greenhouse operations (Personal communication, February 18, 1993). They could not give

[3] Prince Greenhouse Ltd.

[4] A world map, "Cosmopolitan Series: World" published by Rand McNally & Company, 1992(?).

specific distance between these sawmills and the greenhouses. I assumed the distance to be 20 km.

(v) Pipeline Transportation of Natural Gas

Natural gas is transported through PVC pipes all the way from Fort St. John, B.C. and Sumas, B.C. Some comes from Alberta. (Mr. Sam Kobayashi, Work leader of Construction Planning at BC Gas Inc., personal communication, February 17, 1993.) I assumed the transportation energy is insignificant considering the huge amount of energy which the transported natural gas contains within itself. Therefore, the transportation energy is assumed nil in this case.

Chapter 5

Case Study

5.1 Definition of the Terms

I will now define the special terms used in the tables and figures in this thesis and its appendices.

(i) Growing Area (GA)

The Growing Area (GA) is defined as the area which the tomato plants occupy. The productivity of agricultural land is expressed as the ratio of the yield (output) against the growing area of land.

(ii) Visible Occupied Area (VOA)

The Visible Occupied Area (VOA) is defined as the total area which includes Growing Area and other service areas such as space for storage of fertilizers, equipment, tomato products, packaging, parking, workshops, the boiler room, and the office.

(iii) Total Land Area with EF/ACC Consideration (TLA)

The Total Land Area with EF/ACC Consideration (TLA) is equal to the sum of Visible Occupied Area and the land-equivalent for other inputs such as energy and materials, etc. required to produce crops on the occupied farmland. This includes energy used in the transportation of agricultural inputs and outputs.

(iv) EF/ACC of Agricultural Practice = TLA per Output per Year

The definition of EF/ACC of agricultural practices, presented in Chapter 2, can be rephrased as "Total Land Area with EF/ACC Consideration per output per year." More specifically, EF/ACC of an agricultural practice is defined as:

the Total Land Area with EF/ACC Consideration (hectrare) per 1000 tonnes of yield per year.

5.2 Comparison of the Data

The following results were obtained by comparing hydroponic greenhouse tomato production with mechanized field tomato production.

(i) A Comparison of Hydroponic Greenhouse Operations and Open Field Operations Based on Total Land Area with EF/ACC Consideration (TLA)

(a) A Comparison of the Ecological Footprint/Appropriated Carrying Capacity of Agricultural Practices

The EF/ACC of a few of the agricultural practices are compared in Figure 5.1. The EF/ACC of an agricultural operation is the Total Land Area with EF/ACC Consideration divided by output per year, i.e., Total Land Area with EF/ACC Consideration (hectare) per 1000 metric tonnes of yield per year.

The EF/ACC of hydroponic greenhouse production is 765 to 919 hectare per 1000 tonnes per year, which is 14 to 21 times larger than the EF/ACC of small-scale field production which is 43 to 56 hectare per 1000 tonnes per year.

(b) A Comparison of the Productivities of the Total Land Areas with EF/ACC Consideration (TLA)

Conversely, let us look at the productivity of Total Land Area with EF/ACC Consideration. Productivity is defined as the yield per unit area of land per year. The productivity of Total Land Area with EF/ACC Consideration, i.e., yield divided by Total Land Area with EF/ACC Consideration is shown in Figure 5.2.

Figure 5.1: EF/ACC of Greenhouse and Field Operations

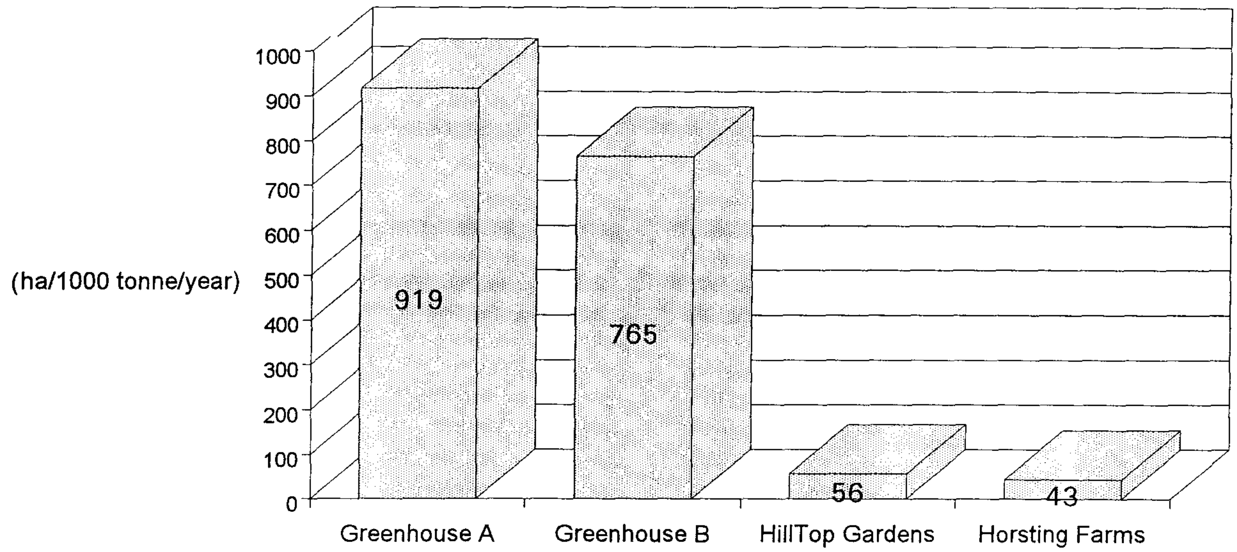


Figure 5.2: Comparison of Productivities of Total Land Areas

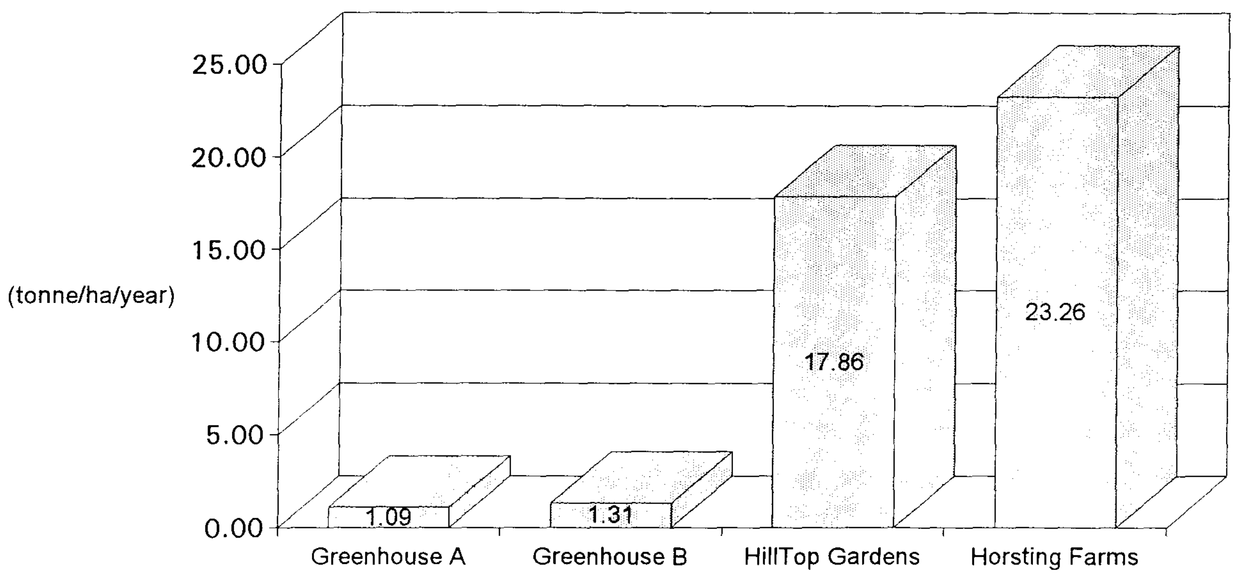


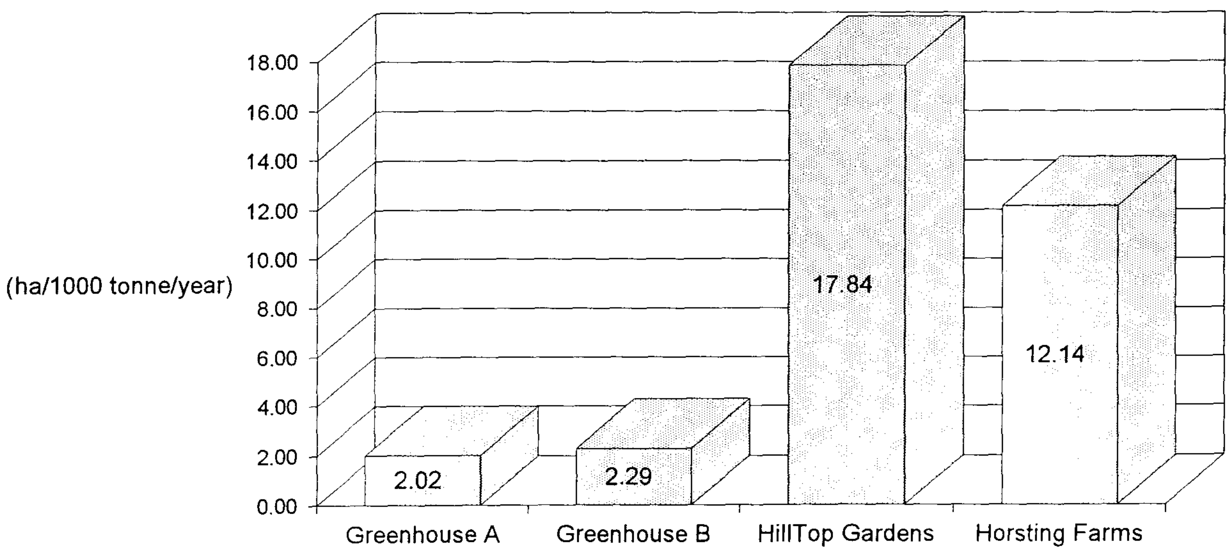
Figure 5.2 shows that the mechanized field operation is approximately 14 to 21 times more productive when it is calculated based on Total Land Area with EF/ACC Consideration. (The fields produce 17900 kg to 23300 kg per hectare, while the greenhouses produce only 1090 to 1300 kg per hectare.)

(ii) A Comparison of Hydroponic Greenhouse Operations and Open Field Operations Based on "only" Growing Areas (without EF/ACC Consideration)

(a) A Comparison of the Required Growing Area for 1000 Tonnes of Tomato Production

Figure 5.3 illustrates that the Growing Area (GA) needed for production of 1000 metric tonnes of tomatoes is only 2.0 to 2.3 hectares for the greenhouse operations, while field production requires from 12 to 18 hectares. This means that greenhouse production is 5 to 9 times more efficient in terms of the Growing Area than field production.

