THERMODYNAMIC INPUT-OUTPUT ANALYSIS OF ECONOMIC AND ECOLOGICAL SYSTEMS FOR SUSTAINABLE ENGINEERING

DISSERTATION

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By

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ABSTRACT

It is widely recognized that conservation of natural capital is vital for sustainable development. However, techniques for evaluating natural capital flows are not yet satisfactorily developed. Traditional methods in engineering, economics and other disciplines tend to focus on economic capital while ignoring the contribution of ecological resources. In this dissertation a new thermodynamic approach is proposed that addresses this shortcoming. The new approach, called Thermodynamic Input-Output Analysis (TIOA), calculates degradation of energy quality in the economic and ecological stages of the production chain of a process or product. In this analysis energy quality is measured in terms of exergy or available energy. TIOA synthesizes data about natural and human resource consumption and emissions from various public domain databases. It uses concepts from systems ecology to determine exergy flows in the ecological stages and economic input-output analysis to determine exergy flows in the economic stages of a production chain. This dissertation applies TIOA to analyze the 91-sector 1992 and the 488-sector 1997 representations of the US economy. It calculates natural capital throughputs of individual industry sectors in terms of their Ecological Cumulative Exergy Consumption (ECEC). It also juxtaposes natural capital throughputs with economic capital throughputs by calculating ECEC/money ratios. These ratios indicate the discrepancy between thermodynamic work and the willingness of people to pay for

economic goods and services. ECEC/money ratios are found to decrease from basic infrastructure industries to value-added service industries suggesting that the service industries are better at valuing ecosystem contribution than the resource extraction and manufacturing industries. These results are shown to have important implications to construction of pro-ecological macroeconomic policies. TIOA also calculates ECEC/ICEC ratios to determine the degree to which conventional thermodynamic techniques underestimate the contribution of ecosystems. The industry-specific ECEC/money and ICEC/money ratios are a major improvement over single economy-wide emergy/$ ratios in emergy analysis and similar aggregate metrics in thermoeconomics. Such industry specific ratios are useful in hybrid thermodynamic analysis of industrial systems and provide a unique insight into their environmental implications. This has been illustrated by comparing alternative electricity generation systems. Industry specific ECEC/money and ICEC/money ratios are also useful in constructing the hierarchical thermodynamic metrics of sustainability. Such metrics have many desirable attributes of ideal sustainability metrics such as stackability, robustness, non-perverseness in indicating progress towards sustainability and communicable to diverse audiences and stake-holders. In the end, this dissertation proposes a multiscale statistical framework for Life Cycle Inventory (LCI) analysis. Such framework treats LCI as a statistical data fusion problem and ensures maximum utilization available data and models. It can also identify missing data, reconcile conflicting data and determine confidence bounds on LCA results by incorporating stochastic and subjective knowledge.

Dedicated to my beloved parents (Maya and Uday Ukidwe) and sister (Nivedita Ukidwe)

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FIELDS OF STUDY

Major Field: Chemical Engineering

Studies in: Process Systems Engineering
Industrial Ecology
Environmental Life Cycle Assessment
Sustainable Engineering

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CHAPTER 1

INTRODUCTION

1.1 Motivation

The scale of human pressures on ecosystems has increased enormously in last century-and even more so in the last few decades. Since 1980, global economy has tripled in size and the world population has grown 30% to 6 billion people. Consumption of everything from food grains and water to refrigerators and cars has grown in tandem. Figure 1.1 shows global trends for some of the key consumption variables and effects thereof on environmental parameters such as atmospheric CO_2 level, loss of rainforests and exploitation of fisheries. These pressures are not likely to subside soon. Global economy is expected to grow five folds in next 50 years and the global population is expected to grow to 9 billion in the same period. Demand for rice, wheat and maize is likely to grow 40% by 2020, pushing water demand for irrigation up by 50% or more (WRI, 2000).

All these socioeconomic changes would come at the cost of ecosystems that are already under severe anthropogenic stress. Following statistics regarding the state of global ecosystems are quite compelling.

- 25% of the world's most important fish stocks are depleted, over-harvested or just beginning to recover from over-harvesting. Another 44% are being harvested at their biological limit and consequently are prone to over-harvesting.
- Freshwater wetlands that store water and moderate flood flows have been reduced as much as 50% worldwide.
- Forest cover has been reduced by 20% worldwide, with some forest ecosystems such as the dry tropical forests of Central America virtually gone. More than 50% of the mangroves in many countries have been reclaimed for human settlements. Grasslands have been reduced by more than 90% in many areas. Only tundra, arctic and deep-sea ecosystems have emerged relatively unaffected, but are being subject to increasing pressure from human activities. Loss of habitat along with pollution, overexploitation, and competition from invasive species has caused significant loss of biodiversity.

Degradation of global ecosystems has also had negative repercussions on social and economic fronts. Collapse of cod fishery in the maritime provinces of Canada in early 1990s left 30,000 fishers dependent on government welfare payments, and adversely affected the economic well-being of 700 communities in Newfoundland alone. Commercial cutting of forests in India has left the traditional system of village management of local forests in shambles, creating scarcity of fuel-wood and building materials to millions of villagers. Introduction of Nile perch and Nile Tilapia in Lake Victoria destabilized the local ecosystem jeopardizing the sustenance of 30 million people in bordering Uganda, Kenya and Tanzania.

One of the primary reasons behind the current state of global ecosystems is the lack of appreciation of their importance in human activities. Traditional methods of analysis in engineering, economics and other disciplines have tended to ignore the role of ecosystems by assuming them to be an “infinite sink” or “free”. This assumption was practical at the beginning of the industrial revolution when natural resources were seemingly endless and the limiting step was the rate at which they could be converted into more value-added products. However, at the turn of the 21^{st} century, industrial revolution has come a long distance, and the limits on the carrying capacity of global ecosystems have been clearly exposed.

This has also motivated development of many techniques to determine contribution of ecosystems to industrial activity in recent years. However most of the existing techniques for environmental accounting have some major shortcomings that entail continued work in developing more rigorous and comprehensive methodologies. Such methodologies would work as a yardstick in measuring the progress towards sustainable development, and would be instrumental in defining the environmental objective in the design of the industrial systems of the future. Sustainable development is classically defined as the “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED, 1997). In other words, sustainable development ensures that each generation bequeaths to its successor at least as large a productive capital base as it inherited from its predecessor (Dasgupta, 2002).

1.2. Business Case for Sustainable Development

Exposed limitations on carrying capacity of ecosystems and the resulting adverse impacts on socioeconomic aspects of the human society is not the sole motivation behind development of better tools for environmental accounting. Leaders in the global business community have also started realizing the strategic significance of “sustainable development” to their operations (Bakshi and Fiksel, 2003). They are realizing that profitability by itself is an inadequate measure of a company’s viability, and many intangible and non-financial concerns are drivers of long-term share holder value. These intangibles include, for instance, brand value that is affected by consumer perception and company’s commitment to social and environmental responsibility.

Sustainable business practices not only improve resource productivity and operational efficiency, but also satisfy a broad range of stake-holders including customers, employees, local communities, regulators and advocacy groups (Hoffman, 2001). As a reflection of this growing realization, 36% of top 100 US companies publish annual sustainability reports (KPMG, 2002). A recent Price-Waterhouse-Coopers survey of 140 US companies, 101 of which were Fortune 1000 companies, showed that 75% had adopted sustainable business practices. The financial community has also recognized that commitment to sustainable operations often translates into better management and financial stability. This is evident from the increasing interest in Dow Jones Sustainability Index that has consistently outperformed the regular Dow Jones Index (DJSI, 2003). The business case for sustainable development provides an additional impetus to development of environmental accounting tools that are accurate, comprehensive, robust, non-perverse in indicating progress towards sustainability and protective of proprietary information.

1.3. Existing Methods for Environmental Accounting

As the importance of ecologically-conscious decision-making is being realized, various techniques are being developed in academia and industry to that effect. Approaches for full or total cost assessment (AIChE, 2002) to include environmental and social aspects along with economic aspects are being developed and used in industry. Techniques such as Life Cycle Assessment (LCA) are being standardized and adopted by many corporations to obtain more holistic and complete information about the impact of their products and processes on the environment. However, LCA focuses mostly on the emissions from industrial processes and their impact and on consumption of nonrenewable resources. It does not account for the contribution of ecosystems to industrial activity. A variety of techniques have attempted to quantify the contribution of ecosystems to economic activity. All techniques face common challenges of combining information represented in a diverse set of units, uncertain knowledge and lack of adequate data about ecosystems. These techniques may be broadly categorized as preference-based and biophysical methods.

Preference based methods assign a monetary value to ecosystem products and services by relying on human valuation. A pioneering study by Costanza et al. (Costanza et al., 1997) estimated the value of ecosystem services to be almost twice that of the global gross economic product. A more recent study indicates that saving the existing unspoiled ecosystems is at least 100 times more valuable than developing them for economic activity (Balmford et al., 2002). Many techniques have been developed for valuation of environmental products and services (Bockstael et al., 2000). Industry groups have also collaborated to develop preference-based methods for Total Cost

Assessment (AIChE, 2002). A significant advantage of these methods is that using a single unit permits ready comparison across economic and ecological contributions. However, valuation methods are often controversial and rely on knowledge about the role of each ecological product and service. Such information, along with satisfaction of scientific laws may be provided by biophysical methods.

Biophysical methods rely on biological and physical principles to account for the role of ecosystems.

- *Mass* based methods have been popular to determine the physical basis of economic activity and its interaction with ecosystems (Adriaanse et al., 1997; Matthews et al., 2000; ConAccount, 2002; NRC, 2004). These methods determine the mass of materials flowing from ecosystems to the economy and the emissions from the economy. Indirect or hidden flows are also quantified. Most of these studies are at the level of the entire economy, and disaggregation to more detailed levels is being developed. Since mass does not capture many other properties of materials, such as their energetic contributions and impact, these Material Flow Analysis (MFA) studies are of limited use by themselves. However, they can provide a good database for developing other more comprehensive methods. Furthermore, existing methods are quite limited in their incorporation of ecosystem services, which cannot be readily captured in terms of mass flow.

- *Energy* based methods such as net energy analysis and full fuel cycle analysis determine the flow of energy through various sectors of the economy (Hannon, 1973; Costanza and Herendeen, 1984; Spreng, 1988). They consider energy content of industrial inputs and outputs including exchanges between economic sectors and those from ecosystems to the economy. The framework of input-output analysis is used for mathematically sound analysis of energy flow in ecological and economic systems (Hannon, 2001). Like mass, energy also does not capture many aspects such as contribution of non-energetic materials, environmental impact of emissions and ignores the second law of thermodynamics.

- *Exergy* based methods satisfy the first and the second law and can capture an array of material and energy streams. They have been popular for assessing thermodynamic efficiency of industrial processes (Szargut et al., 1988) and to analyze the behavior of ecosystems (Jorgensen, 1997). Exergy is the energy available to do useful work. It can capture various quality aspects of streams as indicated by their mass, energy, concentration, velocity and location. Thus, *exergy can characterize both mass and energy streams, and is the only truly limiting resource on this planet* (Connely and Koshland, 1997; Sciubba, 2001; Wall, 2002). Various extensions of exergy analysis such as Industrial Cumulative Exergy Consumption (ICEC) analysis (Szargut et al., 1988) and Exergetic LCA (Cornelissen and Hirs, 1997) have been developed in the past to analyze industrial systems. ICEC analysis considers cumulative exergy consumption in the industrial links of a production chain, and has a strong basis in engineering thermodynamics. Similarly Extended Exergy Accounting (EEA) proposed by Sciubba determines cumulative exergy consumption associated with not only raw material inputs but also labor and capital inputs and non-energetic externalities (Sciubba, 2001; Sciubba 2004). However, all the aforementioned exergy based methods ignore the contribution of ecosystems, and the impact of emissions.

EEA does assume the exergetic cost of zero-impact to be proportional to the physical and chemical exergies of the pollutant, an assumption that is, at best, controversial and unsubstantiated. *Furthermore, exergy analysis at the level of economic sectors is not yet available*. Other studies that account for the contribution of ecosystems are at the scale of the entire national or global economy, and rely on economic valuation (Costanza et al., 1997) or material flow analysis (Adriaanse et al., 1997; Matthews et al., 2000). Studies at the level of economic sectors are available in energy analysis (Costanza, 1980), but these are not as comprehensive as the study presented in this dissertation, and may violate the second law. Exergy analysis has also been used to analyze societies (Wall et al., 1994; Ertesvag, 2001), but the focus is mainly on comparing exergetic efficiencies of economic sectors, and neither the impact of emissions nor contribution of ecosystems are included.

- *Emergy* based methods developed by systems ecologists have also been used to analyze ecological and economic systems. Emergy is the available energy used directly or indirectly to make any product or service, and is measured in solar equivalent joules (sej) (Odum, 1996). The key strength of emergy analysis is that it *does* account for the contribution of ecological products and processes. However, emergy analysis is often misunderstood, faces quantitative and algebraic challenges, and its broad claims about ecological and economic systems are quite controversial (Brown and Herendeen, 1996; Hau and Bakshi, 2004a). Besides, emergy analysis has not been done at the economic input-output scale.
- *Ecological Cumulative Exergy Consumption (ECEC)* is an extension of Industrial Cumulative Exergy Consumption to include ecosystems (Hau and Bakshi, 2004b).

ECEC provides insight into emergy analysis by exposing its thermodynamic underpinning, and its close relationship with ICEC analysis. Under conditions of identical analysis boundary, allocation method and approach for combining global exergy inputs, emergy is shown to be identical to ECEC, with transformities (Odum, 1996) being equivalent to the reciprocal of the cumulative degree of perfection (CDP), a measure of efficiency, in ICEC analysis. Very importantly, ECEC is free from all the controversial aspects of emergy analysis such as the maximum empower principle and the emergy theory of value that have hindered its use. Other issues such as considering solar inputs from prehistory are also not used in the proposed approach, since ECEC only includes concurrent exergy flows. ECEC relies only on those elements of emergy analysis that quantify the direct contribution of ecosystem products and services. Thus, ECEC combines the scientific rigor of exergy analysis with the ability of emergy analysis to account for ecological products and services without relying on any of the controversial aspects of emergy analysis. Further details about ECEC analysis have been provided in Chapter 2 of this dissertation.

1.4. Research Contribution

This dissertation develops a new methodology that provides a unique insight into the reliance of economic sectors on ecosystems for obtaining their inputs and for dealing with their outputs. The new methodology is called Thermodynamic Input-Output Analysis (TIOA), and is based on the theoretical foundation provided by ECEC Analysis. The distinguishing features of TIOA are as follows.

- Unlike traditional methods for environmental accounting, TIOA successfully incorporates the contribution of ecological resources to economic activity by synthesizing data and concepts from systems ecology, material and energy flow accounting and economic input-output analysis.
- TIOA treats the joint economic and ecological system as a single network of energy flows with exergy as the ultimate limiting resource. Consequently, TIOA can deal with a variety of material and energy streams in a theoretically rigorous fashion. Furthermore, unlike mass- and energy- based methods, TIOA can acknowledge quality differences between ecological resources.
- Use of economic input-output data enables TIOA to do an industry-specific analysis. Such analysis is more disaggregate, and hence more useful, than an aggregate analysis for the entire economy as is the case in the state-of-the-art emergy analysis and thermoeconomics.

Furthermore, this dissertation applies TIOA to 91-sector 1992 and 488-sector 1997 US economic models. It presents data for natural resource inputs and emissions for the two economic models, and calculates total ECEC requirements of individual industry sectors. Total ECEC requirement represents the thermodynamic basis of industrial activity and is conceptually similar to *ecological cost*. It also determines industry-specific ECEC/money ratios for the two economic models. ECEC/money ratio demonstrates the discrepancy between thermodynamic work required to produce an ecological resource and the willingness of people to pay for it. Such discrepancy could lead to a suboptimal allocation of ecological resources through the economic system (Ayres, 1998). Moreover, the industry-specific ECEC/money ratios provide a more accurate alternative to a single emergy/money ratio (Odum, 1996) or exergy/money ratio (Sciubba, 2001) currently being used in emergy and exergy analyses. TIOA also calculates ECEC/ICEC ratio to demonstrate the extent to which existing thermoeconomic techniques underestimate the contribution of ecosystems. This ratio reflects quality differences between ecological resources including their renewable or non-renewable nature. Besides ECEC/money and ECEC/ICEC ratios can be used in conjunction to generate industry-specific ICEC/money ratios that could be used to improve upon the ad hoc procedures currently used in thermoeconomics to determine cumulative exergy consumption of purchased goods and services. The results obtained in this dissertation may also provide a complementary biophysical approach to valuation-based methods (Costanza et al., 1997) for quantifying the importance of ecosystems. Economic input-output LCA (EIOLCA, 2004) is similar to the proposed approach in its use of the toxic release inventory data to determine emissions from each sector. However, unlike previous approaches, the work described in this dissertation also accounts for ecological inputs, and uses end-point methods of impact assessment, with exergy as the common thermodynamic unit.

The rest of this dissertation is organized as follows. Chapter 2 provides background information about economic input-output analysis and the thermodynamic principles relevant to ECEC analysis. This chapter discusses the equivalence between cumulative exergy consumption and emergy, and proposes an algorithm for applying ECEC analysis to networks of industrial systems. Chapter 3 presents Thermodynamic Input-Output Analysis (TIOA) methodology, and illustrates it with a small hypothetical example. This chapter also discusses the integrated economic-ecological-social system.