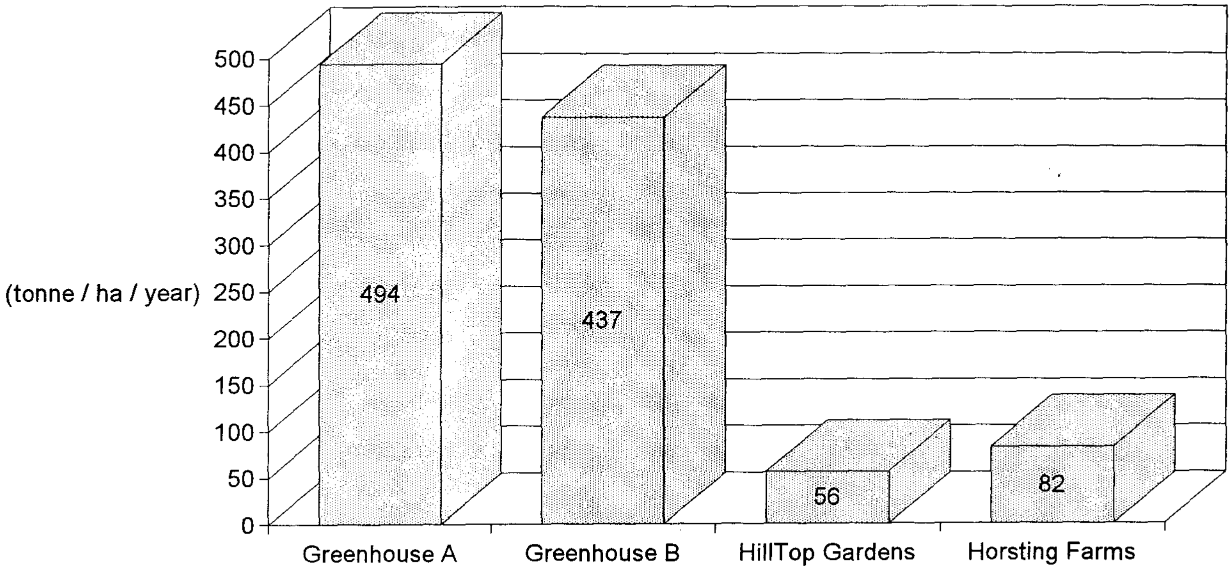
Figure 5.3: Growing Area Needed for Production of 1000 tonnes of Tomatoes



(b) A Comparison of the Productivity of Growing Areas

Figure 5.4 shows that the direct productivity of Growing Areas (i.e., output divided by Growing Area) for greenhouses is 5 to 9 times higher than that of field operations.

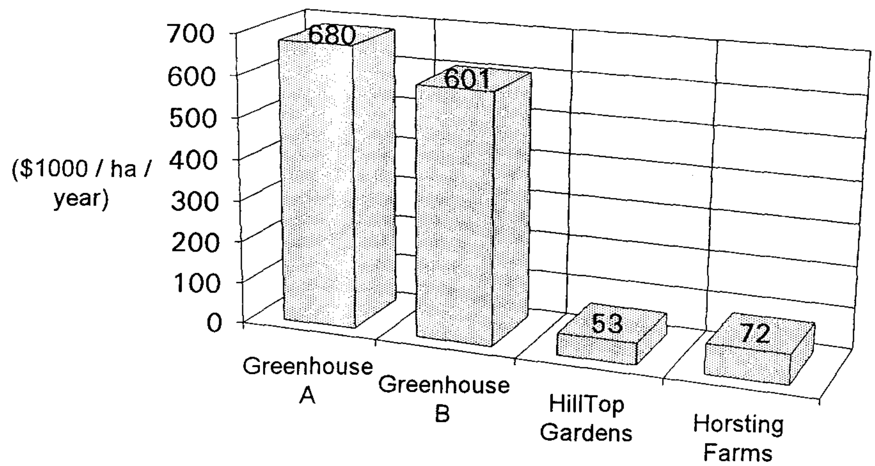
Figure 5.4: Productivity of Growing Area



(c) A Comparison of the Revenue of Growing Areas

Figure 5.5 reveals that the revenue per hectare of the Growing Area of greenhouses is 8 to 13 times higher than that of field production.

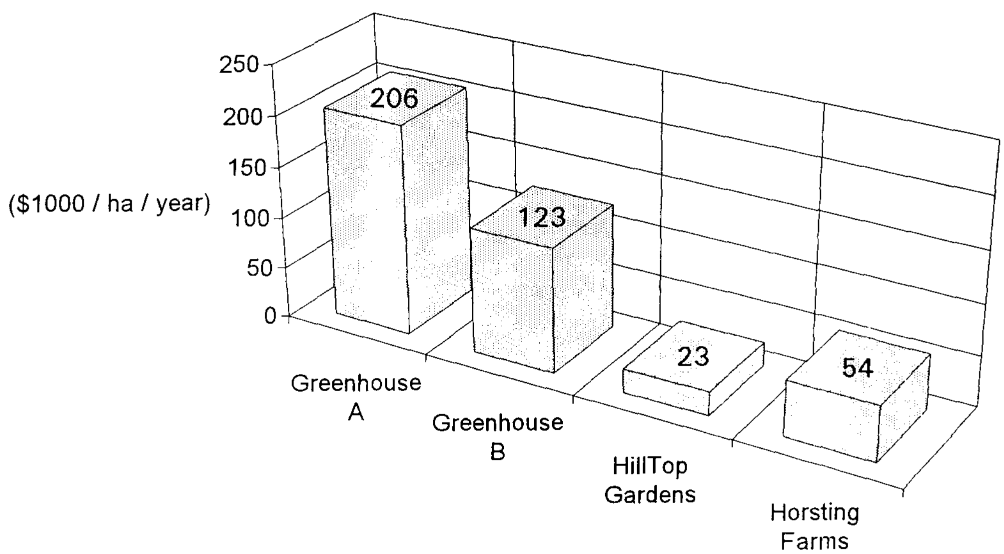
Figure 5.5: Revenue of Growing Area



(d) A Comparison of the Profitabilities of Growing Areas

The net profit per hectare of Growing Area of the greenhouse production is 2 to 9 times higher than that of the field production as shown in Figure 5.6.

Figure 5.6: Profitability of Growing Area



(iii) Components of EF/ACC

(a) Components of EF/ACC for Hydroponic Greenhouse Operations

The Components which contribute to the EF/ACC of hydroponic greenhouse operations are illustrated in the following figures:

Figure 5.7: Components of EF/ACC for Greenhouse A

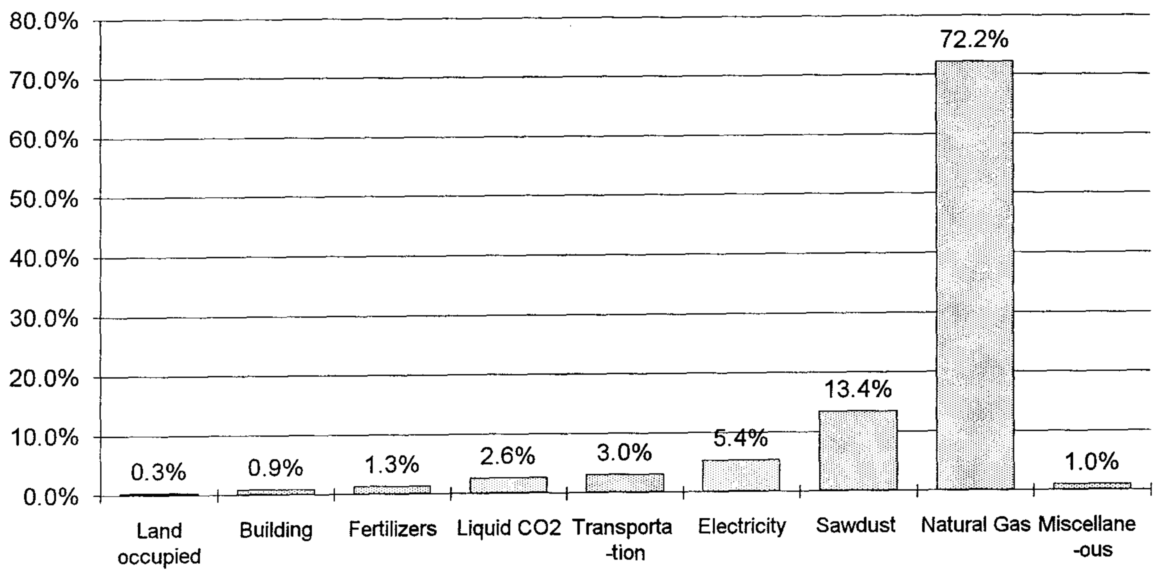
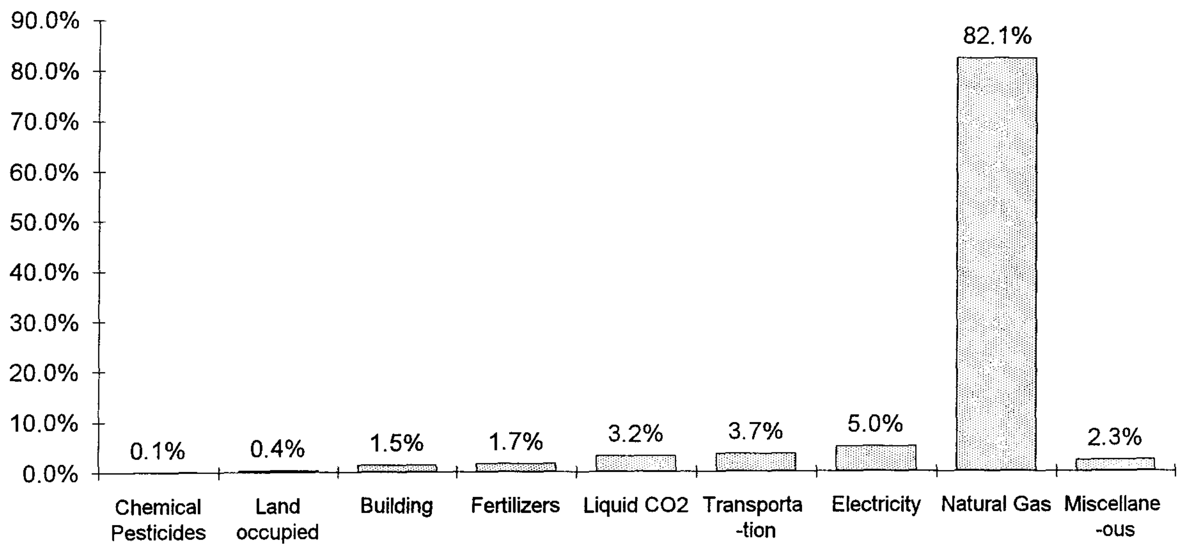


Figure 5.8: Components of EF/ACC for Greenhouse B



From the above two figures, we can conclude that reducing the use of natural gas and sawdust could significantly contribute to the reduction of the EF/ACC of a hydroponic greenhouse operation.