Chapter 4 applies TIOA to 91-sector 1992 model of the US economy, whereas Chapter 5 applies it to the 488-sector 1997 benchmark model of the US economic system. Both these chapters provide detailed data about ecological resources and emissions along with corresponding data sources. They also present results about total ECEC requirements, ECEC/money ratios and ECEC/ICEC ratios for individual industry sectors from the two economic models.

TIOA has numerous applications at micro- as well as macro-scales. Some of these applications have been discussed in Chapter 6. Chapter 6 presents a comparative evaluation of coal-fired thermoelectric and geothermal electricity generation systems using results for the 1992 economic model. This chapter also presents results for a more comprehensive case study comparing environmental implications of six electricity systems, including coal-, NG- and oil-fired thermoelectric facilities and geothermal, hydroelectric and wind-based systems. This case study uses results for the 1997 model of the US economy. Chapter 6 also presents hierarchical thermodynamic metrics of sustainability that are easy to calculate and have many desirable attributes of ideal sustainability metrics. At a more macro-scale, Chapter 6 studies accumulation of natural and economic capitals along supply chains of industry sectors. The results reveal a hierarchical organization of the US economy that resembles an "ecological food-chain". Basic infrastructure and resource extraction industries such as mining and utilities are found to be at the basis of such a hierarchy, whereas more value-added industries such as finance, real estate and services are at the top. These results have been analyzed from the standpoints of weak and strong sustainability paradigms. The results have important implications to outsourcing, sustainable international trade and corporate restructuring.

Chapter 7 proposes a new framework for Life Cycle Inventory (LCI) analysis. The new framework treats the LCI problem as a multiscale statistical data fusion problem. The resultant Multiscale Life Cycle Inventory (MSLCI) methodology utilizes all available data and can be easily extended to include stochastic variables and subjective or expert knowledge. The application of MSLCI has been discussed via a hypothetical example that determines embodied CO_2 content of the output of a polymer manufacturer. Finally Chapter 8 presents concluding remarks and future work.

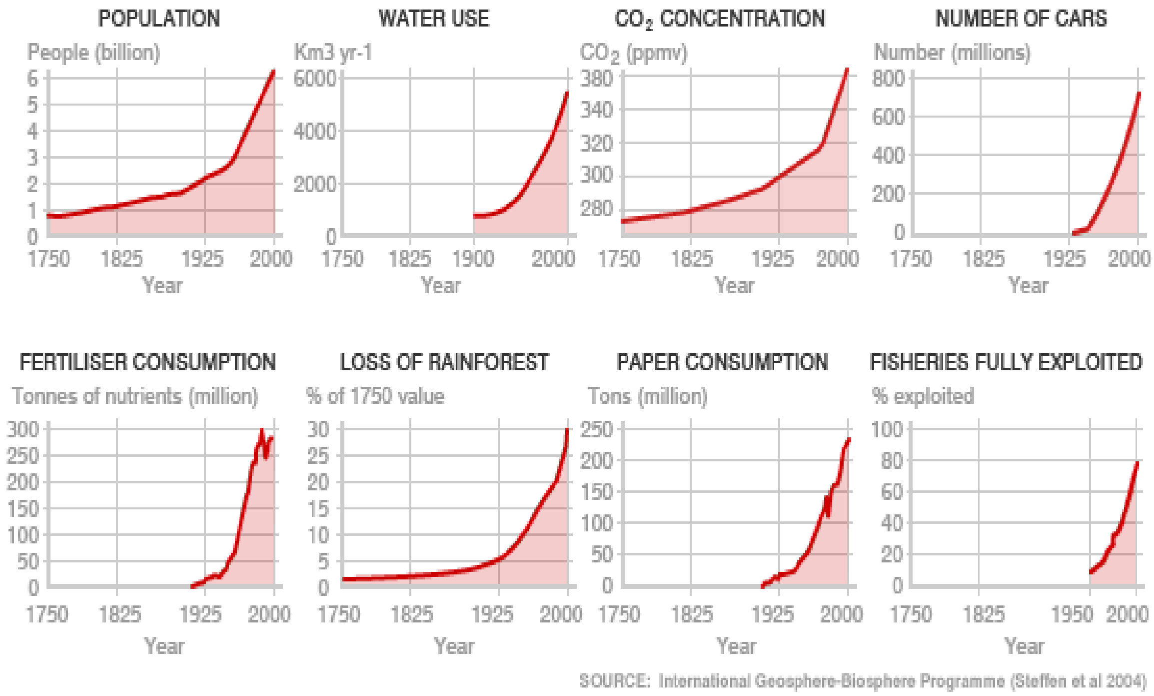


Figure 1.1: Changing Environment: Some Global Trends (1750-2000) (Steffen et al., 2004)

CHAPTER 2

BACKGROUND

2.1 Input-Output Analysis

Input-output analysis is a general equilibrium model that describes interactions between different units of a network (Leontief, 1936; Miller and Blair, 1985). It can be applied to any network as long as interactions between network units are linear. Figure 2.1 shows one such network containing three units, S_1, S_2 and S_3. This network may represent process equipment such as a reactor, a distillation column and a heat exchanger in chemical process design; photosynthetic plants, herbivores and carnivores in ecosystems; or three industry sectors in an economy.

The network shown in Figure 2.1 can also be conveniently represented in the form of a transaction table shown in Table 2.1. Here, X_{ij} represents the magnitude of the transaction from unit i to unit j. *Final Demand* (FD), F_i, represents output from the i-th unit that does not go to any other unit of the network. Similarly *Value Added* (VA), V_i, represents the input to unit i that does not come from any other unit of the network. When applied to an economic network, final demand represents sale of goods and services to consumers, government establishments etc., whereas value added represents employee compensation, indirect business taxes and property type income (Miller and Blair, 1985). *Intermediate Input* (II), I_i, is the sum of inputs to unit i from all other units of the network. Similarly *Intermediate Output* (IO), O_j, is the sum of outputs from unit j to all other units of the network. Input-output analysis establishes a balance on each network unit. This is represented by Equation 2.1.

$$(\sum_{i=1}^{n} X_{ik}) + V_k = I_k + V_k = (\sum_{i=1}^{n} X_{ki}) + F_k = O_k + F_k = X_k \quad \text{for } k = 1,...,n \tag{2.1}$$

If transaction coefficients are defined as $D_{ik} = X_{ik}/X_k$ and $D_{vk} = V_k/X_k$, where $X_k = \sum_{i=1}^{n} X_{ik} + V_k$; Equation 2.1 can be rewritten as follows;

$$(\sum_{i=1}^{n} D_{ik}) \cdot X_k + D_{vk} X_k = (\sum_{i=1}^{n} D_{ki} \cdot X_i) + F_k \quad \text{for } k = 1,...,n \tag{2.2}$$

Since

$$(\sum_{i=1}^{n} D_{ik}) + D_{vk} = 1 \quad \text{for } k = 1,...,n \tag{2.3}$$

Equation 2.2 can be written as;

$$X_k = (\sum_{i=1}^{n} D_{ki} \cdot X_i) + F_k \quad \text{for } k = 1,...,n \tag{2.4}$$

or alternatively in matrix form as,

$$\mathbf{x} = \mathbf{D} \cdot \mathbf{x} + \mathbf{f} \tag{2.5}$$

$$\mathbf{x} = (\mathbf{I} - \mathbf{D})^{-1} \cdot \mathbf{f} \tag{2.6}$$

$$\text{if } \mathbf{T} = (\mathbf{I} - \mathbf{D})^{-1} \approx \mathbf{I} + \mathbf{D} + \mathbf{D}^2 + ... + \mathbf{D}^n \quad \text{for large } n \tag{2.7}$$

$$\mathbf{x} = \mathbf{T} \cdot \mathbf{f} \tag{2.8}$$

In input-output literature **D** is called the *direct requirements matrix* and **T** is called the *total requirements matrix*. The direct requirements matrix captures only the first order interactions whereas the total requirements matrix captures all higher order interactions. For example, in an economic network an increase in demand for automobiles entails corresponding increase in direct inputs such as steel and plastic. Change in direct inputs has a further cascading effect throughout the economy. Additional production of steel requires additional consumption of electricity. Additional generation of electricity requires additional consumption of coal and so on. Thus, in this example, direct inputs such as steel and plastic represent the first order interactions whereas indirect inputs such as electricity and coal represent second and third order interactions respectively. A network comprising n units can have infinite-order interactions.

If transaction coefficients are defined as $\gamma_{ki} = X_{ki} / X_k$ and $\gamma_{kf} = F_k / X_k$, where $X_k = \sum_{i=1}^{n} X_{ki} + F_k$; Equation 2.1 can be rewritten as follows;

$$(\sum_{k=1}^{n} \gamma_{ik} \cdot X_i) + V_k = (\sum_{i=1}^{n} \gamma_{ki} \cdot X_k) + \gamma_{kf} \cdot X_k \quad \text{for } i = 1,...,n \tag{2.9}$$

Since,

$$(\sum_{i=1}^{n} \gamma_{ki}) + \gamma_{kf} = 1 \tag{2.10}$$

Equation 2.9 can be written as;

$$(\sum_{i=1}^{n} \gamma_{ik} \cdot X_i) + V_k = X_k \quad \text{for } k = 1,...,n \tag{2.11}$$

or alternatively in matrix form as,

$$\mathbf{x} = \boldsymbol{\gamma}^{\mathbf{T}} \cdot \mathbf{x} + \mathbf{v} \tag{2.12}$$

$$\mathbf{x} = (\mathbf{I} - \boldsymbol{\gamma}^{\mathbf{T}})^{-1} \cdot \mathbf{v} \tag{2.13}$$

Equation 2.13 is used in the Thermodynamic Input-Output Analysis proposed in this dissertation.

The ability to incorporate direct as well as indirect inputs via a simple mathematical formulation represented by Equations 2.6 and 2.13, is one of the biggest fortes of input-output analysis. Since direct and indirect inputs will be referred to quite often in subsequent chapters, they are explained in further detail with the aid of following illustrative example that consists of two network components θ_A and θ_B. The interactions between the two components can be expressed in a single consistent unit for ease of calculation, or in different units to produce hybrid transaction matrices. In case of physical systems such as an ecosystem, the single consistent unit could be mass, energy or exergy. In the case of socio-economic system the common unit could be money.

System in Figure 2.2 can be redrawn to break the feedback loop as shown in Figure 2.3. Table 2.2 shows cumulative final demands from θ_A and θ_B after successive iterations. To calculate total throughput required to generate net final demands of 20 and 40 from θ_A and θ_B respectively, the efficient matrix algebra of input-output analysis can be used. Input-Output Analysis begins with the transaction coefficient matrix that represents normalized interactions between different system units. For instance, matrix **D** shown in Equation 2.14 is the direct requirements matrix defined according to Equation

2.5. Similarly, matrix $\boldsymbol{\gamma}$ shown in Equation 2.15 is an alternative representation of direct requirements matrix defined according to Equation 2.12.

$$\mathbf{D} = \begin{matrix} \theta_A & 0 & 1 \\ \theta_B & 0.4 & 0 \end{matrix} \tag{2.14}$$

$$\boldsymbol{\gamma} = \begin{matrix} \theta_A & \theta_B \\ 0 & 0.8 \\ 0.5 & 0 \end{matrix} \tag{2.15}$$

Therefore if $\mathbf{f} = [20\ 40]^T$, throughput vector $\mathbf{x}$ can be calculated using Equations 2.6 and 2.14.

$$\mathbf{x} = [\mathbf{I} - \mathbf{D}]^{-1} \cdot \mathbf{f} = [100 \quad 80]^T \tag{2.16}$$

Similarly if $\mathbf{v} = [60\ 0]^T$, the throughput vector $\mathbf{x}$ can be calculated using Equation 2.13 and 2.15.

$$\mathbf{x} = [\mathbf{I} - \boldsymbol{\gamma}^T]^{-1} \cdot \mathbf{v} = [100 \quad 80]^T \tag{2.17}$$

Thus through the use of $\mathbf{D}$ and $\boldsymbol{\gamma}$ matrices, input-output analysis can incorporate all feedback loops very efficiently, and can calculate first- as well as higher-order network interactions. In calculating total ECEC requirements of industry sectors, Equation 2.13 has been used. In such case, $\boldsymbol{\gamma}$ represents the inter-industry transaction coefficient matrix and $\mathbf{v}$ represents ecological resource input vector.

Input-output analysis was developed by Professor Wassily Leontief in late 1930s, for which he received the Nobel prize in 1973 (Leontief, 1936; Leontief, 1941). The term inter-industry analysis is also used to refer to input-output analysis, as the primary purpose of input-output framework was to analyze the interdependence of industries in an economy. Historically, the idea of developing a detailed accounting of inter-industry activity is much older than Leontief's formalization. In 1758, Quensay published "Tableau Economique" which provides a diagrammatic representation of how expenditure can be traced through an economy in a systematic way. More than a century after Quensay, Léon Walras applied notions of Newtonian mechanics in developing a theory of general equilibrium in economics (Walras, 1874). Walras utilized a set of production coefficients that related the quantities of factors required to produce a unit of a particular product to levels of total production of that product. Leontief's model, as it turns out, was an approximation of Walras' work that enabled the theory of general equilibrium to be applied to economics. Economic Input-Output Analysis has been extensively used for forecasting, sensitivity testing, flow and structural analysis and decision-making in macroeconomics. Many countries compile national input-output accounts for their economies on a periodic basis.

Since its development to study monetary interdependencies in the economic system (Leontief, 1936), input-output analysis has also been widely used to address several environmental issues pertinent to industrial ecology (Cumberland, 1966; Leontief, 1970; Noble, 1978). For instance, Leontief et al. (1982) explored the integration of material flows of 26 nonfuel materials in conventional input-output models. Ayres developed the material-process product model to address questions on the boundary between traditional economic criteria such as cost and prices and material processing (Ayres, 1972; Saxton and Ayres, 1976; Ayres 1978). Duchin's structural economics approach combined the physical interconnectedness in the economic system with corresponding representation of costs and prices (Duchin, 1994). Input-output analysis has also been applied to study energy flows in the economic system (Costanza, 1980;

Costanza and Herendeen, 1984; Casler and Hannon, 1989). Such Net Energy or Full Fuel Cycle Analysis establishes a correlation between embodied energy intensities of economic goods and services and their economic prices (Bullard and Herendeen, 1975; Hannon, 1982; Spreng, 1988). Economic Input-Output Life Cycle Assessment (eio-LCA) (Lave et al., 1995; EIOLCA, 2004) applies input-output analysis to overcome the problem of system boundaries in Life Cycle Assessment. With the national economy as the analysis boundary, eio-LCA calculates economy-wide total environmental burden vector, **e**, associated with an exogenous final demand vector, **f**.

$$\mathbf{e} = \mathbf{R}.\mathbf{x} = \mathbf{R}.(\mathbf{I} - \mathbf{D})^{-1}.\mathbf{f} \tag{2.18}$$

R is a $k \times n$ matrix of environmental burden coefficients wherein R_{kj} is the environmental burden k per dollar output of sector j. Equation 2.18 captures how emissions from different industry sectors change in response to any change in their economic activity. Though eio-LCA successfully calculates total emissions over the entire life cycle of an industrial sector, it does not calculate their impacts on human or ecosystem health. Moreover, it gives results in disparate units, such as tons of CO_2 equivalents and tons of SO_2 equivalents. As a result, comparison across different impact categories, in this case total global warming potential and total acidification potential, cannot be done without arbitrary human valuation.

2.2 Historical Perspective on Thermodynamic Laws

Thermodynamics is the branch of science concerned with the nature of heat and its conversion to other types of energy. The laws of thermodynamics are the result of several thousand years of discoveries in mechanics and in the study of heat (Goldstein and Goldstein, 1993). The ancient Greeks already had a good understanding of the relation between force and work that are central to mechanics. For instance, they knew how to produce a large force by the application of a smaller force with the help of a lever. They were also aware of the existence of heat, though its relation to work was not clear. The great breakthrough for mechanics came around 1666, when English scientist Isaac Newton came up with the three laws of motion. Advances in the study of heat started with the advent of the steam engine and development of the caloric theory by the end of the eighteenth century. When it came to heat, there were disagreements between mechanics and the caloric theory; to a large extent because supporters of the caloric theory believed that heat was a material substance. Throughout the years, heat and other phenomena of nature such as kinetic and potential energy, electricity, and chemical reactions were regarded as unconnected. They were developed independently and even measured in different units. In the early nineteenth century, it became apparent that these phenomena were interchangeable, i.e. it was possible to produce one out of the other. This raised the question of whether there was something that did not change in the intercourse of all these transformations.

It was between 1840 and 1850 that English physicist James Joule found a quantitative relation between heat and work, showing that they were just examples of energy and that heat was not a substance (Goldstein and Goldstein, 1993). Joule's work led to the first law of thermodynamics, which states that the total energy of a system is conserved, regardless of the nature and number of transformations that the system undergoes. At this point, it was clear that the previously studied phenomena of nature were interchangeable, measurable in the same units and that it was their total amount that was conserved. Nowadays, the use of the first law is indispensable for the design and operation of any industrial process.