(b) Components of EF/ACC for Field Operations

Components of the EF/ACC of small-scale mechanized field tomato production are highlighted in the following figures:

Figure 5.9: Components of EF/ACC for HillTop Gardens Operation

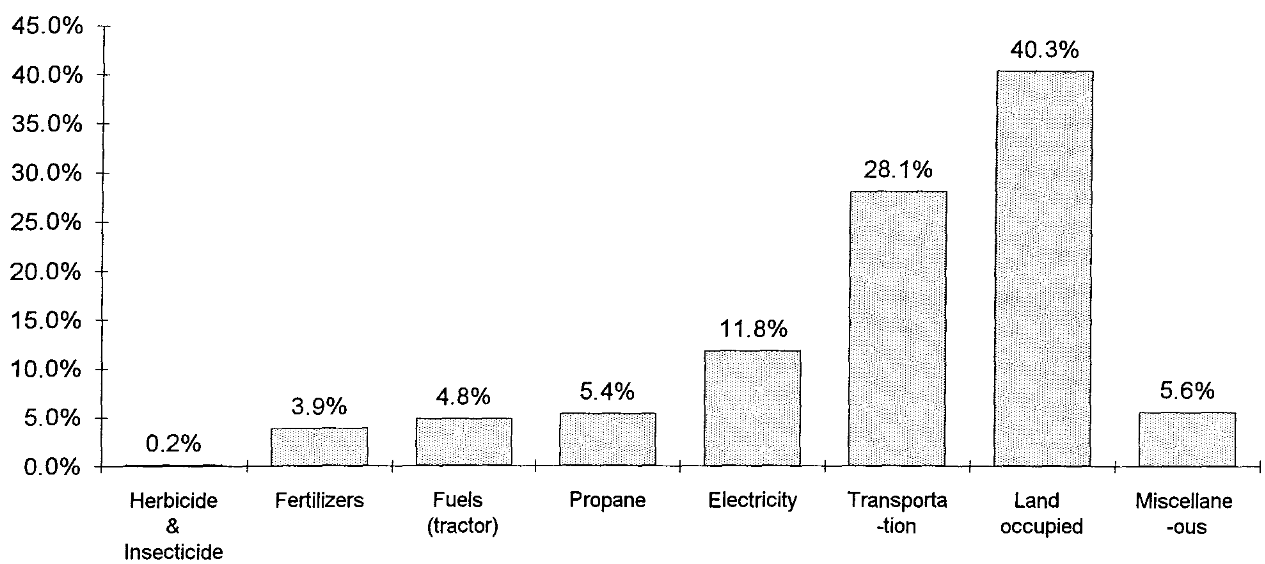
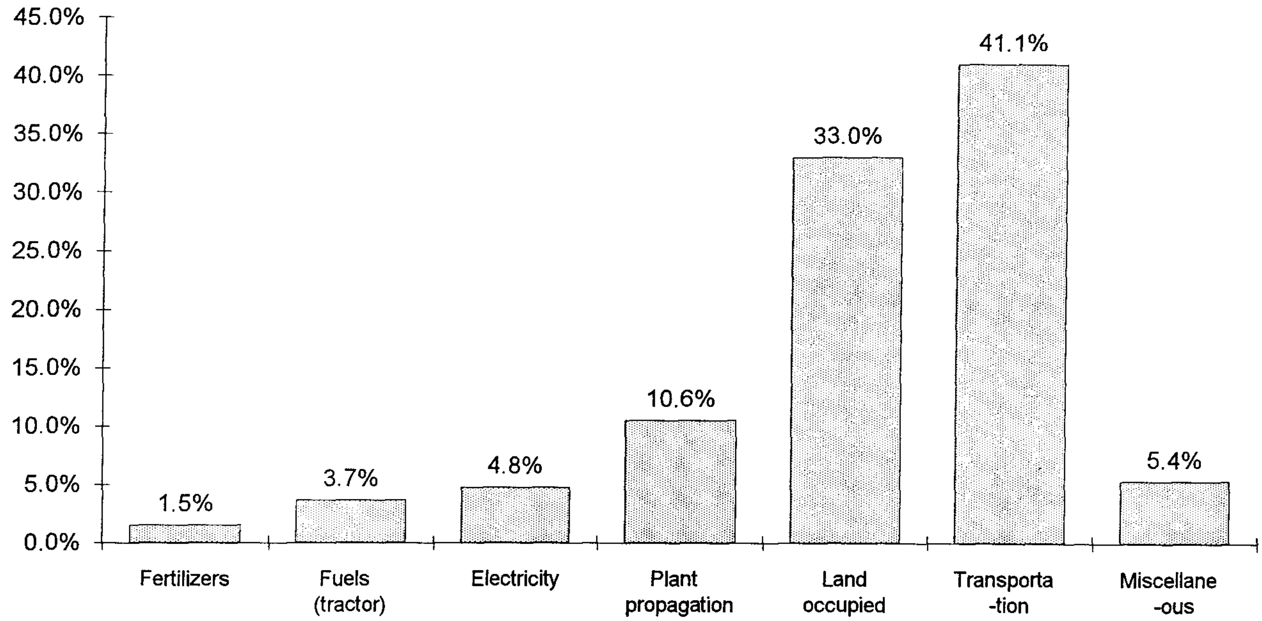


Figure 5.10: Components of EF/ACC for Horsting Farms Operation



The figures illustrate that land occupied, transportation, plant propagation, and electricity are major contributors to the EF/ACC of mechanized field tomato production.

Chapter 6

Analysis, Policy Implications and Directions for Further Study

6.1 Analysis

(i) The Hydroponic Greenhouse: An Inefficient Mode of Production

The case studies of tomato production show that the first question of this thesis has been clearly answered. Can a heated hydroponic greenhouse sustain a higher productivity compared to traditional mechanized field farming practice? The answer is "NO."

If the comparison is based only on the Growing Area directly occupied for production, a hydroponic greenhouse operation is more productive than a field operation (from 5 to 9 times more productive). However, if we look at the same operations from the EF/ACC perspective, the mechanized field operation is more efficient. Indeed, the hydroponic greenhouse makes an ecological footprint 14 to 21 times larger than a field operation producing the same output.

Given the fact that similar technologies are used for other vegetable crops, results for these might be expected to be similar. Further studies, however, are required for these crops. Once EF/ACC is considered it becomes apparent that greenhouse operations do not increase efficiency. Rather, such operations appropriate a large area of land in the production of inputs and in the assimilation of wastes. Greenhouse operations reduce the long-term productivity of the earth.

(ii) The Conflict between Individual Economic Benefit and Total Ecological Constraints

This research reveals a conflict that is invisible to conventional economic analysis. Greenhouse farmers make a higher monetary profit per hectare of growing area than field farmers (from 2 to 9 times more). However, using the EF/ACC approach it becomes clear that greenhouse operations are not ecologically sound or sustainable. Greenhouses appropriate a disproportionate share of the global carrying capacity while contributing significantly to the depletion of natural resources such as natural gas, fertilizer, and other energy intensive inputs.

This study shows that typical economic analysis does not necessarily lead to ecologically satisfactory conclusions. The underpricing of depletable energy, fertilizer, and other inputs to hydroponic production enables operators to profit while unconsciously appropriating the productive capacity of a landscape vastly larger than their own physical plant. Monetary measures of agricultural efficiency should, therefore, be accompanied by analysis of physical flows of their land (natural capital) equivalents if long-term sustainability is at issue. Otherwise, the gross ecological inefficiency of energy-intensive greenhouse operations will be obscured by the illusionary economic superiority of high-input greenhouses.

6.2 Policy Implications

Several important policy implications flow from the EF/ACC and economic analyses of tomato production:

(i) First and Foremost, Society Should Not Come to Depend on Greenhouse Production for Our Food

Reliance on greenhouse production for food does not make sense because of the following two reasons.

a) Greenhouse production undermines conventional agriculture. It can lead to land conversion from agriculture to urban use. There is global destruction of agricultural land caused by soil erosion, salination.[1] Converting the arable land that still exists to urban use makes the problem even more serious.

b) Greenhouse production appropriates more land than field production. It is inherently unsustainable. Greenhouses do not increase productivity. Greenhouses consume 14 to 21 times more land than a field operation which produces the same quantity of yield. If we become dependent on greenhouse production, we will reduce the sustainable production of food. It could lead to more hunger and malnutrition because the world population is increasing steadily at the same time. Our survival may be possible if we conserve our remaining limited agricultural land and if we try to restore it from the degradation. High-tech agriculture does not help us do this.

(ii) Field Agriculture Should be Promoted

This study showed that small-scale field agriculture is far more ecologically sustainable than high-tech greenhouse operations. Decision-makers, all over the world, would be wise to encourage traditional small-scale field agricultural practices, rather than high-tech, high-input greenhouse production. Promoting field agriculture will help create a strong basis for a more sustainable food supply. Encouraging field agriculture is a prerequisite for a sustainable future.

For this reason, the following objectives should be included in agricultural and urban policies worldwide. They should also be included in international development policies.

[1] salting of soil by irrigation

Objectives:

a) Prevent urbanization of limited agricultural land,

b) Secure the land supply for agriculture,

c) Restore degraded arable land.

(iii) Field Tomato Production in B.C. Should be Encouraged

The interior region of British Columbia is particularly suited to tomato production. The hot, dry summers in areas like Spences Bridge, Cache Creek and Ashcroft are good for tomato production.[2] The soil in this region is fertile volcanic ash, which is good for most crops.[3] This land's potential should be taken advantage of. Policies that encourage field tomato production in this region should be implemented.

This area was well-known for its national tomato production until about 35 years ago. Thousands of acres were cultivated for tomato growing in this area.[4] Safeway, a national supermarket chain, had contracts with farmers in this area to supply its stores with tomatoes.[5]

A large canning factory was constructed in Ashcroft, a town between Cache Creek and Spences Bridge and started its operation in 1920. This cannery specialized in tomatoes and employed 400 workers.[6]

Two main factors caused the decline of the tomato industry in this area. Approximately 35 years ago, conflicts arose between the growers and Safeway concerning the price of tomatoes. Safeway decided to purchase cheaper tomatoes from California. The

[2]Mr. Ted Horsting, a grower in Cache Creek and a past President of the Lower Mainland Horticultural Improvement Association, stated this fact during an interview held January 27, 1993.

[3]Ms. Helen Forster, Curator of Ashcroft Museum, made this statement during an interview held April 21, 1993.

[4]Ms. Helen Forster explained the history of tomato production and a cannery operation in the area during the same interview as the previous note.

[5]Mr. Ted Horsting explained this history of tomato production in the same interview as the previous note. Professor Art Bomke of the Faculty of Agricultural Sciences at the University of British Columbia recounted a similar story in a personal interview held February 23, 1993.

[6]Ms. Helen Forster, the same interview as the previous note.