The first law does not rule out the possibility of having a machine that takes in one type of energy, transforms it into heat and back again into its original form in a perpetual cycle without any need for additional energy. If electricity could be recycled this way, there would be no need for fossil fuels. Since the middle ages, scientists have intuitively known that such machines cannot exist – yet there have always been attempts to create them. This statement was not made formal until 1824 by French engineer Sadi Carnot and then in 1850, when German physicist Rudolf Clausius first proposed the second law of thermodynamics (Goldstein and Goldstein, 1993). In 1865, Clausius introduced a new property of matter called *entropy* and stated the second law by saying that the entropy of the universe tends to a maximum. Although there is no simple way of defining entropy, in an abstract way, it can be interpreted as a measure of molecular disorder of matter. To cite an example, crystals have ordered molecular arrangements and low entropies, while gases have chaotic molecular structure and high entropies. The repercussions of the second law were tremendous because it explains why processes occur naturally in a certain direction. For instance, in a glass of water, heat always flows from the water to the ice and not in the opposite direction. Although the reverse process obeys the first law, it violates the second.

2.3 Exergy Analysis

An alternate way to interpret the second law is that although energy is neither created nor destroyed, it is converted from useful to useless as work is performed. For instance, friction in pipelines diminishes the amount of useful energy in the fluids transported because it converts kinetic energy into dissipated heat, which is energy without any capacity to do work (Hau and Bakshi, 2004b). This *useful* or *available* energy is sometimes referred to as *exergy*. An opportunity for doing work exists whenever two systems at different states are allowed to interact as, in principle, work can be obtained as the two are allowed to come into equilibrium. When one of the two systems is an idealized system called an *environment*, also called surrounding or reference state, and the other is some system of interest, exergy is the maximum theoretical useful work obtainable as the systems interact to equilibrium, heat transfer occurring with the environment only. Alternatively, exergy is the minimum amount of work that needs to be expended to form a substance from elements occurring in its environment and to bring it to the specified physico-chemical state. Exergy is a measure of the departure of the system from its environment, and is an attribute of the system and the environment together.

> *Definition 1*: Exergy, *B*, is a measure of the maximum amount of useful energy that can be extracted when the matter is brought to equilibrium with its environment (Szargut et al., 1988).

Mathematically, in the absence of nuclear, magnetic, electrical and interfacial effects, Exergy is defined as (Szargut et al., 1988)

$$B = \left(H - T_0 S + \dot{r}^2/2 + zg\right)_{Actual\ State} - \left(H - T_0 S + \dot{r}^2/2 + zg\right)_{Reference\ State} \qquad (2.19)$$

where, H is enthalpy, T_0 is temperature of the reference state (environment), S is entropy, $\dot{r}$ is relative velocity, z is relative height and g is acceleration due to gravity. In ecological systems determination of the reference state, which by definition must be in thermodynamic equilibrium, is usually difficult because ecological systems are typically far from equilibrium. Such is the case with all self-organized systems including economic and social systems. The reference state, in such case, is chosen to correspond with the environmental conditions: 298K temperature, 1atm pressure and composition of the natural geobiosphere.

Exergy analysis has been used extensively for identifying inefficiencies and opportunities for saving energy in industrial systems. Although exergy is a more useful concept than energy, it provides information only about the current state of the system and its future ability to do work. It does not provide any information about the thermodynamic history or life cycle of the product or service, which is especially relevant in environmentally conscious decision-making.

2.4. Emergy Analysis

Emergy analysis is a part of a much larger theory developed by late H. T. Odum about the functioning of ecological and other systems. The theory explains how systems survive and organize in hierarchies by using energy at the efficiency that generates the most power (Odum and Odum, 1981). As pointed out by Hall (1995), the hypothesis about the role of energy in survival and evolution of systems has roots in the 19^{th} century and was first stated explicitly by the biologist Alfred Lotka, who called the maximum power principle the fourth law of thermodynamics (1922). H. T. Odum started developing the concept of emergy in 1950s when E. P. Odum identified the importance of energetics to ecology (Odum, 1953). From this concept, H. T. Odum extended the original concept as the maximum empower principle, and developed an energy systems language for the thermodynamics of open systems. By 1970s, during the crest of energy crisis, Odum had already recognized the critical role that ecosystems play in the global economy, and that economic activities were shaped not only by economic rules, but also by ecosystem constraints. He also developed the concept that energy offered a common ground for integrating economic and ecosystem sciences.

Emergy stands for *embodied energy* or *energy memory*. It is defined as the total amount of energy, required directly and indirectly, to make any product or service. Every commodity on earth is produced through a series of energy transformation steps that are ultimately driven by three fundamental sources of energy, namely sunlight, geothermal or deep earth heat and tidal or gravitational forces. Emergy analysis ignores the fourth fundamental source of energy, namely nuclear energy, because it does not appear naturally in the environment. The basic idea in emergy analysis is to identify this series and to determine the amount of energy from the fundamental sources necessary to initiate it. Emergy analysis is very useful when disparate units such as monetary and material are to be considered simultaneously. Moreover, emergy analysis is built on an ecosystem perspective, acknowledging ecosystem structure and functions, which is appropriate for this dissertation.

Definition 2: Emergy, *M*, is the available solar energy used up directly and indirectly to make a service or product (Odum, 1996).

Figure 2.4 shows the relation between emergy and exergy through a hypothetical energy transformation series. As seen from Figure 2.4, exergy decreases along the energy transformation series. On the contrary, emergy remains the same along the energy transformation series. The relation between emergy and exergy is given via transformity, τ, as;

$$M = \tau \times B \tag{2.20}$$

The unit of transformity, as used in systems ecology, is sej/J. Transformity compares the energy quality of a stream with that of sunlight. In other words, emergy analysis characterizes all products and services in equivalents of solar energy, that is, how much energy would be needed to do a particular task if solar radiation were the only input. Higher the quality of energy higher is the transformity and vice versa. In Figure 2.4, as one goes from the Sun to Predators/Electricity quality of energy increases and so does the transformity value. Energy quality of electricity is better than that of solar energy because electricity can do more types of work and can be transformed more easily into other kinds of energy than sunlight.

Definition 3: Solar Transformity is the solar emergy required to make one joule of a service or product (Odum, 1996)

Emergy and Transformity are both path-dependent properties, as they require knowledge about how a particular product or service was produced, starting from the primary sources of energy. This could be a very challenging task as complete knowledge about ecosystems and all the energy transformation steps is seldom available. Emergy analysis addresses this challenge by using a rather unique network algebra technique that will be discussed further in Section 2.5.4. Some of the advantages and criticisms of emergy analysis are discussed here. Advantages of emergy analysis are as follows:

- Emergy analysis provides a bridge that connects economic and ecological systems. It enables comparison of economic and ecological aspects on an objective basis that is independent of their monetary perception. Therefore, emergy analysis offers an ecocentric valuation rather than an anthropocentric valuation.
- It allows all resources to be compared on a common basis. Emergy analysis recognizes differences between quality aspects of material and energy streams.
- Emergy analysis provides a more holistic alternative to other state-of-the-art methods for environmental decision-making. Most existing methods such as Life Cycle Assessment and exergy analysis focus more on emissions and their impact, and ignore the crucial contribution of ecosystems to industrial activity. The concept of critical natural capital and a framework to account for it have been suggested recently (Ekins et al., 2003). Emergy analysis can quantify the contribution of natural capital for sustaining economic activity (Bakshi, 2000)

On the flip side, emergy theory has been criticized as simplistic, contradictory, misleading and inaccurate. Rebuttals to these criticisms have also been published (Patten, 1993; Odum, 1995). However, much of the persistent criticism seems to step from the lack of formal links between emergy and more established concepts in other disciplines. Some of the harshest criticisms of emergy analysis have been listed below.

- *Emergy and Economics.* Odum argues that money cannot be used directly to measure environmental contributions to the public good, since money is paid only to people for their services, and not to the environmental services generating resources or assimilating wastes. Since emergy, at least theoretically, does consider all contributions to the public good and truly measures value, it is suggested as a complete measure of wealth and a substitute for money. This theory, called Emergy Theory of Value, is one of the most controversial aspects of emergy analysis (Ayres, 1998; Cleveland et. al, 2000; Spreng, 1988), and has been vehemently rejected by economists. What most critiques of emergy analysis seem to miss is that emergy analysis provides an *ecocentric* value of products and processes, whereas economics provides an *anthropocentric* value for the same. Clearly, the later is dominant today. However, emergy analysis and its ecocentric perspective can support, rather than compete against, economics and its anthropocentric perspective and rationalize the later for sustainable development.

- *Maximum Empower Principle.* This principle, which has its roots in the work of Boltzman and Lotka (1922), claims that all self-organized systems tend to maximize their rate of emergy use or empower (Odum, 1988; Odum, 1996). This is a very bold hypothesis as, if true, it can explain the behavior of all self-organized systems in the universe and can provide a unified theory that the scientists have been looking for. Not surprisingly, such broad and yet unsubstantiated claim, has made this principle extremely controversial attracting sharp criticism. Mansson and McGlade (1993) and Ayres (1998), for instance, argue that the behavior of complex systems cannot be described by a single, maximization objective, and this principle and its superset, that is emergy analysis, are too simplistic and speculative. They also claim to have invalidated this principle, though the validity of their proof itself is moot (Odum, 1995; Patten, 1993). Unfortunately, the critiques of emergy analysis fail to recognize that for engineering applications, agreement or disagreement with maximum empower principle is not essential.

- *Combining Disparate Time Scales.* Since emergy is the total energy required, directly and indirectly, to produce a good or service, calculation of emergy of some stored natural resource, such as metal, coal or petroleum, would require knowledge of energy inputs over prehistoric or geological time-scales. This could be problematic, if not impossible. Some common questions concern how to account for the emergy of metals that existed from the formation of earth and whether the emergy of fossil fuels includes the emergy of the living systems from where they were derived. Odum addresses these concerns by distinguishing between emergy of storage and emergy necessary to make that storage available for human consumption. For instance, emergy of coal would require knowledge about how coal was formed thousands of years ago, but emergy required to make coal available for human consumption would only require knowledge of Earth Sedimentary Cycle that occurs in concurrent time scale. Transformities of many resources such as coal and petroleum, as used in various applications of emergy analysis, consider only the current emergy, and not that stored since prehistory.
- *Problems of Allocation.* Emergy analysis uses a method for partitioning inputs between multiple outputs that is quite unique and challenging. Particularly to engineers, who are used to conservation equations, emergy algebra can be very confusing. Emergy algebra can be very sensitive to amount of knowledge available about the network structure of the system and interactions between its various components. Allocation is an important issue encountered in many disciplines

including traditional cost accounting and life cycle assessment. Current rule-of-thumb in LCA community that is also endorsed by ISO-14000 standardization guidelines is to avoid allocation whenever possible. When avoiding allocation is not possible, the sensitivity of the results to the allocation procedures should be evaluated. Hau and Bakshi (2004b) have proposed a formal algorithm based on network algebra that can be used for emergy analysis. Their approach prefers allocation that conserves emergy if information about the network and all its products is available. This is usually the case for industrial systems. However, if such information is not available, as is usually the case for ecological systems, allocation is avoided by assigning the same emergy to all the outputs. In the later case double counting must be avoided. The allocation algorithm of Hau and Bakshi is discussed further in Section 2.5.4 of this chapter.

- *Relation with Other Thermodynamic Properties.* The relation between emergy and other thermodynamic concepts such as energy and enthalpy has also been a source of criticism. The quantitative difference, as recognized by Odum and coworkers, is that unlike emergy, these thermodynamic properties do not recognize the difference in quality of various energy sources. For instance, a joule of a fossil fuel is very different from a joule of sunlight in the sense that they cannot do the same kind of work (Brown et al., 1995). Lack of literature articulating connections between emergy and other thermodynamic properties leads to the impression that emergy analysis is fundamentally very different from other thermodynamic methods (Ayres, 1998; Emblemsvag and Bras, 2001). In reality, this is not true. As shown by Hau and

Bakshi (2004b), a theoretically rigorous connection exists between emergy and cumulative exergy consumption that is discussed in the next section.

2.5. Cumulative Exergy Consumption (CEC) Analysis

2.5.1. Industrial Cumulative Exergy Consumption (ICEC) Analysis

One of the major shortcomings of exergy analysis is that it focuses only on the process under investigation while ignoring the performance of its production chain. Extensions of exergy analysis such as Cumulative Exergy Consumption (CEC) Analysis, Thermoeconomics and Extended Exergy Accounting address this shortcoming by determining exergy loss in the process as well as that in the important stages of its supply chain. Figure 2.5(a) depicts ICEC methodology. A stream is considered to be a natural resource if it is a direct product from ecological processes. Examples of natural resources include coal, iron, fresh water and atmospheric O_2.

Definition 4: Industrial Cumulative Exergy Consumption of a process is the sum of exergy of all natural resources expended in the process as well as all industrial stages in its production chain.

In general ICEC of the production chain, C_p, can be calculated using Equation 2.21.

$$C_p = C_n = \sum_{k=1}^{N_i} C_{n,k} \tag{2.21}$$

where, N_i is the number of units in the production chain, $C_{n,k}$ and $C_{p,k}$ are cumulative exergies of natural resource inputs and finished product outputs respectively. ICEC analysis assumes exergy and cumulative exergy of natural resource inputs to be equal. Mathematically, this is represented by Equation 2.22. Furthermore, Equation 2.23 defines Industrial Cumulative Degree of Perfection (ICDP), η_p, which is the overall exergetic efficiency of the entire production chain.

$$C_{n,k} = B_{n,k} \quad \text{for } k = 1,\ldots,N_i \tag{2.22}$$

$$\eta_p = \frac{B_p}{C_n} = \frac{\sum_{k=1}^{N_i} B_{p,k}}{\sum_{k=1}^{N_i} C_{n,k}} \tag{2.23}$$

Definition 5: Industrial Cumulative Degree of Perfection (ICDP), η_p, is the ratio of the exergy of the final product(s) to the cumulative exergy consumed to make the product(s).

Moreover, cumulative exergies of natural resource inputs to individual components of the production chain, $C_{n,k}$, can be allocated to cumulative exergies of outputs from the individual components, $C_{p,k}$, according to following matrix equation.

$$\mathbf{C_p} = \mathbf{\Gamma_i} \cdot \mathbf{C_n} \tag{2.24}$$

In Equation 2.24, $\mathbf{C_p}$ is a $k \times 1$ vector of output CEC, $C_{p,k}$, $\mathbf{C_n}$ is a $k \times 1$ vector of input CEC, $C_{n,k}$, and $\mathbf{\Gamma_i}$ is a $k \times k$ allocation matrix.

ICEC analysis has been used widely and calculations for many industrial processes are available (Szargut et al., 1988). ICEC analysis shares some features of LCA since both methods consider supply chains of products and processes. However, ICEC analysis completely ignores exergy consumption in the ecological stages of the production chain and, consequently, cannot distinguish quality differences between ecological products and services. This shortcoming is addressed in Ecological Cumulative Exergy Consumption Analysis that is discussed next.

2.5.2. Ecological Cumulative Exergy Consumption (ECEC) Analysis

Ecological stages of a production chain include various natural functions responsible for converting, concentrating and transporting ecological resources into forms that can be used by industrial processes. Including ecological processes requires expansion of system boundaries in ICEC analysis beyond the scale of the economy to that of ecosystems. Therefore, Figure 2.5(a) needs to be modified by including exergy consumption in ecological processes as shown by Figure 2.5(b). The exergy and cumulative exergy of inputs that drive ecological processes are represented as, $B_{e,k}$ and $C_{e,k}$, respectively.

Unlike ICEC analysis, ECEC analysis does not have to assume that exergy, $B_{n,k}$, and cumulative exergy, $C_{n,k}$, of natural resources are equal. Rather, in ECEC analysis, the two are related according to Equation 2.25.

$$\mathbf{C_n} = \boldsymbol{\eta}_\mathbf{n}^{-1} \cdot \mathbf{B_n} \tag{2.25}$$

where $\boldsymbol{\eta}_\mathbf{n}$ is $(N_i + N_e) \times (N_i + N_e)$ diagonal matrix with $\eta_{n,k}$ forming the diagonal elements. N_e denotes the number of units included in the ecological supply chain. Variable $\eta_{n,k}$ represents efficiency with which ecological processes create natural resources entering the k-th process unit from global exergy inputs. ICEC analysis implicitly assumes that these efficiencies are 100%. This assumption is clearly wrong as, like industrial processes, ecological processes are also thermodynamically irreversible and hence far from being 100% efficient. ECEC analysis relaxes this assumption by considering exergetic efficiencies of ecological processes as obtained in systems ecology. Cumulative exergies of natural resources, $C_{n,k}$, are related to those of global energy inputs, $C_{e,k}$, by following matrix equation.

$$\mathbf{C_n} = \mathbf{\Gamma_e} \cdot \mathbf{C_e} \tag{2.26}$$

Here, $\mathbf{\Gamma_e}$ is the allocation matrix for mapping ecological inputs to natural resource outputs. From Equation 2.24 and 2.26, ecological inputs can be mapped to industrial outputs via a lumped transaction matrix $\mathbf{\Gamma}$ that is defined according to Equation 2.27.

$$\mathbf{C_p} = \mathbf{\Gamma} \cdot \mathbf{C_e} \quad \forall\, \mathbf{\Gamma} = \mathbf{\Gamma_i} \cdot \mathbf{\Gamma_n} \tag{2.27}$$

An alternate equation for ECEC may be written as follows.

$$\mathbf{C_p} = \mathbf{\Gamma} \cdot \boldsymbol{\eta}_\mathbf{e}^{-1} \cdot \mathbf{B_e} \quad \text{as } \mathbf{C_e} = \boldsymbol{\eta}_\mathbf{e}^{-1} \cdot \mathbf{B_e} \tag{2.28}$$

Equation 2.28 indicates that ECEC of industrial outputs, $\mathbf{C_p}$, can be determined if exergy of ecological inputs, $\mathbf{B_e}$, cumulative efficiencies of ecological processes, $\boldsymbol{\eta}_\mathbf{e}$, and the lumped allocation matrix, $\mathbf{\Gamma}$, are known.