Californian tomato supply was more constant and reliable.[7]

The second factor involved the canning factory. Delmonte, a big canning industry in the United States, did not want to compete with the B.C. canning industry. Therefore, Delmonte purchased the canning plant under the pretence of helping improve the operation. After a while, in 1958 they closed the plant and tomato production moved south.[8]

British Columbia has very good potential for tomato production. This potential has not been fully utilized. Not only are we wasting this capability, but, we are also wasting other natural resources and land base by depending on inefficient greenhouse tomato production. This trend has to be corrected.

Some may argue that we cannot produce field tomatoes in spring or winter. This is true. However, do we really need tomatoes in spring or winter? In winter, we can use canned tomatoes which are suitable for most purposes. We can supplement our nutritional requirements by eating other vegetables in winter. As mentioned in Chapter 1, tomatoes are not the best source of nutrients. We have other good sources of vitamins which can last long past harvest time, such as sweet potatoes, carrots, peas, sweet corn and potatoes. I think that eating tomatoes in winter is a luxury which can no longer be ecologically permissible given that greenhouse operations are ecologically inefficient, as revealed by EF/ACC analysis, and from the fact that the majority of the people in the third world countries have problems of malnutrition.

(iv) EF/ACC Should be Incorporated into Decision-Making Tools of Agriculture

Since EF/ACC analysis is a powerful tool to identify the ecological reality, the B.C. Ministry of Agriculture, Fisheries and Food, Agriculture Canada, Canadian International

[7] Mr. Ted Horsting, the same interview as the previous note.
[8] Ms. Helen Forster, the same interview as the previous note.

Development Agency (CIDA), U.S. Department of Agriculture, Food and Agriculture Organization (FAO) of the United Nations and the World Bank should use EF/ACC analysis in their agricultural policy decision-making process in addition to conventional economic analysis. EF/ACC analysis will enable them to identify the most sustainable and suitable agricultural style and project in each region. This will contribute to achieving sustainable agriculture.

(v) EF/ACC Should be Used to Assess Sustainability of All Kinds of Technologies, Human Activities and Civilization Itself

This study revealed the inefficiency of a seemingly efficient mode of agricultural technology and practice. It is easily inferred that EF/ACC should be able to assess the efficiency and sustainability of various kinds of technology and economic activities. It is widely believed that technology will solve global ecological and environmental problems. So called "environmentally benign products" or "ecologically sound technologies" are enjoying more and more attention. Japan is praised as an "energy efficient society" which has achieved both economic success and environmental protection. It is, however, necessary for us to re-examine these products, technologies, and the way the society operates from an EF/ACC perspective. Some of them may be revealed to be ecologically unsound though they appear to be environmentally friendly from the superficial analysis.

Western civilization is based on scientific technology. Analysing scientific technologies with EF/ACC also means examining the EF/ACC of this civilization itself. At present, civilization faces a dilemma as to where to go. EF/ACC will help assess civilization's ecological footprint and help determine the future directions of our society from a truly ecological perspective. This will eventually lead to sustainability for our civilization.

(vi) Educational Programmes Should be Implemented to Prompt Changes in Consumers' Behaviour

Society does not recognize that high-tech agriculture is an inefficient mode of production and that it is ecologically unsustainable. This is because the dominant economic analysis is not capable of assessing ecological efficiency and sustainability. There has not been an adequate analytical tool for assessing ecological sustainability. EF/ACC is a powerful and suitable tool to do this task. The results of EF/ACC analysis should be revealed to the public through education. Educating consumers and prompting their behavioural change would encourage more ecologically sound modes of agricultural production. Specific educational curricula should be introduced in schools and in community levels (e.g. community colleges, and community centres). Mass media could also be used to educate the public.

Educational efforts should not be only directed toward agricultural practices but also to other human activities. As mentioned in the previous section, EF/ACC can assess the sustainability of various kinds of technology, operations and activities.

To assist teachers and educators, teaching manuals and teaching materials should be developed at the same time. Teaching materials could be in the form of print material, newsletters, slides, videos, audio tapes, and computer game software. For example, in 1992, B.C. Hydro developed a computer game called "the Power Smart Game," which requires Hypercard program software and a MacIntosh computer. This is for youths in grades 8 to 10. This game enables students to understand visually and easily how much energy is going to be saved depending on everyday behavioural changes. This might be a good model.[9]

[9]There are several energy and the environmental educational materials of different kinds which are developed by B.C. Hydro. The Greater Vancouver Regional District produced a print material called *No Time to Waste* in 1992 which teaches children how to reduce household wastes. This is not directly relevant to our topic. Nevertheless, this will be a good model for education regarding sustainable agriculture because this is well written and organized.

6.3 Directions for Further Study

(i) Similar Studies Should be Attempted in Other Regions

Especially, it is urgent to study EF/ACC of large-scale mechanized field tomato production in California and other parts of the United States. They are heavily subsidized by underpriced fossil fuels in the forms of low cost irrigation water, chemical fertilizers and fuels for agricultural vehicles. We Canadians have to stop and ponder whether their operation is ecologically sound, before we purchase California tomato products because our individual behavior contributes to the regional (both Canada and U.S.) and global ecological crises.

(ii) The Same Studies Should be Conducted in Different Crops

I only studied tomato production. Even though tomatoes are typical crops which are grown in greenhouses, we should do research of other crops to know the general figure of greenhouse operations.

(iii) Different Modes of Agriculture Should be Analysed in Terms of EF/ACC

In order to achieve sustainable agriculture, we have to know which agricultural practices are more sustainable than others. For example, agroforestry, permaculture, [10] natural farming, [11] and organic farming should be analysed using EF/ACC concepts. We should be able to find out which mode of production is more ecologically sound.

These findings should be incorporated not only into agricultural policies in each country, but also in international development policies of international development agencies,

[10] Mr. Bill Morrison started a new way of agriculture called "Permaculture", which emphasises vertical material flows between orchard trees and vegetables and does not require much cultivation after two or three years initial setup. For details see his book, *Permaculture*, 1990. Washington, D.C.: Island Press.

[11] Mr. Masanobu Fukuoka started a new mode of agriculture with no tillage, no chemical fertilizers and no pesticides in Japan in the late 1940s which is called "Natural Farming." For detail, see his book, *One-Straw Revolution: An Introduction to Natural Farming.* 1978. Emmaus: Rodale Press. This was translated from Japanese. The original version is available under the title of *Shizen Noho: Wara Ippon no Kakumei* (Second edition). 1983. Tokyo: Shunju-Sha.

such as the Canadian International Development Agency, the World Bank and the Organization for Economic Cooperation and Development. These agencies have strong influences on development policies of third world countries. Thus, changing policies of these aid agencies will lead to altering the policies of the developing countries. Global ecological, agricultural and population trends show that the problems are profound and urgent. We have no time to waste. We need to act now for the very survival of humankind on this planet.

(iv) Other Technologies and Economic Activities Should be Analysed in Terms of EF/ACC

It is urgent for us to study whether our technologies and our activities are sustainable. Our civilization has to be re-examined from an ecological perspective. Civilization is in a crisis because of the global ecological degradation caused by civilization! This problem is now threatening the very survival of humankind. EF/ACC is capable of providing a more realistic picture of what we do to our "Mother Earth" and can show us more appropriate directions for our civilization to follow. EF/ACC will and should be an indispensable decision-making tool for the survival of our species on this planet.

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Appendix A

Calculation Process of Fertilizer Energy Intensity

There is no documentation of some of the energy intensity figures of chemical fertilizers. I, therefore, estimate the missing figures to be as follows.

Generally speaking, fertilizers are composed of three chemical substances: nitrogen (abbreviated as N), phosphorus (P) and potassium (K). For example, a fertilizer called "plant starter" contains three of these elements. Its composition is 10 % of N, 52 % of P and 10 % of K.

Energy intensity figures of N, P_2O_5, and K_2O are documented in scientific literature. Helsel ed. (1987, p. 6) presents figures of 78.13 MJ/kg, 17.45 MJ/kg and 13.70 respectively. These include energy which is required for transportation and application of the fertilizers. To use these gross figures would be double counting, because I count the energy required for transportation and application in different categories. I subtracted half of the PTA[1] energy requirement from these figures to avoid double counting. Then I get the following adjusted figures: 73.84 MJ/kg, 12.58 MJ/kg and 10.04 respectively. I use these figures as a calculation basis in combination with the above information regarding the composition of elements in a fertilizer.

For example, the energy intensity of "plant starter" is calculated as follows:

$$0.1 \times 73.84 + 0.52 \times 12.58 + 0.1 \times 10.04 = 14.93\text{MJ/kg}.$$

[1]PTA stands for packaging, transportation of raw material and product, and application (Helsel ed. 1987 p. 6)

The following table presents some examples of estimated figures of fertilizers computed as above.

Table A.1: Estimated Energy Intensity of Chemical Fertilizers

			N	P	K
Unit Energy Intensity (MJ/kg)			73.84	12.58	10.04
Mono Potassium Phosphate		Composition (%)	0	52	34
	9.96	MJ/kg	0.00	6.54	3.41
Potassium Nitrate		Composition (%)	13.00	0.00	46.00
	14.22	MJ/kg	9.60	0.00	4.62
Calcium Nitrate		Composition (%)	15.50	0.00	0.00
	11.45	MJ/kg	11.45	0.00	0.00
All Purpose(20-20-20)		Composition (%)	20	20	20
	19.29	MJ/kg	14.77	2.52	2.01
Plant Starter (10-52-10)		Composition (%)	10	52	10
	14.93	MJ/kg	7.38	6.54	1.00
12-5-0		Composition (%)	12	5	0
	9.49	MJ/kg	8.86	0.63	0.00
0-0-50		Composition (%)	0	0	50
	5.02	MJ/kg	0.00	0.00	5.02
0-0-60		Composition (%)	0	0	60
	6.02	MJ/kg	0.00	0.00	6.02

Appendix B

Average Figures of Energy Intensity for Pesticides

Table B.2: Energy Intensity Figures of Chemical Herbicides, Insecticides, and Fungicides

(from Helsel 1987, p. 168)

	Herbicides	Insecticides	Fungisides
	130	160	61
	85	209	99
	135	454	115
	295	153	375
	170	58	
	518	580	
	220	250	
	278	58	
	290	229	
	365	138	
	141	70	
	270		
	355		
	190		
	80		
	150		
	400		
	460		
	454		
	290		
	201		
	434		
	160		
	276		
Average(MJ/kg)	264.46	196.58	162.50

(from Pimentel. 1980. p.46)

	Herbicides	Insecticides	fungicides
	30952	24200	15250
	64290	38100	23570
	45240	13810	27380
	35170	108100	26620
	109520	36430	
	24200		
	56700		
	71400		
	19080		
	52240		
	69050		
	70240		
	108100		
	95240		
Average (Kcal/kg)	60815.86	44128.00	23205.00
Average (MJ/kg)	254.45	184.63	97.09

Appendix C

Spreadsheet for ACC Calculation of Greenhouse and Field Operations

- Greenhouse A
- Greenhouse B = Otsuki Greenhouses Ltd.
- HillTop Gardens Farms Ltd. (Mechanized Field Operation)
- Horsting Farms (Mechanized Field Operation)

Table C.3: Spreadsheet for "Greenhouse A" Hydroponic Greenhouse Tomato Production

as of April 25, 93

Number	Inputs	Material	Volume or Length (cub.m etc)	Mass (kg)	Energy Intensity (MJ/kg)	Embodied Energy (MJ)	Life Expectancy (years)	Embodied Energy/Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000 ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	Energy Required for Transport (MJ/tn/km)	Energy for Transport (MJ/year)
1	**Land occupied**								3.5040	1.3704	2.7718	($18,963.65)				
1.1	Growing Area								2.5570	1.0000	2.0227					
1.2	Other Service Areas								0.9470	0.3704	0.7491					
2	**Embodied Energy of Facilities**															
2.1	**Building**			995393		16646825.5	20	832341.3	10.4043	4.0689	8.2302		30855.4			31991.1
2.1.1	Glass	glass		253296	14	3546141.2	20	177307.1	2.2163	0.8668	1.7532	($19,525.84)	12664.8	640	1.5800	12806.6
2.1.2	Post&Framework	steel		189357	30	5680711.5	20	284035.6	3.5504	1.3885	2.8085	($64,778.26)	9467.9	16390	0.0650	10086.7
2.1.3	Framework etc.	alminium		16623	240	3989496.0	20	199474.8	2.4934	0.9751	1.9724		831.1	16390	0.0650	885.5
2.1.4	Foundation (import)	concrete		85779	1.3	111512.3	20	5575.6	0.0697	0.0273	0.0551		4288.9	16390	0.0650	4569.3
2.1.5	Foundation(domest)	concrete		450338	1.3	585439.8	20	29272.0	0.3659	0.1431	0.2894	($1,401.76)	3602.7	640	1.5800	3643.1
2.1.6	Other Service Bldgs	(sq. m)	960		1713	1644480.0	20	82224.0	1.0278	0.4020	0.8130					
2.1.7	Electrical											($3,942.44)				
2.1.8	Construction	7% of embodied energy of material				1089044.7	20	54452.2	0.6807	0.2662	0.5384	($18,662.53)				
2.2	**Irrigation system**															
2.2.1	Tube & pipes	plastic		2100	85	178500.0	3	59500.0	0.7438	0.2909	0.5883	($6,426.10)	700.0	640	1.5800	707.8
2.2.2	Tank	steel		3288	30	98640.0	20	4932.0	0.0617	0.0241	0.0488	($194.17)	164.4	16390	0.0650	175.1
2.2.3	Tank	plastic		340	85	28900.0	20	1445.0	0.0181	0.0071	0.0143	($171.07)	17.0	16390	0.0650	18.1
2.2.4	Pump	steel		305	30	9150.0	20	457.5	0.0057	0.0022	0.0045	($1,121.40)	15.3	16390	0.0650	16.2
2.2.5	Pond Sheet	plastic		27904	85	2371840.0	30	79061.3	0.9883	0.3865	0.7818	($2,025.38)	930.1	16390	0.0650	990.9
2.3	**Ventilation System**											($206.46)				
2.3.1	Elec. Motors	steel	10 motors	70	30	2100.0	20	105.0	0.0013	0.0005	0.0010		3.5	16390	0.0650	3.7
2.3.2	Rods	aluminum		1190	240	285600.0	20	14280.0	0.1785	0.0698	0.1412		59.5	16390	0.0650	63.4
2.3.3	Steel Shaft	steel		12333	30	369990.0	20	18499.5	0.2312	0.0904	0.1829		616.7	16390	0.0650	657.0
2.4	**CO2 Dist. Sys**	plastic	7776 m	78	85	6604.5	1	6604.5	0.0826	0.0323	0.0653	($721.80)	77.7	16390	0.0650	82.8
2.5	**Heating Systems**											($52,635.91)				
2.5.1	Boilers	steel	1.86	14646	30	439369.2	10	43936.9	0.5492	0.2148	0.4344		1464.6	640	1.5800	1481.0
2.5.2	Pipes (small)	steel	13.82	108819	30	3264560.4	20	163228.0	2.0404	0.7979	1.6140		5440.9	640	1.5800	5501.9
2.5.3	Pipes (medium)	steel	1.24	9764	30	292912.8	20	14645.6	0.1831	0.0716	0.1448		488.2	640	1.5800	493.7
2.5.4	Pipes(large)	steel	0.25	1969	30	59055.0	20	2952.8	0.0369	0.0144	0.0292		98.4	640	1.5800	99.5
2.6	**Dranage Pipe**	plastic	9.24	12942	85	1100045.6	20	55002.3	0.6875	0.2689	0.5439	($1,142.26)	647.1	640	1.5800	654.3
2.7	**Spray Equipment**	steel		15	30	450.0	20	22.5	0.0003	0.0001	0.0002	($25.76)	0.8	640	1.5800	0.8
2.8	**Electric & Hand Car**										0.0000	($2,496.93)				
2.8.1	Electric Cart	steel		490	30	14700.0	10	1470.0	0.0184	0.0072	0.0145		49.0	16390	0.0650	52.2
2.8.2	Hand Cart	aluminum		165	240	39600.0	10	3960.0	0.0495	0.0194	0.0392		16.5	16390	0.0650	17.6
2.9	**Fork Lift**	steel		2750	30	82500.0	15	5500.0	0.0688	0.0269	0.0544	($2,790.90)	183.3	640	1.5800	185.4
2.10	**Pallet Jacks**	steel		300	30	9000.0	30	300.0	0.0038	0.0015	0.0030	($83.21)	10.0	640	1.5800	10.1
2.11	**Tracks**	steel etc	0.5track	2914	30	87420.0	15	5828.0	0.0729	0.0285	0.0576	($310.10)	194.3	640	1.5800	196.4
2.12	**Computer Equipment**			20			20					($3,864.11)	1.0	640	1.5800	1.0
Sub Total of Fixed Facilities & Equipments (1 - 2.12)						25387763.0		1314072.2	16.4259	6.4239	12.9936	($201,490.04)				

Table C.3: Spreadsheet for "Greenhouse A"

(Continued)

Number	Inputs	Material	Volume or Length (cub.m etc)	Mass (kg)	Energy Intensity (MJ/kg)	Embodied Energy (MJ)	Life Expectancy (years)	Embodied Energy/Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000 ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	Energy Required for Transport (MJ/tn/km)	Energy for Transport (MJ/year)
3	**Variable Inputs I.**						1									
3.1.	**SawdustBag&RockWool**															
3.1.1	Plastic Bag	plastic		1361	85	115668.0	1	115668.0	1.4459	0.5654	1.1437	($6,571.36)	1360.8	640	1.5800	1376.0
3.1.2	Sawdust	sawdust		238140			1		156	60.8710	123.1232	($1,483.03)	238140.0	20	1.5800	7525.2
3.1.3	Rockwool	rockwool		3266	28	91448.0	1	91448.0	1.1431	0.4470	0.9042	($86,004.67)	3266.0	7736	0.0650	1642.3
3.1.4	Rock Wool Wrap	plastic		185	85	15725.0	1	15725.0	0.1966	0.0769	0.1555		185.0	7736	0.0650	93.0
3.2	**Ground Cover**	plastic	3700	2220	85	188700.0	1	188700.0	2.3588	0.9225	1.8659	($10,720.00)	2220.0	640	1.5800	2244.9
3.3	**White wash**	gypsum		500	4.2	2100.0	1	2100.0	0.0263	0.0103	0.0208	($163.28)	500.0	640	1.5800	505.6
3.4	**Electricity([el]:[th]=0.3kWh:1kWh)**			416160	kwh[el]	4988926.1	1	4988926.1	62.3616	24.3886	49.3306	($20,161.15)				
3.5	**Natural Gas**			777483	86.3	67089000.0	1	67089000.0	838.6125	327.9673	663.3769	($172,854.47)	777482.9			
3.6	**Car Fuels**															
3.7	**Labour Force**						1					($226,156.87)	0.0			
4	**Variable Inputs II.**															
4.1	**Fertilizers**															
4.1.1	Potassium Sulfate			4082	3.5	14287.0	1	3354.0	0.0419	0.0164	0.0332	($193.20)	780.0	640	1.5800	788.7
4.1.2	Potassium Chloride			780	4.3	3354.0	1	36150.0	0.4519	0.1767	0.3575	($5,767.20)	3615.0	640	1.5800	3655.5
4.1.3	Mono Potassium Phosphate			3615	10.0	36150.0	1	222045.4	2.7756	1.0855	2.1956	($11,830.20)	15637.0	640	1.5800	15812.1
4.1.4	Potassium Nitrate			15637	14.2	222045.4	1	360697.5	4.5087	1.7633	3.5666	($6,811.48)	31365.0	640	1.5800	31716.3
4.1.5	Calcium Nitrate			31365	11.5	360697.5	1	360697.5	4.5087	1.7633	3.5666	($12,302.40)	31365.0	640	1.5800	31716.3
4.1.6	Ammonium Nitrate			1440	66.6	95889.6	1	95889.6	1.1986	0.4688	0.9482	($447.00)	1440.0	640	1.5800	1456.1
4.1.7	Phosporic Acid			5187	17.5	90772.5	1	90772.5	1.1347	0.4437	0.8976	($7,027.20)	5187.0	640	1.5800	5245.1
4.1.8	Magnesium Sulphate			14550	2.0	29100.0	1	29100.0	0.3638	0.1423	0.2877	($6,948.00)	14550.0	640	1.5800	14713.0
4.3	**Biological Pest Control**						1			0.0000	0.0000	($71,352.32)	0.0	640	1.5800	0.0
4.4	**Seeds**			0.38	38.7	14.8	1	14.8	0.0002	0.0001	0.0001	($10,211.44)	0.4	640	1.5800	0.4
4.5	**Liquid CO2**			417252	5.7	2386680.3	1	2386680.3	29.8335	11.6674	23.5995	($53,297.00)	417251.8	300	1.5800	197777.4
4.6	Miscellaneous Variable Costs (phone,insurance,consultation,etc.) which are missing from above											($238,842.81)				
4.7	**Managers' Salary**											($60,000.00)				
Sub Total of Variable Inputs (3. - 4.7)								76076968.6	1106.6092	432.7764	875.3732	($1,009,145.09)				
Grand Total of Fixed Inputs and Variable Inputs								**77391040.8**	**1126.5391**	**440.5706**	**891.1386**	**($1,210,635.13)**				**359668.0**

Table C.3: Spreadsheet for "Greenhouse A"

(Continued)