2.5.3. Relation between ECEC and Emergy

Equation 2.20 relating exergy and emergy can be written in matrix form as follows.

$$\mathbf{M_p} = \mathbf{T_p} \cdot \mathbf{B_p} \tag{2.29}$$

Here, $\mathbf{M_p}$ and $\mathbf{B_p}$, are vectors of emergy and exergy respectively, and $\mathbf{T_p}$ is the diagonal matrix of transformities. Alternatively, emergy of industrial outputs, $\mathbf{M_p}$, can be connected to emergy of natural resource inputs, $\mathbf{M_n}$, according to Equation 2.30, where $\mathbf{\Gamma'_i}$ is the allocation matrix for emergy analysis.

$$\mathbf{M_p} = \mathbf{\Gamma'_i} \cdot \mathbf{M_n} \tag{2.30}$$

$\mathbf{\Gamma'_i}$ contains information about the allocation rule for emergy in the industrial network, that is how emergy is assigned between co-products, splits and joints. Similarly, emergy of natural resources, $\mathbf{M_n}$, can be calculated according to Equation 2.31.

$$\mathbf{M_n} = \mathbf{\Gamma'_e} \cdot \mathbf{M_e} \tag{2.31}$$

Here $\mathbf{\Gamma'_e}$ is the allocation matrix for the ecological network. Furthermore, emergy and exergy of global inputs are related according to Equation 2.32.

$$\mathbf{M_e} = \mathbf{T_e} \cdot \mathbf{B_e} \tag{2.32}$$

Here, $\mathbf{T_e}$ represents solar transformities of global inputs. From Equation 2.30, 2.31 and 2.32,

$$\mathbf{M_p} = \mathbf{\Gamma'_i} \cdot \mathbf{\Gamma'_e} \cdot \mathbf{T_e} \cdot \mathbf{B_e} = \mathbf{\Gamma'} \cdot \mathbf{T_e} \cdot \mathbf{B_e} \tag{2.33}$$

where $\mathbf{\Gamma'}$ is the lumped allocation matrix, and is similar to that defined in Equation 2.27. From Equations 2.28 and 2.33,

$$\mathbf{\Gamma} \cdot \boldsymbol{\eta}_\mathbf{e}^{-1} = \mathbf{\Gamma'} \cdot \mathbf{T_e} \tag{2.34}$$

For a fair comparison, it is essential for both ECEC and emergy analysis to have same analysis boundary. Secondly if the allocation matrix used in emergy analysis is identical to that used in ECEC analysis, that is $\mathbf{\Gamma'} = \mathbf{\Gamma}$,

$$\boldsymbol{\eta}_\mathbf{e}^{-1} = \mathbf{T_e} \tag{2.35}$$

Equation 2.35 is significant because it indicates equivalence between transformity and reciprocal of cumulative efficiency. The later being an established thermodynamic concept, Equation 2.35 also relates emergy with more conventional thermodynamic principles. In summary, Ecological Cumulative Exergy Consumption and emergy are equivalent if the following three conditions are satisfied (Hau and Bakshi, 2004b)

1. Identical analysis boundary
2. Same allocation method
3. Same approach for combining global energy inputs

2.5.4. ECEC Allocation in Networks

The network algorithm of Input-Output Analysis discussed in Section 2.1 provides a rigorous and convenient way to determine ECEC flows in large networks. In such case, ECEC throughput of network can be calculated according to Equation 2.36.

$$\mathbf{C} = (\mathbf{I} - \boldsymbol{\gamma}^{\mathbf{T}})^{-1} \cdot \mathbf{C_n} \tag{2.36}$$

Here, $\mathbf{C_n}$ is the vector of cumulative exergies of natural resource inputs to industrial system, $\mathbf{C}$, is the vector of cumulative exergy throughputs of network units, $\boldsymbol{\gamma}$ is the transaction coefficient matrix for the industrial system, and $\mathbf{I}$ is the identity matrix of appropriate dimensions. Equation 2.36 is comparable to Equation 2.13. Furthermore, if $\boldsymbol{\gamma_p}$ is a diagonal matrix representing the fraction of unit's cumulative exergy throughput that does not go to any other unit of the network, cumulative exergy of outputs from industrial system, $\mathbf{C_p}$, can be calculated according to Equation 2.37.

$$\mathbf{C_p} = \boldsymbol{\gamma}_{\mathbf{p}} \cdot (\mathbf{I} - \boldsymbol{\gamma}^{\mathbf{T}})^{-1} \cdot \mathbf{C_n} \tag{2.37}$$

Use of Equation 2.37 depends on amount of available information about network structure and interactions. In fully defined networks cumulative exergy can be split in proportion to exergy contents of individual outlet streams. This is explained further in Figure 2.6(a). Similarly, in network joints cumulative exergy can be added without the fear of double counting. If knowledge about network structure and interactions is not complete, Equation 2.36 cannot be used for allocating cumulative exergy of inputs to the multiple outputs. For instance Figure 2.6(b) shows a network unit for which only two of the output streams are fully defined. There are more output streams that do exist, but for which no information is available. This is usually the case with ecosystems as complete knowledge about ecological networks and all interactions between ecosystem components is seldom available. One strategy for dealing with such partially known networks is to avoid the allocation altogether. Therefore, in Figure 2.6(b), cumulative exergy is not partitioned, and the same input CEC is assigned to both the output streams. Furthermore, to be consistent with avoidance of allocation in network splits, CEC is not added in network joints. Rather the maximum CEC amongst the input streams is assigned to the output stream. This is necessary to avoid double counting. One of the advantages of this allocation approach is that it enables definition of allocation matrix, $\boldsymbol{\gamma}$, even when some of the network connections and flows are unknown. Figure 2.7 compares the allocation approaches used in exergy, ICEC and ECEC analyses. To summarize, ICEC analysis apportions exergy losses among the output streams. In ECEC analysis losses are uncertain because output streams are not completely specified. In such case allocation is avoided and the maximum ECEC of input streams is assigned to all the output streams.

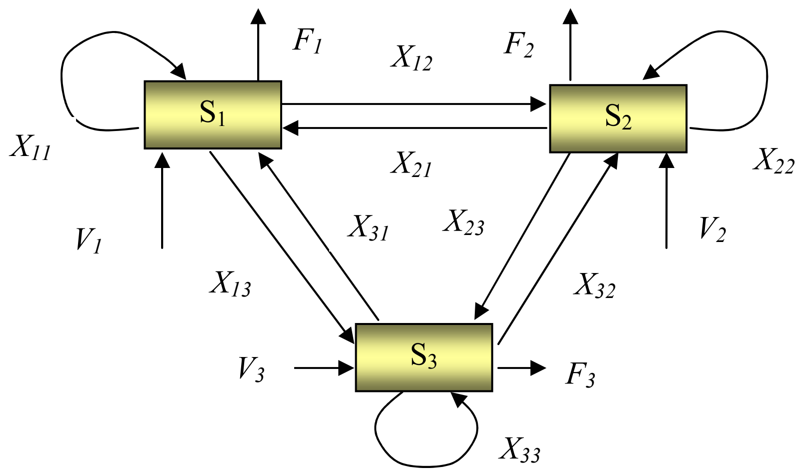


Figure 2.1: Network Structure of a Typical Input-Output System

Output Input	**S_1**	**S_2**	**S_3**	**Intermediate Output (IO)**	**Final Demand (FD)**	**Total Output (TO)**
S_1	X_{11}	X_{12}	X_{13}	O_1	F_1	X_1
S_2	X_{21}	X_{22}	X_{23}	O_2	F_2	X_2
S_3	X_{31}	X_{32}	X_{33}	O_3	F_3	X_3
Intermediate Input (II)	I_1	I_2	I_3			
Value Added (VA)	V_1	V_2	V_3			
Total Input (TI)	X_1	X_2	X_3			

Table 2.1: Transaction Table for the System Shown in Figure 2.1

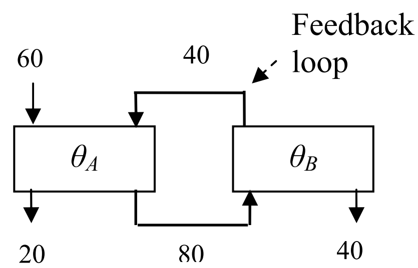


Figure 2.2: Network Structure of a Simple System with Feedback Loop.

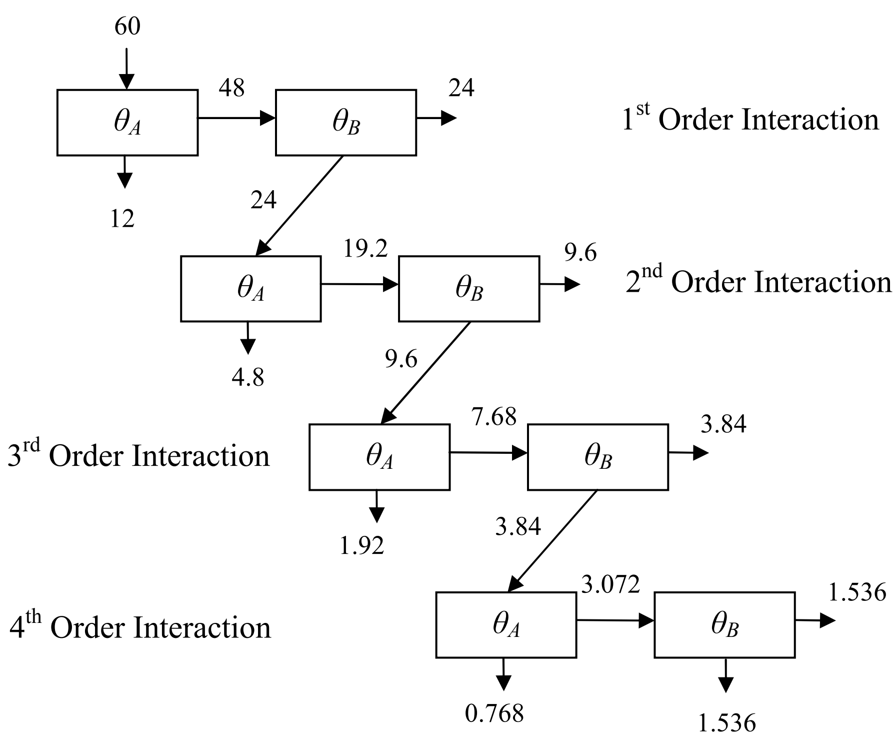


Figure 2.3: Alternate Representation of Network System Shown in Figure 2.2 with Broken Feedback Loop

No. of Iteration	Cumulative Final Demand from θ_A	Cumulative Final Demand from θ_B
1	12	24
2	16.8	33.6
3	18.72	37.44
4	19.488	38.976
:	:	:
∞	20	40

Table 2.2: Cumulative Final Demands from θ_A & θ_B After Each Iteration

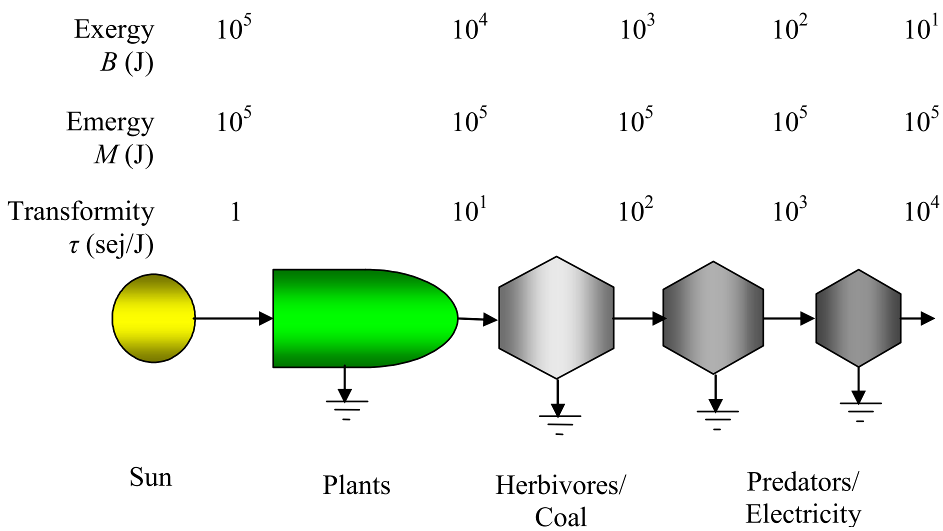


Figure 2.4: Energy Transformation in Food or Industrial Chain (Bakshi , 2002)

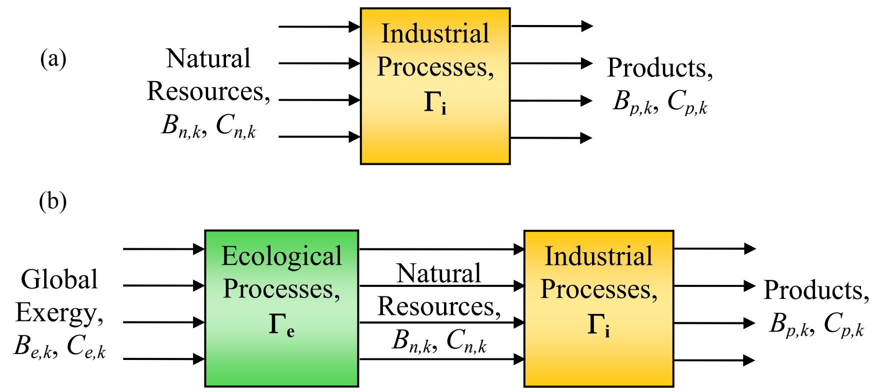


Figure 2.5: (a) Industrial Cumulative Exergy Consumption (ICEC) analysis; (b) Ecological Cumulative Exergy Consumption (ECEC) analysis (Hau and Bakshi, 2004b).

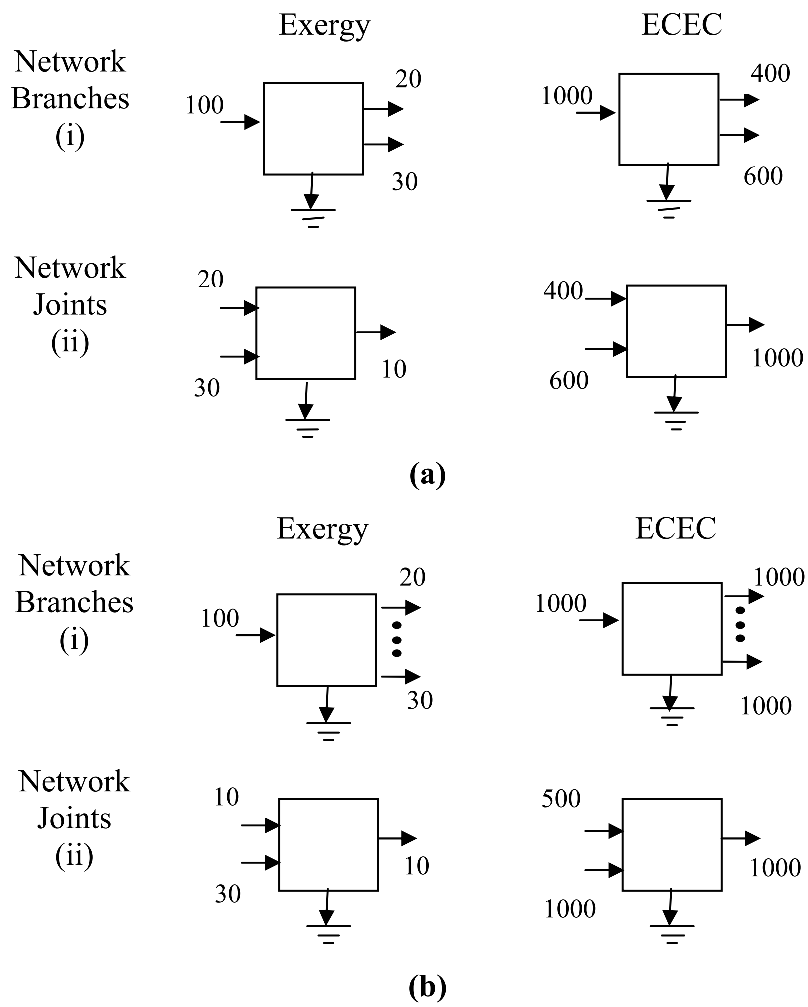


Figure 2.6: Allocation Schemes (a) All output known/ inputs from additive sources (b) Some outputs unknown/ inputs from non-additive dependent sources (Hau and Bakshi, 2004b)

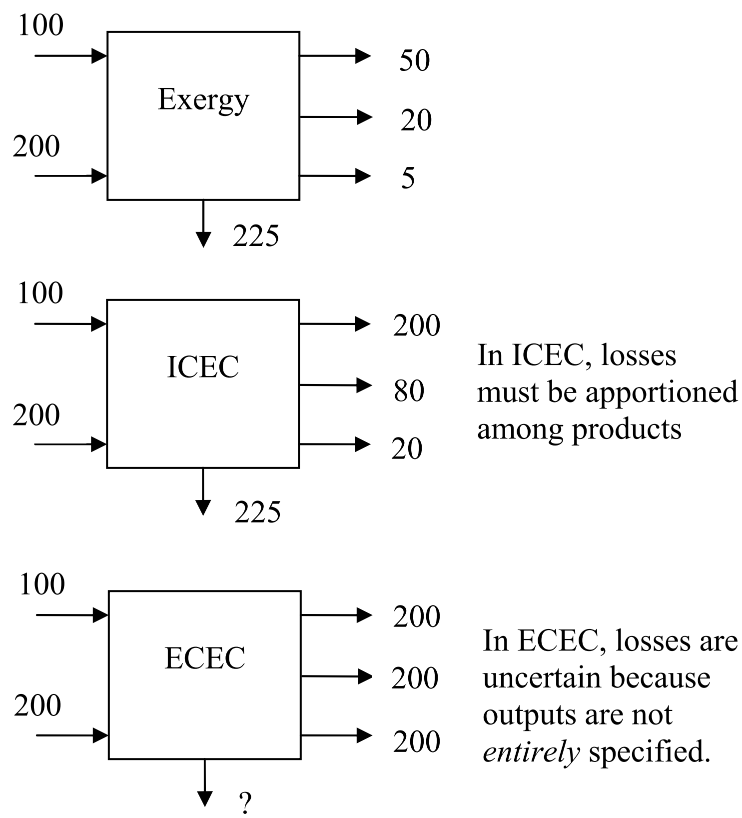


Figure 2.7: Allocation Rules in Exergy, ICEC and ECEC Analysis

CHAPTER 3

THERMODYNAMIC INPUT-OUTPUT ANALYSIS: METHODOLOGY

This chapter applies the Ecological Cumulative Exergy Consumption Analysis discussed in Chapter 2 to determine contribution of ecosystem products and services to economic sectors via input-output analysis. The resultant methodology is called Thermodynamic Input-Output Analysis. A thermodynamic approach provides a common currency or a way to deal with a diverse set of units, as any system, economic or ecological can be considered as a network of energy flows. Furthermore, as discussed in the previous chapter, ECEC analysis can deal with partially known ecological networks using appropriate allocation rules. Money can also provide a common currency by using economic valuation methods to capture the contribution of ecosystems (Costanza et al., 1997; Bockstael et al., 2000; Balmford et al., 2002). If monetary values for the ecosystem products and services required by each economic sector were available, the approach proposed in this analysis may also be used to determine the monetary contribution of ecosystems at the sectoral level. The proposed thermodynamic approach is not meant to replace, but to complement an economic approach.

3.1 Integrated Economic-Ecological-Social (EES) System

Thermodynamic Input-Output Analysis recognizes the network structure of the integrated Economic-Ecological-Social (EES) system shown in Figure 3.1. Such system is driven by three fundamental sources of energy, namely solar radiation, tidal forces and geothermal heat. The economy consists of a large number of industry sectors defined according to their Standard Industrial Classification (SIC) or North American Industrial Classification System (NAICS) codes. Ecological system consists of four conceptual ecospheres, namely Lithosphere (land), Hydrosphere (water), Atmosphere (air) and Biosphere. Social sphere, also referred to as human resources, consists of consumers. Thermodynamically, the EES system is an open system with material and energy flows across system boundaries. For instance, energy enters the system from the three fundamental sources of energy and exits in the form of long wave radiation. Material enters the system in the form of imports and exits in the form of exports. Small amounts of celestial matter may also enter earth's atmosphere. Consideration of imports and exports is theoretically possible if the boundary of the EES system could be expanded to coincide with the global economy. Practically it is a daunting task, as it requires information about industrial networks in the global economy and its interactions with global ecological resources. In this dissertation, the boundary of the EES system is assumed to coincide with the US economic system, and imports to and exports from it are ignored.

Solid lines in Figure 3.1 represent tangible interactions that include raw materials from and emissions to ecosystems and human resources. Interactions shown with dotted lines in Figure 3.1 are less tangible and occur as a consequence of emissions. For example, the dotted line between the economy and ecosystems represents ecosystem services required for dissipating industrial emissions and the impact of emissions on ecosystems. Similarly the dotted line from human resources to economy represents impact of industrial emissions on human health. Dotted line from ecosystems to human resources represents impact of anthropogenic emissions on human health.

The detailed network structure of the economic system is typically well-known, and is being used in the Thermodynamic Input-Output Analysis. Conversely, the network structure of ecological system need not be completely known as the underlying ECEC analysis can deal with partially-known ecological networks using appropriate allocation rules (Odum, 1996; Hau and Bakshi, 2004b). At this point it is necessary to note that the emphasis of this work is not to predict the structure of the EES system or how it would evolve under the influence of the three external energy drivers. This is a very challenging task, as it would require full understanding of the epistemological palette proposed by Kay and Regier (2000). An EES system is a non-linear, holarchic, chaotic, self-organizing and dynamically stable system with multiple steady states (Kay and Regier, 2000; Holling, 2001; Gunderson and Holling, 2001). Such system is characterized by emergent behavior which suggests that complete understanding of the system cannot be obtained by merely looking at its parts. Such system also demonstrates catastrophic behavior with moments of unpredictable behavior (bifurcations), sudden discontinuities and rapid changes (flips) and shifting steady state mosaic (Holling's four box cycle). Accurate modeling of such system is not yet possible. Thermodynamic Input-Output Analysis does not try to predict the structure of the EES system, but rather analyzes observed material and energy interactions between its various components.

3.2 Algorithm of Thermodynamic Input-Output Analysis (TIOA)

The algorithm for Thermodynamic Input-Output Analysis focuses on the economic system and its interactions with ecosystems and human resources shown in Figure 3.1. It consists of following three tasks.

- *Task 1* is *to identify and quantify ecological and human resource inputs to the economic system*. Such inputs include ecosystem products like coal, wood and water, ecosystem services like wind, rain and carbon sequestration, impact of emission on human health and human resources consumed by economic activities in the form of labor employment.
- *Task 2* is to *calculate ECEC of ecological inputs* using transformity values from systems ecology, and to classify inputs as additive or non-additive to avoid double counting. In general, non-renewable resources are additive, while renewable resources are non-additive (Odum, 1996; Hau and Bakshi, 2004b). This is so because in case of non-renewable resources such as minerals and fossil fuels, allocation is possible and is typically done in proportion to their mass fraction in earth's sedimentary cycle. In case of renewable resources, however, such allocation is not possible as they are by-products of the same energy input to the earth system.
- *Task 3* is to *allocate direct ecological and human resource inputs to economic sectors* based on input-output data and the network algebra of ECEC analysis (Hau and Bakshi, 2004b). More details about determination of ECEC of direct ecological inputs and their allocation through the economic system have been discussed in detail in subsequent sections of this chapter. The network algebra of ECEC analysis is based on a static input-output representation of the economic system. Dynamic versions of

input-output analysis that consider temporal changes in the economic network are also available, and need to be explored. Also, use of monetary data for allocation is not a limitation of the approach, but is rather caused by lack of comprehensive material or energy accounts of inter-industry interactions. Recently, Earth and Life Studies division of National Research Council has undertaken an initiative called *Materials Count: The Case for Material Flow Analysis* that promises to make detailed biophysical accounts of the US economy available (NRC, 2004). If initiatives such as this bear fruit, more accurate transaction matrices can be used in Thermodynamic Input-Output Analysis.

3.3 ECEC of Direct Ecological Resources

Determining the direct contribution of ecosystems relies on selected transformity numbers from emergy analysis. As discussed in Section 2.4, the necessary transformities are based on knowledge from geological, atmospheric, and environmental sciences, are thermodynamically sound, and are independent of all the controversial aspects of emergy analysis.

3.3.1 Ecosystem Products

Certain industry sectors, such as agriculture, metallic ores mining, coal mining, crude petroleum and natural gas, agricultural fertilizers and chemicals and water and sanitary services are at the economy-ecosystem interface and are direct consumers of ecological goods. These are the *peripheral* economic sectors. Remaining economic sectors rely on peripheral sectors and consume ecological resources indirectly. These are the *embedded* industry sectors.

Data about consumption of ecological products is generally available in material or energy units. To determine nature's contribution in making these products available to the industrial system, transformity values from systems ecology are used (Odum, 1996). The relation between mass or energy content and ECEC content of ecological resources is given by Equation 2.20. For instance, transformity of coal as reported in emergy literature is 10^9sej/g. Hence 1g of coal input to the sector of coal mining translates into 10^9sej of ECEC input. Furthermore, transformity of petroleum, as reported in emergy literature, is 53,000sej/J. Hence 1J of petroleum input to the sector of oil and gas extraction translates into 53,000sej of ECEC input. Though 1g of coal and 1J of petroleum cannot be added due to disparate units, corresponding ECEC flows can be as they are in the same unit.

3.3.2 Ecosystem Services

Ecosystem services refer to various natural functions that support industrial activities and are vital to their sustenance. They can be broadly classified into physical and value-based services. For example, dissipation of emissions by wind or water streams and use of geothermal heat or tidal waves for electricity generation are accompanied by material or energy flows. These are the physical ecosystem services. In contrast, aesthetic, recreational, and cultural ecosystem services need not be accompanied by any material or energy transactions. These services depend on how people value them, and consequently are called value-based services. Value-based services are difficult to quantify via thermodynamics alone, and have been omitted from this work. They have been dealt with in Costanza et al. (1997) and Balmford et al. (2002).

Ecosystem services such as wind and water streams necessary for diluting industrial emissions have also been considered in literature (Ulgiati and Brown, 2002). The contribution of these services has been determined using mass rate of emission, m, base concentration of the pollutant in air or water, ξ, and the transformity of the relevant ecosystem service, τ^{service}. In such case, ECEC of the ecosystem service can be determined according to Equation 3.1.

$$C^{\text{service}} = \tau^{\text{service}} . \left(\frac{\rho^{\text{service}} \cdot m \cdot v^2}{2\xi} \right) \qquad (3.1)$$

Here, ρ^{service} is the density of air or water, v is the velocity of the stream and C^{service} is the ECEC content of the ecosystem service. However, use of Equation 3.1 to determine ECEC of ecosystem services for pollution dissipation is very controversial. Equation 3.1 only addresses the advective component of wind or water stream. Though it could account for shaft work in turbines or work done in pushing sailboats, it is a poor measure for pollution dissipation. It is the dispersive component of wind or water stream that contributes to dissipating emissions. The dispersive component is also related to wind velocity or velocity of water stream, but not according to Equation 3.1. The error is in the fact that Equation 3.1 computes kinetic exergy, but not kinetic exergy losses. For these reasons, ECEC of wind or water streams required for dissipating industrial emissions has been ignored in this work. Its inclusion would entail deeper understanding of atmospheric dispersion, turbulent mixing and environmental chemistry.

3.3.3 Impact of Emissions on Human Health

Techniques for evaluating impact of emissions can be broadly distinguished between midpoint and endpoint categories. In line with Bare et al (2000), midpoints refer to points in the cause effect chain (environmental mechanism) of a particular impact category, intermediate between emissions (stressors) and impact (endpoint). Midpoint techniques have been quite popular in Life Cycle Assessment field. Prominent examples of midpoint assessment approaches include CML thematic approach (Heijungs et al., 1992), Sandestin workshop on Life Cycle Impact Assessment (Fava et al., 1993), the Nordic LCA guide (Lindfors et al., 1995), and Eco-Indicator 95 (Goedkoop, 1995). On the contrary, endpoints refer to those elements of an environmental mechanism that are in themselves of value to society (Udo de Haes and Lindeijer, 2001). ISO 14042 mentions forests and coral reefs as examples. Other examples are the physical aspects of human health, like lifetime or bodily functions. While midpoint refers to the ambient concentration of an emission in the environment, endpoint refers to the actual impact it has in terms of human casualties or disabilities and loss of flora and fauna. Examples of endpoint techniques include EPS approach from Steen and Ryding (1992) and Eco-Indicator 99 (Goedkoop and Spriensma, 1999). Since midpoint techniques estimate impact in terms of selected impact categories such as global warming potential, acidification potential, eutrophication potential etc., they yield multiple metrics that cannot be summed without arbitrary valuation. Endpoint techniques, on the contrary, combine impact estimates from multiple categories using more structured and informed weighing including common parameters such as Disability Adjusted Life Years (DALYs). As a result, endpoint techniques can yield hierarchical metrics of impact that are more useful than multiple metrics in disparate units. In this work endpoint assessment technique proposed in Eco-Indicator 99 has been used (Goedkoop and Spriensma, 1999).

Eco-indicator 99 begins by determining the base concentration of the pollutant in the natural environment. The actual impact of the emission on human or ecosystem health depends on this base concentration and on whether it is more than a certain threshold value. The impact itself depends on the exposure and effect analyses. Eco-indicator 99 measures human health impact in terms of DALYs (Goedkoop and Spriensma, 1999) that measure the total amount of healthy life lost to all causes, whether from premature mortality or from some degree of disability during a period of time. Impact on ecosystems is measured in terms of the *potentially affected fraction* (PAF) or *potentially disappeared fraction* (PDF) of vascular plant species in the selected geographical area.

Impact of emission on human health can alternatively be viewed as an additional input of human resources to the polluting industry sector. In such case, the corresponding ECEC flow can be calculated according to Equation 3.2.

$$C^{\text{impact}} = m.d.\tau^{\text{HR}} \tag{3.2}$$

Here C^{impact} is the ECEC equivalent of impact of emission on human health, m is the mass rate of emission, d is the DALY value of the particular pollutant and τ^{HR} is the transformity of human resource. The approach for computing τ^{HR} is discussed in the next section. Such an approach can also be used for converting ecological impact of emission into thermodynamic terms, provided transformities of affected or disappeared species of vascular plants are known. However, there is great deal of uncertainty regarding distribution of vascular plant species in a given geographical area. If the impact of emission on ecosystems has to be determined using Eco-Indicator approach, spatial and temporal variations in distribution of vascular plant species must be taken into account. This is beyond the scope of this work which focuses only on human impact of emissions.

3.3.4 Human Resources

Human Resources represent consumers in the economy. Industry consumes human resources in the form of employment of labor. Moreover, different industry sectors have different average annual payrolls suggesting distinction in skill levels. In this dissertation, the skill level of a sector's employees is assumed to be directly proportional to its average annual payroll, P_i. The sector with minimum average annual payroll, $P_{\min}$, is assigned the transformity of unskilled labor, $\tau^{\text{unskilled}}$. $\tau^{\text{unskilled}}$ is calculated by dividing the total annual emergy budget of the US in 1992 (7.85×10^{24}sej/yr) by the total population of the US in 1992 (230×10^{6} individuals) (Odum, 1996). Total population not only includes employed people but also unemployed people, minors and retirees. In 1992, approximately 111×10^{6} people were employed in the US (BLS, 2003). Since close to half the population was unemployed, an average τ for human resources, τ^{HR}, coincides with the lowest skill level of the labor force, and hence can be used to represent unskilled labor, $\tau^{\text{unskilled}}$. For other sectors transformity is scaled according to Equation 3.3

$$\tau_i = \tau^{\text{unskilled}}.(P_i / P_{\min}) \tag{3.3}$$

Thus, if the number of man hours employed in sector i , h_i, and its average annual payroll are known, ECEC equivalent of the contribution of human resources to that industry sector, $C^{HR}{}_i$ can be calculated using Equation 3.4.

$$C^{HR}{}_i = h_i.\tau_i \qquad (3.4)$$

In this analysis, contribution from human resources actually represents contribution from ecological resources that are stored in human resources. Since such contribution arises from a storage, it can be added with other additive ecosystem products and services as per the rules of emergy and ECEC analyses.

3.4 Allocation Through The Economic Network

Once the direct inputs are quantified in thermodynamic terms, the next step is to calculate the total throughputs of system units. Since industry sectors have multiple inputs and outputs, it becomes necessary to allocate the multiple inputs to a system unit to its various outputs. Many methods have been suggested based on market value, mass, energy or exergy content of outputs. Alternatively, if a process is producing two or more different products avoiding allocation altogether may be appropriate. Techniques for avoiding allocation by altering system boundary have been suggested and are recommended in ISO 14000 standards. In Thermodynamic Input-Output Analysis network algebra techniques proposed in ECEC methodology and discussed in Section 2.4 are used. Accordingly, resources are distinguished as either *additive* or *non-additive* depending on their source and allocation method. Two resources can be considered to be additive if their ECEC is calculated via the scheme of Figure 2.6(a). Otherwise the two resources are considered to be non-additive. Due to the algebra used in emergy analysis, renewable resources are considered to be non-additive and non-renewable resources are considered to be additive.