	Mass (kg)	Energy Intensity (MJ/kg)	Embodied Energy (MJ)	Life Expectancy (years)	Embodied Energy/Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000 ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	Energy Required for Transport (MJ/tn/km)	Energy for Transport (MJ/year)
Grand Total of Fixed Inputs and Variable Inputs					**77391040.8**	**1126.539069**	**440.5706**	**891.1386**	**($1,210,635.13)**				**359668.0**
Output Per Year (kg/yr)	1264157									1264157	640	3.0000	2427181.4
Revenue per year ($/ yr.)									$1,738,215.88				
Net Profit per year ($/yr)									$527,580.75				
GROWING AREA without ACC consideration						2.5570	1.0000	2.0227					
Required Area per Unit Output (ha/1000ton/yr)						2.0227	2.0227	2.0227					
Output per hectare per year (kg/ha/yr)	494391												
Revenue per hectare per year ($/ha/yr)									$679,787.20				
Net Profit per hectare per year ($/ha/yr)									$206,328.02				
VISIBLE OCCUPIED AREA without ACC consideration						3.5040	1.3704	2.7718					
Required Area per Unit Output (ha/1000ton/yr)						2.7718	2.7718	2.7718					
Output per hectare per year (kg/ha/yr)	360775												
Revenue per hectare per hear ($/ha/yr)									$496,066.17				
Net Profit per hectare per year ($/ha/yr)									$150,565.28				
TOTAL LAND with ACC consideration (except transportation)						1126.5391	440.5706	891.1386					
Required Area per Unit Output (ha/1000ton/yr)						891.1386	891.1386	891.1386					
Output per hectare year (kg/ha/yr)	1122												
Revenue per hectare per year ($/ha/yr)									$1,542.97				
Net Profit per hectare per year ($/ha/yr)									$468.32				
Inputs for Transportation (Importing materials) per year						4.4958	1.7583	3.5564					
Inputs for Transportation (Exporting products) per year						30.3398	11.8654	24.0000					
TOTAL LAND with ACC consideration including transportation						1161.3747	454.1942	918.6950					
Required Area per Unit Output (ha/1000ton/yr)						918.6950	918.6950	918.6950					
Output per hectare per year (kg/ha/yr)	1089												
Revenue per hectare per year ($/ha/yr)									$1,496.69				
Net Profit per hectare per year ($/ha/yr)									$454.27				
1 **Land Greenhouse**						2.5570	1.0000						
Land-packng&office&nutrient						0.0960	0.0375						
Land-Pond						0.6040	0.2362						
Land Docking & Parking Area						0.1500	0.0587						
Land Septic Place						0.0010	0.0004						
Land Roadway						0.0960	0.0375						
Land Total for Tomatoes						3.5040	1.3704						

Table C.4: Spreadsheet for "Greenhouse B" Hydroponic Greenhouse Tomato Production

(Otsuki Greenhouses Ltd.)

as of April 25, 93

Number	Inputs	Material	Volume or Length (cub.m etc)	Mass (kg)	Energy Intensity (MJ/kg)	Embodied Energy (MJ)	Life Expectancy (years)	Embodied Energy/Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	Energy Required for Transport (MJ/tn/km)	Energy for Transport (MJ/year)
1	**Land occupied**								0.9242	1.3884	3.1742	$28,273.08				
1.1	Growing Area								0.6656	1.0000	2.2861					
1.2	Other Service Areas								0.2586	0.3884	0.8880					
2	**Embodied Energy of Facilities**															
2.1	**Building**			274951		5267697.4	20	263384.9	3.2923	4.9464	11.3081	($46,727.75)	8484.0			8791.3
2.1.1	Glass	glass		71242	14	997389.7	20	49869.5	0.6234	0.9366	2.1411		3562.1	640	1.5800	3602.0
2.1.2	Post&Framework	steel		49957	30	1498712.7	20	74935.6	0.9367	1.4073	3.2173		2497.9	16390	0.0650	2661.1
2.1.3	Framework etc.	alminium		4558	240	1093881.6	20	54694.1	0.6837	1.0272	2.3482		227.9	16390	0.0650	242.8
2.1.4	Foundation (import)	concrete		23871	1.3	31032.4	20	1551.6	0.0194	0.0291	0.0666		1193.6	16390	0.0650	1271.6
2.1.5	Foundation(domest)	concrete		125323	1.3	162920.3	20	8146.0	0.1018	0.1530	0.3497		1002.6	640	1.5800	1013.8
2.1.6	Other Service Bldgs	(sq. m)	665		1713	1139145.0	20	56957.3	0.7120	1.0697	2.4454					
2.1.7	Electrical						20					($881.78)				
2.1.8	Construction	7% of embodied energy of material				344615.7	20	17230.8	0.2154	0.3236	0.7398	Included in building cost				
2.2	**Irrigation system**															
2.2.1	Tube & pipes	plastic		546	85	46410.0	4	11602.5	0.1450	0.2179	0.4981	($1,291.56)	136.5	640	1.5800	138.0
2.2.2	Tank	steel		1512	30	45374.4	20	2268.7	0.0284	0.0426	0.0974	($89.90)	75.6	16390	0.0650	80.6
2.2.3	Tank	plastic		156	85	13294.0	20	664.7	0.0083	0.0125	0.0285	($79.20)	7.8	16390	0.0650	8.3
2.2.4	Pump	steel		140	30	4209.0	20	210.5	0.0026	0.0040	0.0090	($519.19)	7.0	16390	0.0650	7.5
2.2.5	Pond Sheet	plastic		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.3	**Ventilation System**											Included in building cost				
2.3.1	Elec. Motors	steel	4 motors	28	30	840.0	20	42.0	0.0005	0.0008	0.0018		1.4	16390	0.0650	1.5
2.3.2	Rods	aluminum		309	240	74256.0	20	3712.8	0.0464	0.0697	0.1594		15.5	16390	0.0650	16.5
2.3.3	Steel Shaft	steel		3207	30	96197.4	20	4809.9	0.0601	0.0903	0.2065		160.3	16390	0.0650	170.8
2.4	**CO2 Dist. Sys**	plastic	4100m	41	85	3485.0	1	3485.0	0.0436	0.0654	0.1496	($379.41)	41.0	16390	0.0650	43.7
2.5	**Heating Systems**											Included in building cost				
2.5.1	Boilers	steel	0.744	5858	30	175747.7	10	17574.8	0.2197	0.3301	0.7545		585.8	640	1.5800	592.4
2.5.2	Pipes (small)	steel	5.53	43527	30	1305824.2	20	65291.2	0.8161	1.2262	2.8032		2176.4	640	1.5800	2200.7
2.5.3	Pipes (medium)	steel	0.50	3906	30	117165.1	20	5858.3	0.0732	0.1100	0.2515		195.3	640	1.5800	197.5
2.5.4	Pipes(large)	steel	0.10	787	30	23622.0	20	1181.1	0.0148	0.0222	0.0507		39.4	640	1.5800	39.8
2.6	**Dranage Pipe**	plastic	2.40	3365	85	286011.9	20	14300.6	0.1788	0.2686	0.6140	($298.91)	168.2	640	1.5800	170.1
2.7	**Spray Equipment**	steel		250	30	7500.0	10	750.0	0.0094	0.0141	0.0322	($18.50)	25.0	640	1.5800	25.3
2.8	**Electric & Hand Car**										0.0000	Included in building cost				
2.8.1	Electric Cart	steel		540	30	16200.0	10	1620.0	0.0203	0.0304	0.0696		54.0	16390	0.0650	57.5
2.8.2	Hand Cart	aluminum		74	240	17760.0	15	1184.0	0.0148	0.0222	0.0508		4.9	16390	0.0650	5.3
2.9	**Fork Lift**	steel		2063	30	61875.0	15	4125.0	0.0516	0.0775	0.1771	($2,104.11)	137.5	640	1.5800	139.0
2.10	**Pallet Jacks**	steel		225	30	6750.0	30	225.0	0.0028	0.0042	0.0097	($31.47)	7.5	640	1.5800	7.6
2.11	**Tracks**	steel etc	0.75track	4845	30	145350.0	20	7267.5	0.0908	0.1365	0.3120	($1,322.67)	242.3	640	1.5800	245.0
2.12	**Computer Equipment**			20			20					($1,011.19)	1.0	640	1.5800	1.0
Sub Total of Fixed Facilities & Equipments (1 - 2.12)						7715569.0		409558.3	5.1195	7.6915	17.5838	($26,482.56)				

Table C.4: Spreadsheet for "Greenhouse B"

(Continuesd)