In determining throughputs of industry sectors both the schemes shown in Figure 2.6 are used. To begin with, each resource is considered separately. Thus, if there are r_1 non-additive resources and r_2 additive resources, throughput vectors for each resource can be written using Equations 3.5 and 3.6,

$$\mathbf{C}^{R_{1,i}} = (\mathbf{I} - \boldsymbol{\gamma}^{\mathbf{T}})^{-1} . \mathbf{C_n}^{R_{1,i}}; \quad \forall \quad i = 1, ..., r_1 \tag{3.5}$$

$$\mathbf{C}^{R_{2,j}} = (\mathbf{I} - \boldsymbol{\gamma}^{\mathbf{T}})^{-1} . \mathbf{C_n}^{R_{2,j}}; \quad \forall \quad j = 1, ..., r_2 \tag{3.6}$$

Here $\mathbf{C_n}^{R_{1,i}}$ and $\mathbf{C_n}^{R_{2,j}}$ are direct input vectors for the i^{th} non-additive resource and the j^{th} additive resource respectively and $\boldsymbol{\gamma}$ is the allocation matrix, which in the case of Thermodynamic Input-Output Analysis, is the monetary inter-industry transaction matrix. For calculating $\mathbf{C}^{R_1}$ and $\mathbf{C}^{R_2}$ scheme of Figure 2.6(a) is applied because the structure of the economic system and the outputs from each industry sector are completely known. After calculating $\mathbf{C}^{R_1}$ and $\mathbf{C}^{R_2}$ the next step is to determine the total throughputs of industry sectors. Addition of all $\mathbf{C}^{R_1}$ and $\mathbf{C}^{R_2}$ is not appropriate because it leads to double counting. Hence, for combining various inputs, following guidelines from ECEC methodology are used.

1. Network interactions for either an additive or a non-additive resource considered independently are computed using the scheme of Figure 2.6(a).
2. Two additive inputs or one additive input and one non-additive input can be added. However, two non-additive inputs cannot be added.

3. For combining two or more non-additive inputs the general principle is to compute network interactions for each input separately using the scheme of Figure 2.6(a), followed by taking the maximum along each branch of the network as shown by the scheme of Figure 2.6(b).

Hence to determine total throughput vector, $\mathbf{C}^{\text{total}}$, the maximum contribution from non-additive resources is added to the sum of contributions from all additive resources. This is shown by Equation 3.7.

$$\mathbf{C}^{\text{total}}(k) = \max_{i=1,\cdots r_1}\left\{\mathbf{C}^{R_{1,j}}(k)\right\} + \sum_{j=1}^{r_2} \mathbf{C}^{R_{2,j}}(k) \quad \forall\, k = 1,\ldots,n \tag{3.7}$$

Here n represents the number of industry sectors. The detailed algorithm for ECEC analysis is available in (Hau and Bakshi, 2004b).

3.5 Illustrative Example and Discussion

This example illustrates Thermodynamic Input-Output Analysis methodology discussed in the previous sections of this chapter. The system under consideration resembles a hypothetical three-sector economy. Figure 3.2 shows the economic input-output structure for this network and Table 3.2 shows the corresponding inter-industry transaction coefficient matrix, $\boldsymbol{\gamma}$. As defined by Equation 2.10, $\boldsymbol{\gamma}$ is derived by normalizing the output from sector i to sector j by the total output from Sector i. The next step is identification and quantification of natural and human resource inputs to the economic system. This is shown in Figure 3.3. Two different renewable resources, Ra_1 and Rb_2, one non-renewable resource, NR_1, human resource, HR_3, emission, E_2, and impact of emission on human health, IM_2, have been considered in this hypothetical example. In each case, the subscript represents the sector that gets the direct input of that particular resource.

The flows depicted in Figure 3.3 are subsequently converted into a consistent thermodynamic unit of solar equivalent joules (sej) as shown in Table 3.3. For this purpose, Equations 2.20 and 3.2-3.4 have been employed. Table 3.3 lists direct ECEC inputs to the hypothetical system. To determine total ECEC throughputs of the three sectors, the direct inputs need to be allocated through the economic network according to the allocation approach discussed in Section 3.4. Accordingly throughput vectors, $\mathbf{C}^{\mathbf{NR_1}}, \mathbf{C}^{\mathbf{Ra_1}}, \mathbf{C}^{\mathbf{Rb_2}}, \mathbf{C}^{\mathbf{HR_3}}, \mathbf{C}^{\mathbf{IM_2}}$, are calculated for individual resources as per Equations 3.5 and 3.6. The allocation matrix $\boldsymbol{\gamma}$, used for calculating these throughput vectors is shown in Table 3.2 and in Equation 3.8.

$$\boldsymbol{\gamma} = \begin{bmatrix} 0.5 & 0.1 & 0.2 \\ 0.25 & 0.0625 & 0.5 \\ 0.133 & 0.2 & 0.067 \end{bmatrix} \tag{3.8}$$

To determine total throughput vector, $\mathbf{C}^{\mathbf{total}}$, throughput vectors for individual resources are added according to Equation 3.9.

$$\mathbf{C}^{\mathbf{total}} = \mathbf{C}^{\mathbf{NR_1}} + \mathbf{max}(\mathbf{C}^{\mathbf{Ra_1}}, \mathbf{C}^{\mathbf{Rb_2}}) + \mathbf{C}^{\mathbf{HR_3}} + \mathbf{C}^{\mathbf{IM_2}} \tag{3.9}$$

Table 3.4 shows direct ECEC input vectors and total ECEC throughput vectors for the hypothetical example, and Figure 3.4 depicts them in graphical form. A similar technique has been used to derive the results for 91-sector 1992 US economic system in Chapter 4 and for 488-sector 1997 US economic system in Chapter 5. Based on the results presented in Table 3.4 several performance metrics can be evaluated. These performance metrics have been listed in Table 3.5 along with their definitions. Yield ratio indicates the proportion of the total ECEC requirement of a process or product that is derived from the economy. A process that derives a larger portion of its inputs directly from ecosystem has a higher yield ratio and vice-versa. Loading Ratio (LR) indicates the relative reliance of a process or product on non-renewable resources. The ratio of YR to LR is called yield-to-loading ratio and is considered in emergy analysis as the index of sustainability. According to this ratio, a process that relies on ecosystems but has lower reliance on non-renewable resources is more sustainable. Furthermore, impact per value added indicates the ratio of human health impact of emissions to some measure of value added such as profitability or productivity. These performance metrics are easy to calculate and provide a useful insight into the environmental implications of industrial products and processes. Table 3.5 also calculates these metrics for the hypothetical example from Figure 3.3. These metrics have been used in the case studies presented in Chapter 6 of this dissertation. Furthermore, Figure 3.5 shows a general network comprising a hypothetical process and its complementary economic network. It also shows direct and indirect inputs of renewable, non-renewable and human resources and emissions and their impact. Table 3.6 shows definitions of the performance metrics for the hypothetical generalized network shown in Figure 3.5.

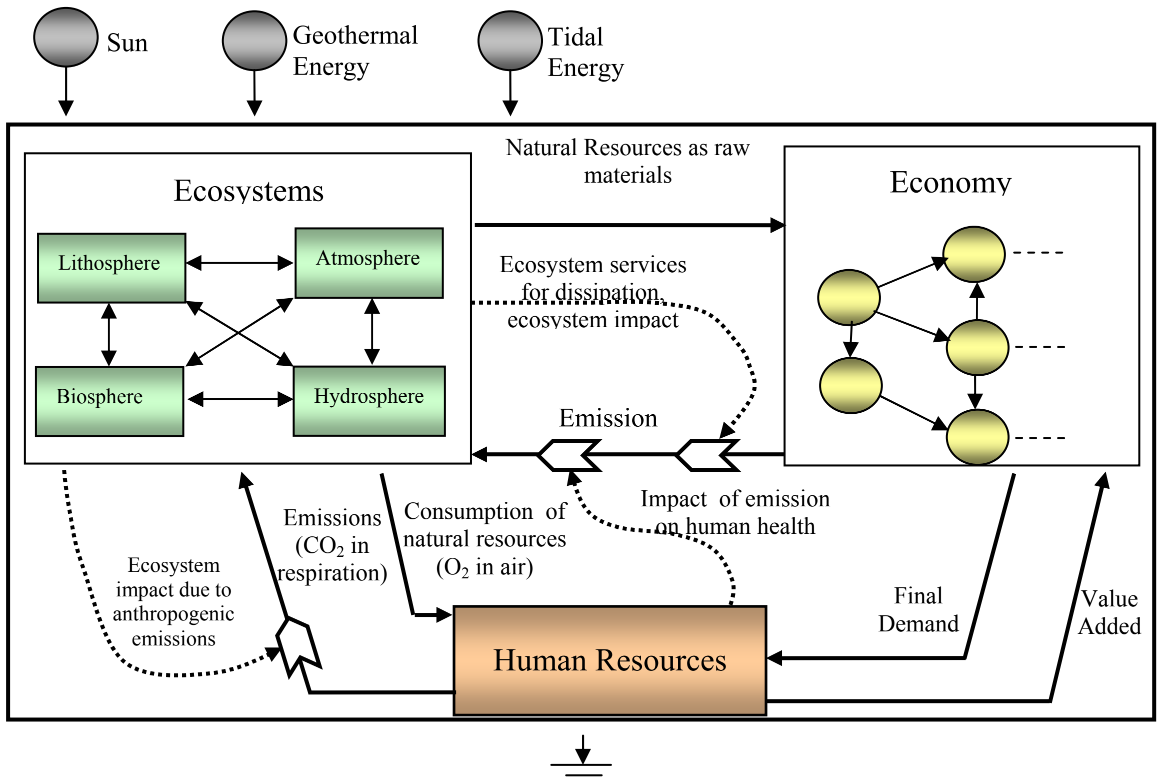


Figure 3.1: Integrated economic-ecological-human resource system. (Solid lines represent tangible interactions, dotted lines represent intangible interactions occurring as a consequence of emissions)

To / From	Ecosystem	Economy	Human Resource
Ecosystem	• Inter-ecosystem interactions e.g. nutrient transport from soil to plants (implicitly considered by transformity values)	• Ecosystem services such as wind, pollination, carbon sequestration etc. • Ecological goods such as coal, minerals, water, atmospheric nitrogen etc.	• Ecological goods such as atmospheric oxygen • Ecosystem services such as clean air, climate regulation and cultural and recreational values
Economy	• Industrial Emissions; available in life cycle inventory databases and toxic release inventory	• Inter-industry interactions; typically captured by economic input-output data	• Final Demand; sale of economic goods and services to consumers
Human Resource	• Anthropogenic emissions e.g. CO_2 from breathing and waste water from houses	• Value added; consumption of human resources in the form of employment of labor	• Social Interactions; not considered in this dissertation

Table 3.1: Interactions between ecosystem, economy, and human resources

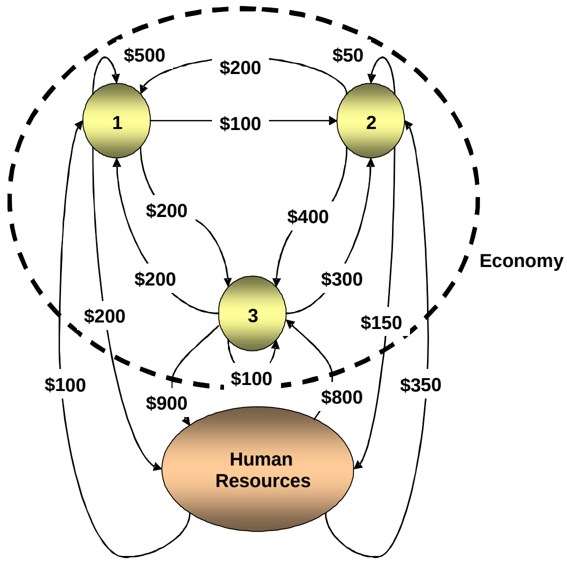


Figure 3.2: Network Representation of the Hypothetical 3-sector Economy

To / From	1	2	3	FD/HR	TO
1	0.5	0.1	0.2	0.2	1
2	0.25	0.0625	0.5	0.1875	1
3	0.133	0.2	0.067	0.6	1
VA/HR	0.08	0.28	0.64		1

Table 3.2: Allocation Matrix for Hypothetical 3-sector Economy Shown in Figure 3.2

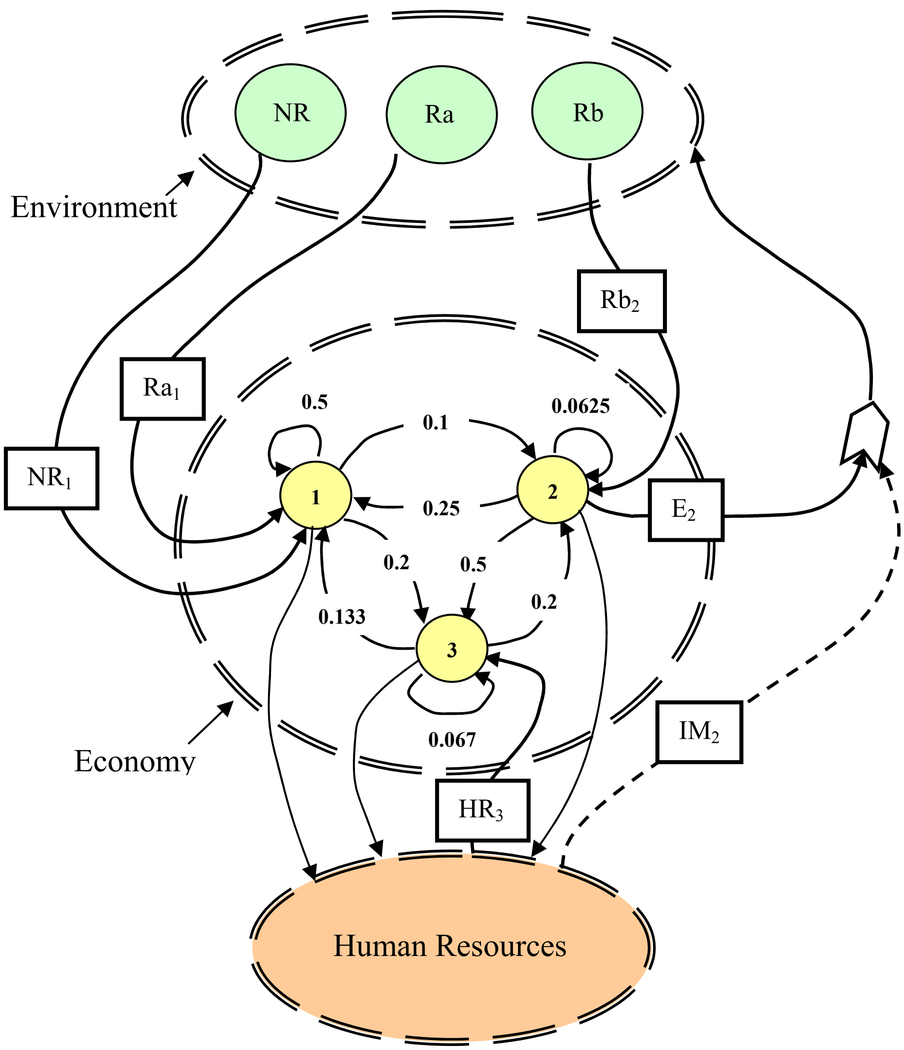


Figure 3.3: Augmented system showing Ecological and Human Resource Inputs to Economic Sectors

Stream Number	Type	Physical Data	Transformity	Direct Input (sej/d)
NR_1	Non-renewable	10tons/d	100,000sej/ton	1,000,000
Ra_1	Renewable	50tons/d	20,000sej/ton	1,000,000
Rb_2	Renewable	100,000J/d	10sej/J	1,000,000
HR_3 †	Human Resource	50hr/d	5,000sej/hr	250,000
E_2	Emission	2kg/d	-	-
IM_2 §	Impact on Human health	2kg/d	1,000sej/hr	1,752,000

† Man hours employed, h_i = 50 hr/d, average annual payroll, P_i = \$80/d, minimum average annual payroll, P_{min} = \$16/d, Transformity of unskilled labor, $\tau^{unskilled}$ = 1,000 sej/hr, Adjusted transformity, $\tau = (P_i/P_{min}).\tau^{unskilled}$ = 5,000sej/hr, $C = h_i \,.\, \tau$ = 250,000 sej/d

§ Mass flow rate of emission, m = 2 kg/d, Disability Adjusted Life Year, $DALY$ = 0.1 yr/kg, τ =1,000 sej/hr $C = m \,.\, DALY$. (365 day/yr) . (24 hr/day) . τ =1,752,000 sej/d

Table 3.3: Ecological and Human Resource Inputs in Figure 3.3 and Corresponding ECEC flows

Direct Input Vectors for Figure 3.3	Throughput Vectors for Figure 3.3
$\mathbf{C_n}^{NR_1} = \left[10^6 \quad 0 \quad 0\right]^\mathbf{T}$	$\mathbf{C}^{NR_1} = \left[2.4\times10^6 \quad 0.4\times10^6 \quad 0.7\times10^6\right]^\mathbf{T}$
$\mathbf{C_n}^{Ra_1} = \left[10^6 \quad 0 \quad 0\right]^\mathbf{T}$	$\mathbf{C}^{Ra_1} = \left[2.4\times10^6 \quad 0.4\times10^6 \quad 0.7\times10^6\right]^\mathbf{T}$
$\mathbf{C_n}^{Rb_2} = \left[0 \quad 10^6 \quad 0\right]^\mathbf{T}$	$\mathbf{C}^{Rb_2} = \left[0.9\times10^6 \quad 1.4\times10^6 \quad 0.9\times10^6\right]^\mathbf{T}$
$\mathbf{C_n}^{HR_3} = \left[0 \quad 0 \quad 2.5\times10^5\right]^\mathbf{T}$	$\mathbf{C}^{HR_3} = \left[1.4\times10^5 \quad 0.9\times10^5 \quad 3.4\times10^5\right]^\mathbf{T}$
$\mathbf{C_n}^{IM_2} = \left[0 \quad 1.8\times10^6 \quad 0\right]^\mathbf{T}$	$\mathbf{C}^{IM_2} = \left[1.6\times10^6 \quad 2.4\times10^6 \quad 1.6\times10^6\right]^\mathbf{T}$
$\mathbf{C_n}^{total} = \left[2\times10^6 \quad 2.8\times10^6 \quad 2.5\times10^5\right]^\mathbf{T}$	$\mathbf{C}^{total} = \left[6.6\times10^6 \quad 4.3\times10^6 \quad 3.6\times10^6\right]^\mathbf{T}$

Table 3.4: Direct ECEC input vectors and total ECEC throughput vectors for the illustrative example shown in Figure 3.3

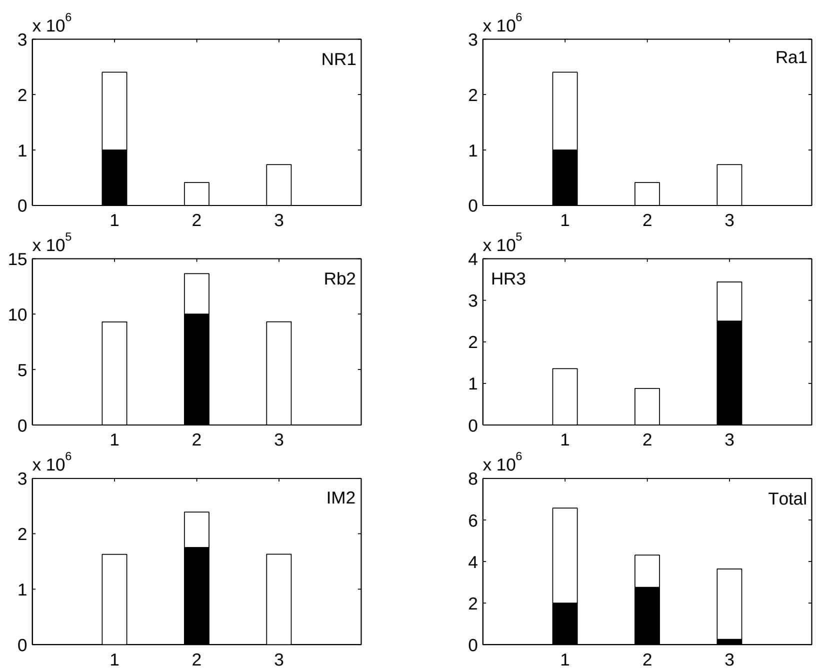


Figure 3.4: Throughput vectors for individual resources and total throughput vector for the network in shown in Figure 3.3. (X-axis: Sector Number, Y-axis: ECEC flow in sej/d; black region is the direct input, white region is indirect input)

Metric	Definition	Formula for the Hypothetical Example Shown in Figure #.#	Result for the Hypothetical System Shown in Figure #.#
Yield (**Y**)	Total ECEC throughput (sej/yr)	$\mathbf{Y} = \mathbf{C}^{total}$	$[6.6\times10^{6} \quad 4.3\times10^{6} \quad 3.6\times10^{6}]$
Total Direct Input (**DI**)	ECEC of direct inputs from the environment and human resources (sej/yr)	$\mathbf{DI} = \mathbf{C_n}^{total}$	$[2\times10^{6} \quad 2.8\times10^{6} \quad 2.5\times10^{5}]$
Total Indirect Input (**II**)	ECEC embodied in purchased inputs from the economy (sej/yr)	$\mathbf{II} = \mathbf{C}^{total} - \mathbf{C_n}^{total}$	$[4.6\times10^{6} \quad 1.5\times10^{6} \quad 3.35\times10^{6}]$
Total Inputs from non-renewable resources (**NR**)	ECEC content of direct and purchased inputs that originates from non-renewable resources (sej/yr)	$\mathbf{NR} = \mathbf{C}^{NR_1}$	$[2.4\times10^{6} \quad 0.4\times10^{6} \quad 0.7\times10^{6}]$
Total Inputs from renewable resources (**REN**)	ECEC content of direct and purchased inputs that originates from renewable resources (sej/yr)	$\mathbf{REN} = \max\{\mathbf{C}^{Ra_1}, \mathbf{C}^{Rb_2}\}$	$[2.4\times10^{6} \quad 1.4\times10^{6} \quad 0.9\times10^{6}]$
Economic Throughput (**ECON**)	Total monetary flows through each sector; these flows include intermediate outputs and final demand ($/yr)	--	$[1000 \quad 800 \quad 1500]$
Yield Ratio (**YR**)	Ratio of total ECEC throughput to ECEC embodied in purchased inputs from the economy	$\mathbf{YR} = \dfrac{\mathbf{C}^{total}}{\mathbf{C}^{total} - \mathbf{C_n}^{total}}$	$[1.43 \quad 2.87 \quad 1.07]$
Environmental Loading Ratio (**LR**)	Ratio of total Inputs from non-renewable resources to total inputs from renewable resources	$\mathbf{LR} = \dfrac{\mathbf{NR}}{\mathbf{REN}} = \dfrac{\mathbf{C}^{NR_1}}{\max\{\mathbf{C}^{Ra_1}, \mathbf{C}^{Rb_2}\}}$	$[1 \quad 0.3 \quad 0.78]$
Yield-to-Loading Ratio (**YLR**)	Ratio of yield ratio to environmental loading ratio; in emergy analysis this ratio is called index of sustainability	$\mathbf{YLR} = \dfrac{\mathbf{YR}}{\mathbf{LR}}$	$[1 \quad 9.57 \quad 1.37]$
Impact-Per-Value Added (**IVA**)	Ratio of human health impact to economic throughput (other measures of value added such as productivity or profitability can also be used) (sej/$)	$\mathbf{IVA} = \dfrac{\mathbf{C}^{IM_2}}{\mathbf{ECON}}$	$[1.6\times10^{3} \quad 3\times10^{3} \quad 1.1\times10^{3}]$

Table 3.5: Performance Metrics using Thermodynamic Input-Output Analysis, Definitions and Illustration for the hypothetical example shown in Figure 3.3.

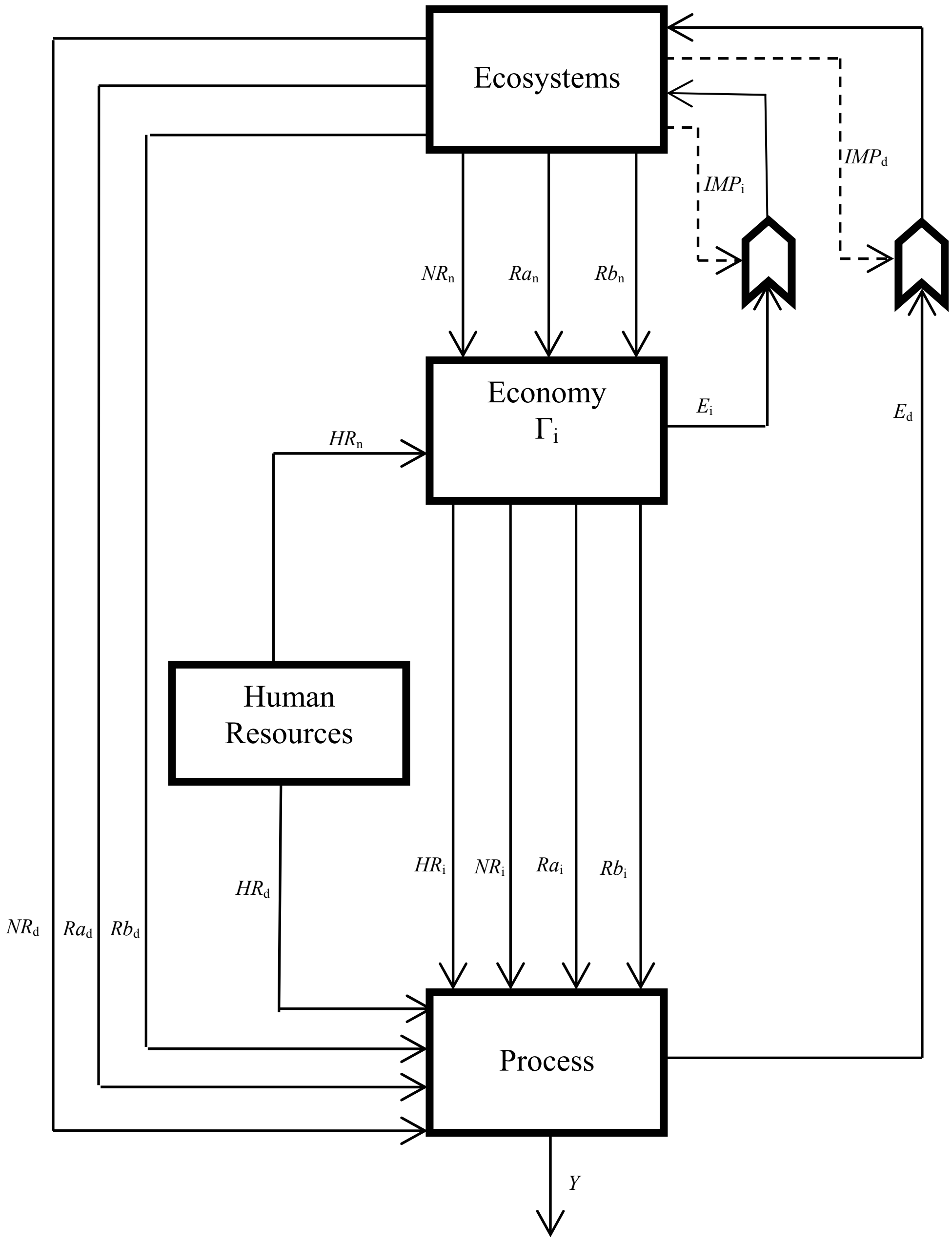


Figure 3.5: Network Diagram Showing Direct and Indirect Flows to a Selected Process. $\theta_i = f(\mathbf{\Gamma}_i, \theta_n)$ According to Equations 2.36 and 2.37.

	Metric	Symbol	Formula
1.	Total Inputs from Nonrenewable resources	NR	$NR_i + NR_d$
2.	Total Inputs from Renewable resources	REN	max $\{Ra_i, Rb_i, Ra_d, Rb_d\}$
3.	Total Direct Inputs	DI	$HR_d + NR_d + IMP_d +$ max $\{Ra_d, Rb_d\}$
4.	Total Indirect Inputs	II	$HR_i + NR_i + IMP_i +$ max $\{Ra_i, Rb_i\}$
5.	Yield	Y	DI + II
6.	Yield Ratio	YR	Y / II
7.	Environmental Loading Ratio	LR	NR/REN
8.	Yield-to-loading Ratio	YLR	YR / LR

Table 3.6: Performance Metrics for the General Network from Figure 3.5

CHAPTER 4

RESULTS FOR 91-SECTOR 1992 US ECONOMY

In this chapter Thermodynamic Input-Output Analysis Methodology discussed in Chapter 3 has been applied to study ecosystem contribution to 91-sector 1992 US economy. Section 4,1 presents data for ecological resource inputs and emissions and their impact for the 1992 US economy. Sections 4.2-4.6 discuss ECEC throughputs of individual ecological resources, human resources and human health impact of bulk and non-bulk pollutants. Section 4.7 presents aggregate metrics that include total ECEC requirements, ECEC/money ratios and ECEC/ICEC ratios. As discussed later, total ECEC requirement represents the thermodynamic basis of industrial activities and is conceptually similar to ecological cost. ECEC/money ratio is a measure of the discrepancy between thermodynamic work required to produce a product or service and the willingness of people to pay for them. It provides a unique insight into the discord between economic prices and ecosystem contribution. Such discord is believed to be the root cause behind the lack of internalization of ecosystems into economic policies. ECEC/ICEC ratio represents the extent to which conventional thermodynamic techniques underestimate the contribution of ecosystems.

4.1 Data Requirements and Sources

This section describes the resources considered in this analysis. All required data have been obtained from public domain database, and corresponding data sources have been provided at appropriate locations in this Section.

4.1.1. Transformities

ECEC of ecosystem products and services is quantified via their transformity values (Odum, 1996; Brown and Bardi, 2001; Brandt-Williams, 2002). As mentioned in Section 2.4, transformities focus only on concurrent energy and do not include energy consumption over geological time scales. Furthermore, the concept of transformity is proved to be equivalent to the reciprocal of cumulative degree of perfection, a measure of global efficiency. They are *not subject* to the most controversial aspects of Odum's work, such as the maximum empower principle and the emergy theory of value. Transformities used in this analysis correspond to the 1996 base of 9.44×10^{24} sej/yr (Odum, 1996).

4.1.2. Ecosystem Products

Ecosystem products refer to an array of ecological resources used as direct raw materials in industrial processes. They are either produced by or are a part of various ecosystem services. For example, water consumed for domestic or industrial purposes embodies constituents of the hydrologic cycle such as rain and water streams, while mineral and fossil resources are made available by the geologic cycle. Ecosystem products are always associated with corresponding material or energy flows. Crude oil in refineries and water for human consumption are some examples of ecosystem products. Table 4.1 shows ecosystem products considered in this analysis along with industry sectors receiving their direct inputs and corresponding data sources. The ecological products are grouped into four ecological spheres; lithosphere, biosphere, atmosphere and hydrosphere depending on their mode of entry into the economic system. Such distinction, though convenient, is not essential to TIOA, and any other user-defined disaggregation scheme would also work as long as renewable and non-renewable resources are distinguished.

4.1.3. Ecosystem Services

Ecosystem services refer to various natural functions that support economic activities. Unlike ecological products, ecosystem services need not always be associated with material or energy flows. For instance, dissipation of emissions by wind and use of geothermal heat for electricity generation are examples of ecosystem services that are associated with mass or energy flows. These are the *supply-based* services. Ecosystem services required for recreational and cultural purposes, on the other hand, are based on human valuation and are not necessarily accompanied by material or energy flows. These are the *value-based* services. This analysis focuses only on the supply-based services listed in Table 4.2. Value-based services are dealt with in Costanza et al. (1997) and Balmford et al. (2002).

4.1.4. Emissions and Their Impact on Human Health

Once emitted to the environment every pollutant is diluted to some base concentration by ecosystem services such as wind and water streams. Several spatial and temporal factors such as dispersion, diffusion and atmospheric chemistry become important in determining this base concentration. If the base concentration is more than a certain threshold value the corresponding emission causes human and ecosystem health impact. The impact itself depends on fate of pollutants in ecosystems, their exposure to people and their effect on human anatomy. There are several established procedures for calculating the impact associated with emissions. The approach employed in this analysis uses eco-indicator 99 (Hofstetter, 1998; Goedkoop and Spriensma, 1999). This work only focuses on impacts on human health as measured by Disability Adjusted Life Years (DALY). Table 4.3 lists various pollutants considered in this work, the impact categories they belong to and the corresponding DALY values per kg of emission. Data on emissions are gathered from the US Environmental Protection Agency's Toxics Release Inventory (TRI) which is published on a periodic basis (USEPA, 1999). DALY values have been obtained from eco-indicator 99. The approach for converting DALY to ECEC is discussed in Section 3.3.3.

4.1.5. Human Resources and Inter-Industry Allocation Matrix

Industry sectors consume human resources in the form of labor. Amount of human resources consumed is a function of number of individuals employed and the skill-level (quality) of the labor. In this analysis, average annual payroll is chosen as a measure of the quality of labor. Data about number of people employed and their average annual payroll are obtained from US Department of Labor's Bureau of Labor Statistics (BLS, 2004). Allocation matrix for 1992 US economy is obtained from Bureau of Economic Analysis (BEA, 2005a).

4.2. Contribution of Ecosystem Products to Industry Sectors

Figure 4.1 shows the contribution of ecosystem products listed in Table 4.1 to the 91 sectors of the 1992 US economy. The sector names, SIC codes and serial numbers of the economic sectors are shown in Table A.1 in the Supplementary Material.

4.2.1. Lithosphere

Figure 4.1(a) shows ECEC requirements of industry sectors from the lithosphere. Sectors of metallic ores mining (SIC 5, 6), coal mining (SIC 7), crude petroleum and natural gas (SIC 8) and non-metallic minerals mining (SIC 9, 10) receive direct inputs from lithosphere. Sector of other agricultural products (SIC 2) has a direct output to the lithosphere on account of return of detrital matter to agricultural soil. This is shown by a small negative peak for SIC 2. However, SIC 2 consumes other products from the lithosphere indirectly and, as a result, has a net positive requirement. Other sectors such as petroleum refining and related products (SIC 31), stone and clay products (SIC 36), electric services (SIC 68A), gas production and distribution (SIC 68B) and industrial and other chemicals (SIC 27A) also have prominent peaks on account of indirect consumption.

4.2.2. Biosphere

Figure 4.1(b) shows ECEC from the biosphere. Sectors of livestock and livestock products (SIC 1) and forestry and fishery products (SIC 3) get direct inputs from the biosphere due to pasture harvesting and timber harvesting, respectively. Sectors of new construction (SIC 11), maintenance and repair construction (SIC 12), food and kindred products (SIC 14) and lumber and wood products (SIC 20, 21) also have prominent peaks because of indirect consumption. The sector of eating and drinking places (SIC 74) also has a substantial indirect requirement from biosphere.