Number	Inputs	Material	Volume or Length (cub.m etc)	Mass (kg)	Energy Intensity (MJ/kg)	Embodied Energy (MJ)	Life Expectancy (years)	Embodied Energy/Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	Energy Required for Transport (MJ/tn/km)	Energy for Transport (MJ/year)
3	**Variable Inputs I.**						1									
3.1.	**SawdustBag&RockWool**															
3.1.1	Plastic Bag	plastic		NA	85	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.1.2	Sawdust	sawdust		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.1.3	Rockwool	rockwool		849	28	23776.5	1	23776.5	0.2972	0.4465	1.0208	($7,572.38)	849.2	7736	0.0650	427.0
3.1.4	Rock Wool Wrap	plastic		48	85	4088.5	1	4088.5	0.0511	0.0768	0.1755		48.1	7736	0.0650	24.2
3.2	**Ground Cover**	plastic		2149	85	182631.0	1	182631.0	2.2829	3.4298	7.8410	($11,053.65)	2148.6	640	1.5800	2172.7
3.3	**White wash**	gypsum		NA	4.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.4	**Electricity([el]:[th]=0.3kWh:1kWh)**			73980	kwh[el]	886872.2	1	886872.2	11.0859	16.6555	38.0767	($4,165.24)				
3.5	**Natural Gas**			169504	86.3	14626520.0	1	14626520.0	182.8315	274.6867	627.9697	($57,806.32)	169504.2			
3.6	**Car Fuels**											($1,470.49)				
	diesel		1,101.32	748.8976	44	33251.1	1	33251.1	0.4156	0.6245	1.4276	($11,053.65)	748.9	640	1.5800	757.3
	gasoline		417.915	284.1822	49	13910.7	1	13910.7	0.1739	0.2612	0.5972	($11,053.65)	284.2	640	1.5800	287.4
3.7	**Labour Force**						1					($58,800.79)	0.0			
3.8	**Managers' Salary**											($30,000.00)				
4	**Variable Inputs II.**															
4.1	**Fertilizers**															
4.1.1	Potassium Sulfate			954	3.5	3337.3	1	1612.5	0.0202	0.0303	0.0692	($557.30)	375.0	640	1.5800	379.2
4.1.2	Potassium Chloride			375	4.3	1612.5	1	15000.0	0.1875	0.2817	0.6440	($93.00)	1500.0	640	1.5800	1516.8
4.1.3	Mono Potassium Phosphate			1500	10.0	15000.0	1	81003.9	1.0125	1.5213	3.4778	($2,400.00)	5704.5	640	1.5800	5768.4
4.1.4	Potassium Nitrate			5705	14.2	81003.9	1	91712.5	1.1464	1.7224	3.9376	($4,244.18)	7975.0	640	1.5800	8064.3
4.1.5	Calcium Nitrate			7975	11.5	91712.5	1	91712.5	1.1464	1.7224	3.9376	($3,030.50)	7975.0	640	1.5800	8064.3
4.1.6	Ammonium Nitrate			250	66.6	16647.5	1	16647.5	0.2081	0.3126	0.7147	($77.50)	250.0	640	1.5800	252.8
4.1.8	Magnesium Sulphate			3998	2.0	7996.0	1	7996.0	0.1000	0.1502	0.3433	($1,839.80)	3998.0	640	1.5800	4042.8
4.1.9	Sodium Molybdate			1	10.0	10.0	1	10.0	0.0001	0.0002	0.0004	($43.00)	1.0	640	1.5800	1.0
4.1.10	Iron Chelate			25	15.0	370.5	1	370.5	0.0046	0.0070	0.0159	($415.67)	24.7	640	1.5800	25.0
4.1.11	Potassium Bicarbonate			100	4.0	400.0	1	400.0	0.0050	0.0075	0.0172	($255.40)	100.0	640	1.5800	101.1
4.2	**Biological Pest Control**			285			1					($8,670.18)	284.8	640	1.5800	288.0
4.3	**Chemical Pesticides**											($1,340.98)				
4.3.1	Agribrom Powder			1.8	264.0	475.2	1	475.2	0.0059	0.0089	0.0204		1.8	640	1.5800	1.8
4.3.2	Kelthane			8.0	197.0	1576.0	1	1576.0	0.0197	0.0296	0.0677		8.0	640	1.5800	8.1
4.3.3	Lorsban			1.4	197.0	275.8	1	275.8	0.0034	0.0052	0.0118		1.4	640	1.5800	1.4
4.3.4	Monzate 200DF			2.5	163.0	407.5	1	407.5	0.0051	0.0077	0.0175		2.5	640	1.5800	2.5
4.3.5	Roccal			13.5	163.0	2200.5	1	2200.5	0.0275	0.0413	0.0945		13.5	640	1.5800	13.7
4.3.6	Sulfotep103			59.9	197.0	11800.3	1	11800.3	0.1475	0.2216	0.5066		59.9	640	1.5800	60.6
4.3.7	Plant Fume 103			48.0	197.0	9456.0	1	9456.0	0.1182	0.1776	0.4060		48.0	640	1.5800	48.5
4.3.8	Vendex			2.3	197.0	453.1	1	453.1	0.0057	0.0085	0.0195		2.3	640	1.5800	2.3
4.4	**Seeds**			0.1	38.7	5.7	1	5.7	0.0001	0.0001	0.0002	($3,915.14)	0.1	640	1.5800	0.1
4.5	**Liquid CO2**			101226.0	5.7	579012.7	1	579012.7	7.2377	10.8739	24.8591	($13,361.85)	101226.0	300	1.5800	47981.1
4.6	Miscellaneous Variable Costs (phone,insurance,consultation,etc.) which are missing from above											($58,673.71)				
Sub Total of Variable Inputs (3. - 4.7)								16683178.2	208.5397	313.3109	716.2695	($291,894.37)				
Grand Total of Fixed Inputs and Variable Inputs								**17092736.6**	**214.5834**	**322.3909**	**737.0275**	**($318,376.93)**				**93231.8**

Table C.4: Spreadsheet for "Greenhouse B"

(Continued)

	Mass (kg)	Energy Intensity (MJ/kg)	Embodied Energy (MJ)	Life Expectancy (years)	Embodied Energy/Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	Energy Required for Transport (MJ/tn/km)	Energy for Transport (MJ/year)
Grand Total of Fixed Inputs and Variable Inputs					**17092736.6**	**214.58336**	**322.3909**	**737.0275**	**($318,376.93)**				**93231.8**
Output Per Year (kg/yr)	291147									291147	640	3.0000	559002.2
Revenue per year ($/ yr.)									$400,327.13				
Net Profit per year ($/yr)									$81,950.19				
GROWING AREA without ACC consideration						0.6656	1.0000	2.2861					
Required Area per Unit Output (ha/1000ton/yr)						2.2861	2.2861	2.2861					
Output per hectare per year (kg/ha/yr)	437420												
Revenue per hectare per year ($/ha/yr)									$601,453.01				
Net Profit per hectare per year ($/ha/yr)									$123,122.29				
VISIBLE OCCUPIED AREA without ACC consideration						0.9242	1.3884	3.1742					
Required Area per Unit Output (ha/1000ton/yr)						3.1742	3.1742	3.1742					
Output per hectare per year (kg/ha/yr)	315043												
Revenue per hectare per hear ($/ha/yr)									$433,184.14				
Net Profit per hectare per year ($/ha/yr)									$88,676.29				
TOTAL LAND with ACC consideration (except transportation)						214.5834	322.3909	737.0275					
Required Area per Unit Output (ha/1000ton/yr)						737.0275	737.0275	737.0275					
Output per hectare year (kg/ha/yr)	1357												
Revenue per hectare per year ($/ha/yr)									$1,865.60				
Net Profit per hectare per year ($/ha/yr)									$381.90				
Inputs for Transportation (Importing materials) per year						1.1654	1.7509	4.0028					
Inputs for Transportation (Exporting products) per year						6.9875	10.4981	24.0000					
TOTAL LAND with ACC consideration including transportation						222.7363	334.6398	765.0303					
Required Area per Unit Output (ha/1000ton/yr)						765.0303	765.0303	765.0303					
Output per hectare per year (kg/ha/yr)	1307												
Revenue per hectare per year ($/ha/yr)									$1,797.31				
Net Profit per hectare per year ($/ha/yr)									$367.92				
1 **Land Greenhouse**						0.6656	1.0000						
Land-packng&office&nutrient						0.0665	0.0999						
Land-Pond						0.0000	0.0000						
Land Docking & Parking Area						0.0310	0.0465						
Land Septic Place						0.0000	0.0000						
Land Roadway						0.1611	0.2420						
Land Total for Tomatoes						0.9242	1.3884						

Table C.5: Spreadsheet for HillTop Gardens Field Tomato Production

As of April 25, '93

Number	Inputs	Material	Vol. etc (cub.m. etc)	Mass (kg)	Energy Int. (MJ/kg)	Embodied Energy (MJ)	Life Expect (years)	Embodied En. Per Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	En.Require. for Trans. (MJ/ton/km)	Energy for Trans. (MJ/year)
1	**Land occupied**								1.5362	1.2654	22.5795	($753.04)				
1.1	Growing Area								1.2140	1.0000	17.8435					
1.2	Other Service Areas								0.3222	0.2654	4.7360					
2	**Embodied Energy of Facilities**															
2.1	**Building**															
2.1.1	Cover	plastic		8.9	64	566.4	7	80.91	0.0010	0.0008	0.0149	($11.28)	1.3	640	1.5800	1.3
2.1.2	Framework	wood	3.75	1575.0			26		0.0396	0.0326	0.5819	$0.00	60.6	87.5	3.0000	15.9
2.1.3	Steel Equipments	steel		145.5	30	4364.7	15	290.98	0.0036	0.0030	0.0535	($51.95)	9.7	640	1.5800	9.8
2.1.4	Other Service Bldgs		14.4	(sq.m)		24670.1	30	822.34	0.0103	0.0085	0.1511					
2.1.5	Construction	7% of embodied energy of material				29601.2		83.60	0.0010	0.0009	0.0154					
2.2	**Irrigation sys**															
2.2.1	Pipe	Alminium	0.05	384.8	240	92343.0	20	4617.15	0.0577	0.0475	0.8483	($79.38)	19.2	640	1.5800	19.5
2.2.2	Pipe & Filter	plastic		2.7	64	169.6	10	16.96	0.0002	0.0002	0.0031	($83.43)	0.3	640	1.5800	0.3
2.2.3	Tube	plastic		22.1	64	1414.4	3	471.47	0.0059	0.0049	0.0866	($185.10)	7.4	640	1.5800	7.4
2.7	**Spray Equipment**	steel		200.0	30	6000.0	15	400.00	0.0050	0.0041	0.0735	($124.69)	13.3	640	1.5800	13.5
2.8	**Tractor**	steel		500.0	30	15000.0	50	300.00	0.0038	0.0031	0.0551	($64.69)	10.0	640	1.5800	10.1
2.9	**Plow&Sheet laying**	steel		250.0	30	7500.0	15	500.00	0.0063	0.0051	0.0919	($155.86)	16.7	640	1.5800	16.9
2.10	**Tracks(0.5*0.5ton)**	steel		250.0	30	7500.0	15	500.00	0.0063	0.0051	0.0919	($519.53)	16.7	640	1.5800	16.9
2.14	**Ground cover**	plastic		89.1	64	5705.0	1	5704.96	0.0713	0.0587	1.0482	($225.12)	89.1	640	1.5800	90.1
Sub Total of Fixed Facilities & Equipments (1 - 2.14)								13788.36	0.2119	0.1746	3.1152	($2,254.07)	244.2			201.6
3	**Variable cost I.**															
3.1	**Electricity([el]:[th]=0.3kWh:1kWh)**			2996.1	kWh[el]	35917.7	1	35917.73	0.4490	0.3698	6.5990	($150.00)				
3.2	**Propane**		666.7	334.0	49.0	16350.1	1	16350.12	0.2044	0.1683	3.0039	($200.00)	334.0	640	1.5800	337.8
3.3	**Fuels(tractor)**	gasoline	430.6	292.8	50.4	14757.5	1	14757.52	0.1845	0.1520	2.7113	($193.34)	292.8	640	1.5800	296.1
3.4	**Labour Forces**											($7,605.00)				
3.5	**Manager's Salary**											($24,000.00)				0.0
4	**Variable cost II.**															0.0
4.1	**Fertilizers**															0.0
4.1.1	All Purpose (20-20-20)			30.0	19.3	578.7	1	578.70	0.0072	0.0060	0.1063	($66.00)	30.0	640	1.5800	30.3
4.1.2	Plant Starter (10-52-10)			30.0	14.9	447.9	1	447.90	0.0056	0.0046	0.0823	($95.30)	30.0	640	1.5800	30.3
4.1.3	Urea (46-0-0)			250.0	36.6	9150.0	1	9150.00	0.1144	0.0942	1.6811	($100.00)	250.0	640	1.5800	252.8
4.1.4	Calcium Nitrate (15.5-0-0)			145.2	11.5	1669.8	1	1669.80	0.0209	0.0172	0.3068	($48.00)	145.2	640	1.5800	146.8
4.2	**Herbicide & Insecticide**														1.5800	0.0
4.2.1	Trifluralin (Treflan545EC)			0.22	150	32.7	1	32.70	0.0004	0.0003	0.0060	($1.49)	0.2	640	1.5800	0.2
4.2.2	Metribuzin (Sencor500F)			0.09	264	22.4	1	22.44	0.0003	0.0002	0.0041	($2.22)	0.1	640	1.5800	0.1
4.2.3	Carbaryl (Sevin50W)			2.70	153	413.1	1	413.10	0.0052	0.0043	0.0759	($27.40)	2.7	640	1.5800	2.7
4.4	**Seeds**			0.048	38.7	1.9	1	1.86	0.0000	0.0000	0.0003	($382.22)	0.0	640	1.5800	0.0
4.5	**Dirt**			13880			1					($214.40)	13880.0	210	3.0000	8744.4
Sub Total of Variable Inputs (3 - 4.5)								79341.87	0.9918	0.8169	14.5772	($33,085.37)	14965.1			9841.6
Grand Total of Fixed & Variable Inputs								93130.23	1.2037	0.9915	17.6924	($35,339.44)	15209.3			10043.2

Table C.5: Spreadsheet for HillTop Gardens
(Continued)

	Mass (kg)	Energy Int. (MJ/kg)	Embodied Energy (MJ)	Life Expect (years)	Embodied En. Per Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	En.Require. for Trans. (MJ/ton/km)	Energy for Trans. (MJ/year)
Grand Total of Fixed & Variable Inputs					93130.23	1.2037	0.9915	17.6924	($35,339.44)	15209.3			10043.2
Output/year (kg/year)	68036.0									68036.0	370	3.0000	75520.0
Revenue/year ($/year)									$63,750.00				
Net Profit/year($/year)									$28,410.56				
GROWING AREA without ACC consideration						1.2140	1.0000	17.8435					
Required Area per Unit Output (ha/1000ton/yr)						17.8435	17.8435	17.8435					
Output/ha/year (kg/ha/year)	56042.8												
Revenue/ha/year ($/ha/year)									$52,512.36				
Net Profit/ha/year ($/ha/year)									$23,402.43				
VISIBLE OCCUPIED LAND without ACC consideration						1.5362	1.2654	22.5795					
Required Area per Unit Output (ha/1000ton/yr)						22.5795	22.5795	22.5795					
Output/ha/year (kg/ha/year)	44288.0												
Revenue/ha/year ($/ha/year)									$41,497.99				
Net Profit/ha/year ($/ha/year)									$18,493.82				
TOTAL LAND with ACC consid. except TRANSPORTATION)						2.7399	2.2570	40.2719					
Required Area per Unit Output (ha/1000ton/yr)						40.2719	40.2719	40.2719					
Output/ha/year (kg/ha/year)	24831.2												
Revenue/ha/year ($/ha/year)									$23,266.94				
Net Profit/ha/year ($/ha/year)									$10,369.04				
Inputs for Transp. (Inoprt of Materials) per year					10043.2	0.1255	0.1034	1.8452					
Inputs for Transp. (Export of products) per year					75520.0	0.9440	0.7776	13.8750					
TOTAL LAND with ACC consid. including TRANSPORTATION)						3.8095	3.1380	55.9921					
Required Area per Unit Output (ha/1000ton/yr)						55.9921	55.9921	55.9921					
Output/ha/year (kg/ha/year)	17859.7												
Revenue/ha/year ($/ha/year)									$16,734.57				
Net Profit/ha/year ($/ha/year)									$7,457.86				
1 Land-Tomato Field						1.2140	1.0000						
Land-Nursary Greenhouse						0.0058	0.0048						
Land-Workshop&Storage						0.0014	0.0012						
Land-Roadway&Parking						0.3150	0.2595						
Total Visible Occupied Land for Tomato Growing						1.5362	1.2654						

Table C.6: Spreadsheet for Horsting Farms Field Tomato Production

As of April 25, '93

Number	Inputs	Material	Vol. etc (cub.m. etc)	Mass (kg)	Energy Int. (MJ/kg)	Embodied Energy (MJ)	Life Expect (years)	Embodied En. Per Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	En.Require. for Trans. (MJ/ton/km)	Energy for Trans. (MJ/year)
1	**Land occupied**								1.4211	1.1706	14.2114	($753.04)				
1.1	Growing Area								1.2140	1.0000	12.1400					
1.2	Other Service Areas								0.2071	0.1706	2.0714					
2	**Embodied Energy of Facilities**															
2.1	**Building**															
2.1.1	Other Service Bldgs		94	(sq.m)		161040.8	30	5368.03	0.0671	0.0553	0.6710					
2.1.2	Construction	7% of embodied energy of material				11272.9		375.76	0.0047	0.0039	0.0470					
2.2	**Irrigation sys**															
2.2.1	Pipe	Alminium	0.05	384.8	240	92343.0	20	4617.15	0.0577	0.0475	0.5771	($79.38)	19.2	640	1.5800	19.5
2.2.2	Pipe & Filter	plastic		2.7	64	169.6	10	16.96	0.0002	0.0002	0.0021	($83.43)	0.3	640	1.5800	0.3
2.2.3	Tube	plastic		22.1	64	1414.4	3	471.47	0.0059	0.0049	0.0589	($185.10)	7.4	640	1.5800	7.4
2.7	**Spray Equipment**	steel		200.0	30	6000.0	15	400.00	0.0050	0.0041	0.0500	($124.69)	13.3	640	1.5800	13.5
2.8	**Tractor(6ton*0.1)**	steel		600.0	50	30000.0	50	600.00	0.0075	0.0062	0.0750	($64.69)	12.0	640	1.5800	12.1
2.9	**Plow&Sheet laying**	steel		250.0	30	7500.0	15	500.00	0.0063	0.0051	0.0625	($155.86)	16.7	640	1.5800	16.9
2.10	**Tracks(3.5ton*0.1)**	steel		350.0	18	6300.0	15	420.00	0.0053	0.0043	0.0525	($519.53)	23.3	640	1.5800	23.6
2.14	**Ground cover**	plastic		89.1	64	5705.0	1	5704.96	0.0713	0.0587	0.7131	($225.12)	89.1	640	1.5800	90.1
Sub Total of Fixed Facilities & Equipments (1 - 2.14)								18474.33	0.2309	0.1902	2.3093	($2,190.84)	181.3			183.4
3	**Variable cost I.**															
3.1	**Electricity([el]:[th]=0.3kWh:1kWh)**			1369.6	kWh[el]	16419.2	1	16419.19	0.2052	0.1691	2.0524	($68.57)				
3.2	**Fuels(tractor)**	diesel	567.75	284.4	44.4	12629.3	1	12629.26	0.1579	0.1300	1.5787	($200.00)	284.4	640	1.5800	287.6
3.3	**Fuels(truck)**	gasoline	378.5	257.4	50.4	12972.0	1	12971.95	0.1621	0.1336	1.6215	($169.95)	257.4	640	1.5800	260.3
3.4	**Labour Forces**											($12,600.00)				
3.5	**Manager's Salary**											($6,000.00)				0.0
4	**Variable cost II.**															0.0
4.1	**Fertilizers**											($300.00)				0.0
4.1.1	12-5-0			340.0	9.5	3230.0	1	3230.00	0.0404	0.0333	0.4038		340.0	640	1.5800	343.8
4.1.2	Ptassium Sulfate (0-0-50)			204.0	5.0	1024.1	1	1024.08	0.0128	0.0105	0.1280		204.0	640	1.5800	206.3
4.1.3	0-0-60			136.0	6.0	816.0	1	816.00	0.0102	0.0084	0.1020		136.0	640	1.5800	137.5
4.1.4	Iron Sulphate (Fe 21%)			14.0	6.3	88.2	1	88.20	0.0011	0.0009	0.0110		14.0	640	1.5800	14.2
4.1.5	Borate 40			11.0	4.0	44.0	1	44.00	0.0006	0.0005	0.0055		11.0	640	1.5800	11.1
4.2	**Seeds**			0.048	39.19	1.9	1	1.88	0.0000	0.0000	0.0002	($382.22)	0.0	640	1.5800	0.0
4.3	**Plant propagation**					36293.4	1	36293.40	0.4537	0.3737	4.5367	($420.00)	350.0	840	3.0000	882.0
Sub Total of Variable Inputs (3 - 4.5)								83517.96	1.04	0.8599	10.4397	($20,140.74)	1596.9			2142.8
Grand Total of Fixed & Variable Inputs								101992.29	1.2749	1.0502	12.7490	($22,331.58)	1778.2			2326.2

Table C.6: Spreadsheet for Horsting Farms
(Continued)

	Mass (kg)	Energy Int. (MJ/kg)	Embodied Energy (MJ)	Life Expect (years)	Embodied En. Per Year (MJ/year)	Land-Equivalant (ha/year)	Land-Equivalant (ha/yr per 1ha of Grow Area)	Land-Equivalant (ha/1000ton /year)	Cost or Benefit Per Year ($/year)	Transported Mass/year (kg/year)	Distance Traveled (km)	En.Require. for Trans. (MJ/ton/km	Energy for Trans. (MJ/year)
Grand Total of Fixed & Variable Inputs					101992.29	1.2749	1.0502	12.7490	($22,331.58)	1778.2			2326.2
Output/year (kg/year)	100000.0									100000.0	370	3.0000	111000.0
Revenue/year ($/year)									$88,000.00				
Net Profit/year($/year)									$65,668.42				
GROWING AREA without ACC consideration						1.2140	1.0000	12.1400					
Required Area per Unit Output (ha/1000ton/yr)						12.1400	12.1400	12.1400					
Output/ha/year (kg/ha/year)	82372.3												
Revenue/ha/year ($/ha/year)									$72,487.64				
Net Profit/ha/year ($/ha/year)									$54,092.61				
VISIBLE OCCUPIED LAND without ACC consideration						1.4211	1.1706	14.2114					
Required Area per Unit Output (ha/1000ton/yr)						14.2114	14.2114	14.2114					
Output/ha/year (kg/ha/year)	70366.1												
Revenue/ha/year ($/ha/year)									$61,922.16				
Net Profit/ha/year ($/ha/year)									$46,208.30				
TOTAL LAND with ACC consid. except TRANSPORTATION)						2.6960	2.2208	26.9604					
Required Area per Unit Output (ha/1000ton/yr)						26.9604	26.9604	26.9604					
Output/ha/year (kg/ha/year)	37091.4												
Revenue/ha/year ($/ha/year)									$32,640.43				
Net Profit/ha/year ($/ha/year)									$24,357.34				
Inputs for Transp. (Inoprt of Materials) per year					2326.2	0.0291	0.0240	0.2908					
Inputs for Transp. (Export of products) per year					126000.0	1.5750	1.2974	15.7500					
TOTAL LAND with ACC consid. including TRANSPORTATION)						4.3001	3.5421	43.0012					
Required Area per Unit Output (ha/1000ton/yr)						43.0012	43.0012	43.0012					
Output/ha/year (kg/ha/year)	23255.2												
Revenue/ha/year ($/ha/year)									$20,464.54				
Net Profit/ha/year ($/ha/year)									$15,271.30				
1 Land-Tomato Field						1.2140	1.0000						
Land-Nursary Greenhouse						0.0058	0.0048						
Land-Workshop&Storage						0.0094	0.0077						
Land-Roadway&Parking						0.1920	0.1582						
Total Visible Occupied Land for Tomato Growing						1.4211	1.1706						