4.2.3. Atmosphere

Figure 4.1(c) shows ECEC from the atmosphere. This graph shows prominent peaks for Sectors of other agricultural products (SIC 2) and Food and Kindred Products (SIC 14). Materials Handling Machinery and Equipment (SIC 46), Non-metallic minerals mining (SIC 9, 10) and Engines and Turbines (SIC 43) are the sectors with the lowest requirements from atmosphere. As mentioned in Table 4.1, only CO_2 consumed during 24-hour photosynthesis has been considered in this analysis. Other atmospheric gases such as N_2 and O_2 have not been considered because their transformity values are unresolved in emergy analysis. Determining transformities of N_2 and O_2 is a non-trivial task because of their presence in several geo-bio-chemical cycles. For instance, O_2 is an integral part of nitrogen, sulfur, carbon and phosphorous cycles all of which are interconnected.

4.2.4. *Hydrosphere*

Figure 4.1(d) shows ECEC requirements from hydrosphere. Only the sector of water and sanitary services (SIC 68C) has direct inputs from hydrosphere. This work concentrates on water bodies such as lakes and rivers that supply water to the sector of water and sanitary services (SIC 68C). Hydrosphere also includes other elements such as rain and its services to economic sectors through climate regulation and cleansing of air. Such elements have not been considered in this analysis.

4.3. Contribution of Ecosystem Services to Industry Sectors

Figure 4.2 shows the contribution of ecosystem services listed in Table 4.2 to the 91-sectors of the 1992 US economy.

4.3.1. *Sunlight*

Figure 4.2(a) shows the contribution of sunlight. Sectors of other agricultural products (SIC 2) and forestry and fisheries products (SIC 3) are the direct recipients of sunlight whereas sectors of food and kindred products (SIC 14), livestock and livestock products (SIC 1) and eating and drinking places (SIC 74) also have prominent peaks on account of indirect consumption.

In this work, sunlight is assumed to enter the US economy through SIC 2 and SIC 3 in proportion to their relative land areas (ForestInfo, 2004; NASA, 2004). This is similar to the assumption made by Costanza who considered solar energy inputs to the

US economy to calculate embodied energy intensities of industry sectors (Costanza, 1980). However, the approach in Costanza (1980) was quite crude as it did not consider indirect routes of solar inputs to industry sectors. Such indirect routes include various bio-geo-chemical cycles like the hydrologic cycle and atmospheric circulation that are driven by solar energy. The approach proposed in this work overcomes this shortcoming as it is able to capture some of these indirect routes via the use of transformity values. Transformity, by definition, captures solar, tidal and geothermal energy embodied in ecosystem products and services. As a result, the approach presented in this dissertation not only considers direct solar inputs to agricultural, forestry and related activities but also indirect solar inputs embodied in ecosystem products and services.

4.3.2. Fertile Soil

Figure 4.2(b) shows ECEC content of topsoil lost due to erosion. Sectors of other agricultural products (SIC 2) and new construction (SIC 9) are directly responsible for the loss of top organic soil. Sector of food and kindred products (SIC 14) also causes substantial loss indirectly. Contribution of soil erosion is significantly larger than that of sunlight because top organic soil is a more concentrated form of resource than sunlight. This is also reflected in a higher transformity value for topsoil in Table 4.2.

4.3.3. Hydropotential

Figure 4.2(c) shows the contribution of hydropotential to industry sectors. Hydropotential refers to the potential energy in water streams that is first converted to kinetic energy and then to electrical energy in hydroelectric power plants. Naturally the sector of electric services (SIC 68A) is the only sector with direct input. The service sectors (SIC 72-77B) have higher indirect ECEC requirements. Especially the sector of retail trade (SIC 69B) has higher indirect contribution from SIC 68A than any other sector. This can be explained considering the dominant position of service industry in the US economy. Service sectors generate 66% of all economic activity in the US, and consequently have high electricity requirements.

The contribution of wind energy and geothermal energy is also calculated but not shown because it is qualitatively identical to that of hydropotential shown in Figure 4.2(c). In all three cases the sector of electric services (SIC 68A) is the only direct recipient. Moreover, the inter-industry allocation matrix used in determining indirect requirements of other industry sectors is also the same. The only difference is in the y-axis magnitude. Contribution from hydropotential is nearly three orders of magnitude higher than that from wind energy.

4.4. Contribution from Human Resources

Figure 4.3 shows ECEC requirements of industry sectors from human resources. Unlike previous graphs, every sector in Figure 4.3 has direct inputs of human resources, since every sector employs labor. Service sectors (SIC 69A-77B) have higher direct inputs than the manufacturing sectors (SIC 14-64). Sector of health services (SIC 77A) has the highest consumption of human resources. Sectors of retail trade (SIC 69B), wholesale trade (SIC 69A) and state and local government enterprises (SIC 79) are other major consumers of human resources. Sectors of new construction (SIC 11), maintenance and repair construction (SIC 12) and food and kindred products (SIC 14) also have high consumption of human resources on account of indirect inputs.

4.5. Human Health Impact of Bulk Pollutants

Figure 4.4 shows the human health impact of the four bulk pollutants considered in this analysis. These are SO_2, NO_2, PM10 and CO_2. As discussed in Section 3.4, each plot is proportional to the DALY value of the corresponding pollutant based on a hierarchist perspective (Goedkoop and Spriensma, 1999).

4.5.1. Sulfur dioxide

Figure 4.4(a) shows the impact associated with SO_2. Power plants are the major emitters of SO_2. Petroleum refining and related products (SIC 31), Food and kindred products (SIC 14) and paper and allied products except containers (SIC 24) are other sectors with significant impact due to SO_2 emission.

4.5.2. Nitrogen oxides

Figure 4.4(b) shows impact associated with NO_2 emissions. Power plants (SIC 68A) are the major emitters of NO_2. Food and kindred products (SIC 14), motor freight transportation and warehousing (SIC 65B) and petroleum refining and related products are other sectors with prominent peaks. Agriculture and livestock sectors (SIC 1, 2) also have significant peaks due to high usage of nitrogenous fertilizers whose production is a source of NO_x.

4.5.3. Carbon dioxide

Figure 4.4(c) shows impact associated with CO_2 emission. CO_2 is emitted in combustion processes such as furnaces and internal combustion engines, and affects human health through climate change and global warming. Sectors of electric services (SIC 68A), petroleum refining and related products (SIC 31), crude petroleum and natural gas mining (SIC 8) have major impact due to CO_2 emission. These sectors are directly involved in extraction and consumption of fossil fuels. Impact of CO_2 emissions, as reported in eco-indicator 99, is the potential impact in future (Goedkoop and Spriensma, 1999).

4.5.4. Particulate matter (PM10)

Figure 4.4(d) shows impact associated with emission of PM10. PM10 is primarily responsible for respiratory disorders. Sectors of new construction (SIC 11), maintenance and repair construction (SIC 12), electric services (SIC 68A) and ordnance and accessories (SIC 13) are major emitters of particulate matter. Some service industries such as owner occupied dwellings (SIC 71A), real estate and royalties (SIC 71B) and state and local government enterprises (SIC 79) also have noticeable peaks due to indirect effects. Among the bulk pollutants, impact associated with SO_2 and CO_2 is two orders of magnitude higher than that for NO_2 and PM10.

4.6. Human Health Impact of Non-Bulk Pollutants

Figures 4.5 and 4.6 show impact of selected non-bulk pollutants. Their immediate destinations and the impact category they belong to are listed in Table 4.3.

4.6.1. Ammonia

Figure 4.5(a) shows impact associated with emission of ammonia. Ammonia is primarily emitted by manufacturing sectors, namely paper and allied products except containers (SIC 24), stone and clay products (SIC 36) and petroleum refining and related products (SIC 31). Other sectors with prominent peaks include primary non-ferrous metals manufacturing (SIC 37) and other printing and publishing (SIC 26B).

4.6.2. Toluene

Figure 4.5(b) shows impact associated with emission of toluene. Sectors of newspapers and periodicals (SIC 26A) and rubber and miscellaneous products (SIC 32) have the highest impact. Other sectors with significant impact are furniture and fixtures (SIC 22, 23), petroleum refining and related products (SIC 31) and motor vehicles (passenger cars and trucks) (SIC 59A).

4.6.3. Methanol

Figure 4.5(c) shows impact associated with emission of methanol. Paper and allied products except containers (SIC 24), lumber and wood products (SIC 20, 21) and industrial and other chemicals are some of the major emitters of methanol. Other sectors with prominent peaks include other printing and publishing (SIC 26B), food and kindred products (SIC 14) and new construction (SIC 11).

4.6.4. 1,1,1-Trichloroethane

Figure 4.5(d) shows impact associated with 1,1,1-Trichloroethane. 1,1,1-TCE plays an active role in ozone layer depletion. Rubber and miscellaneous plastic products (SIC 32), motor vehicles (passenger cars and trucks) (SIC 59A), heating, plumbing, fabricated structural metal products (SIC 40) are some of the major emitters of 1,1,1-TCE. New construction (SIC 11) and food and kindred products (SIC 14) also have substantial impact due to indirect effects.

4.6.5. Styrene

Figures 4.6(a) to 4.6(c) show impact associated with emission of styrene. Styrene is a carcinogenic substance that is released to soil, water and air. Depending on the immediate destination of Styrene emission human health impact could be very different. This is demonstrated by figures 4.6(a) to 4.6(c). Impact of Styrene emission to air is two orders of magnitude higher than that to water or soil. Sectors of rubber and miscellaneous plastic products (SIC 34) and motor vehicles (passenger cars and trucks) (SIC 59A) are the major emitters of styrene to air. Industrial and other chemicals (SIC 27A), paper and allied products except containers (SIC 24) and lumber and wood products (SIC 20, 21) are the primary emitters of styrene to water streams. Sector of health services (SIC 77A) also has appreciable impact on human health due to indirect effects.

4.7. Aggregate Metrics

This section presents and interprets aggregate metrics based on the results obtained in Sections 4.2-4.6. Such aggregation is facilitated by the fact that all the results obtained in Sections 4.2-4.6 are expressed in a single consistent thermodynamic unit of solar equivalent joule (sej). Use of a single consistent thermodynamic unit provides a systematic way of combining information available in disparate units. For instance, ecosystem products and service are typically measured in disparate units like tones of coal and joules of sunlight. Moreover, ecological resources that do get expressed in the same unit cannot be combined without appreciating their quality differences. As a result, existing methods for environmental decision making such as EIOLCA report consumption data for ecological resources and emission data for various pollutants separately. It is then the job of the user to distill these data into a smaller number of indices that are easy to use and, yet, sufficiently representative. There is no established method for combining the data expressed in disparate units, and arbitrary valuation is often employed. Thermodynamic Input-Output Analysis is useful to address this issue, since it presents a systematic way of aggregating resource consumption and emission data into a smaller number of indices. Consequently, the proposed approach is useful in constructing hierarchical metrics of sustainability that are discussed further in Chapter 6 of this dissertation (Schwarz et al., 2002; Bakshi and Fiksel, 2003; Yi et al., 2004).

Care must be taken in aggregating the results obtained in Figures 4.1 through 4.6 because simple, across-the-board addition may lead to double counting. The solution proposed in emergy analysis (Odum, 1996) and ECEC analysis (Hau and Bakshi, 2004b) is to divide the resources into two groups: additive and non-additive. This distinction is due to the allocation methods used for ecological inputs in emergy analysis to avoid double-counting. Accordingly renewable resources are non-additive, while non-renewable resources are additive. In the context of this analysis, inputs from atmosphere, hydrosphere and ecosystem services are non-additive, whereas inputs from lithosphere, biosphere, human resources and impact of emissions on human health are additive. Since the choice of allocation rules is usually subjective, the sensitivity of the results to different allocation rules should be evaluated. It may also be possible to select system boundaries that avoid allocation altogether. The application of such techniques to the analysis presented in this analysis is a part of the on-going work. Additional details about allocation rules in ECEC analysis have been provided in Section 2.5.4 of this dissertation.

4.7.1. Total ECEC Requirements

Total ECEC of each industry sector is shown in Figure 4.7. Figure 4.7 is a semi-log plot that shows relative contributions of renewable resources, non-renewable resource, human resources and human health impact of emissions to the total ECEC of each sector. The sector of non-metallic minerals mining (SIC 9, 10) is found to have the highest ECEC. Other sectors with high ECEC values are New Construction (SIC 11), Health Services (SIC 77A) and Petroleum Refining and Related Products (SIC 31).

Sectors with the smallest ECEC are, footwear, leather, and leather products (SIC 33, 34), tobacco products (SIC 15), and pipelines, freight forwarders and related services (SIC 73D).

Total ECEC requirement is similar to the concept of *ecological cost* proposed by Szargut as "the cumulative consumption of non-renewable exergy in all links of the production network and connected with the fabrication of the considered product" (Szargut, 1999). However, ECEC actually calculates this cost and also captures the cumulative consumption of exergy in all the links of the production network. It enhances ecological cost in two aspects – unlike ecological cost, total ECEC considers renewable *and* non-renewable resources, and ECEC also accounts for the exergy consumed in the ecological links of a production network. Figure 4.7 can be easily modified to represent ECEC requirements of industry sectors from non-renewable resources alone. *Such a graph can be useful in determining industry-specific pro-ecological tax as proposed by Szargut and others* (Szargut, 2002). ECEC by itself is of limited use for sustainable decision making. A normalized metric that compares ecosystem contribution to economic activity is more insightful, and is discussed next.

4.7.2. ECEC/Money Ratio

This ratio compares ecological and economic throughputs of industry sectors. Figure 4.8 shows ECEC/money ratio of each of the 91 industry sectors on a semi-log plot. It is calculated by dividing total ECEC throughput of each sector shown in Figure 4.7 by its total economic throughput. Similar to Figure 4.7, Figure 4.8 also shows

ECEC/money ratio for renewable resources, non-renewable resources, human resources and human health impact of emissions separately. The ECEC/money ratio is analogous to the emergy/money ratio used in emergy analysis, and similar ratios suggested in exergy analysis (Szargut, 2002; Sciubba, 2003). However, unlike the single ratio in emergy or exergy analysis for the entire economy, Figure 4.8 provides a separate ratio for each sector. The variation in Figure 4.8 confirms the heterogeneous nature of the economy. The ratio of the direct ecological inputs to the 1992 GDP of the US is 2.10×10^{12} sej/\$, which is close to the emergy/\$ ratio of 1.44×10^{12} sej/\$ obtained by Odum. The former ratio is slightly higher because it also includes the human health impact of emissions which is ignored in emergy analysis. *The ECEC/money ratio does not support or debunk any theory of value, but is rather meant to provide insight into the magnitude of discrepancy between thermodynamic work needed to produce a product or service and people's willingness to pay for it.* ECEC/money ratios can be used to quantify ecological cumulative exergy contained in purchased inputs of industrial processes. Such industry-specific ratios provide a more accurate alternative to the single emergy/$ ratio used in emergy analysis, and similar ad hoc procedures used in thermoeconomics. Normalization with respect to money is possible because monetary outputs of industry sectors are well-known. However, normalization with respect to exergy to determine Transformity or CDP values of industry sectors is more difficult due to lack of information about exergetic outputs of industry sectors.

The ECEC/money ratio is a measure of cumulative exergy consumption in the production chain of an industry sector to generate $1 of economic activity. Table B.2 in the Supplementary Material lists ECEC/money ratios for the 91 industry sectors. Some salient observations about this ratio are as follows.

- The ECEC/money ratio for the sectors of non-metallic minerals mining (SIC 9, 10) and metallic ores mining (SIC 5, 6) are the highest. Sectors with the smallest ECEC/money ratios are owner-occupied dwellings (SIC 71A) and advertising (SIC 73D). Sector of Radio and TV Broadcasting (SIC 67) also has a high ECEC/money ratio due to high human resource inputs.
- Specialized sectors such as tobacco products (SIC 15), drugs (SIC 29A) and computer and office equipment (SIC 51) have smaller ECEC/money ratios than basic sectors such as petroleum refining and related products (SIC 31) and primary iron and steel manufacturing (SIC 37).
- Average ECEC/money ratio for mining sectors (SIC 5-10) is 22 times the average ECEC/money ratio for service industry sectors (SIC 69A-79).
- Among peripheral sectors, or the sectors that lie at the economy-ecosystem interface, agricultural, forestry, livestock, fisheries and water and sanitary services sectors (SIC 1-4, 68C) have an average ECEC/money ratio that is 11% of that for mining sectors (SIC 5-10).

The wide variation in ECEC/money ratio indicates the discord between ecological activity and corresponding economic valuation. This may be because market prices do not fully reflect the contribution of ecosystems. Since economic value is not inherent in objects but is a product of a variety of consumer judgments, the variation in this ratio may also reflect a lack of consumer awareness about ecosystem contribution towards economic activity. Thus, sectors with larger ratios seem not to appreciate or value ecosystem products and services as much as those with smaller ratios. This not only corroborates the lack of integration of the “eco-services” sector with the rest of the economy but also quantifies the magnitude of this discrepancy (Ayres, 1998a; Ayres, 1998b).

Furthermore, ECEC/money ratio tends to decrease along supply chains of industrial processes. Basic infrastructure sectors that lie at the economy-ecosystem interface and the sectors that rely more heavily on non-renewable resources have higher ECEC/money ratios. This suggests that sectors with high ECEC/money ratio consume natural capital in a manner that is disproportionate to their contribution to economic capital. These observations match other work on the relationship between environmental impact and economic value along supply chains of industrial processes (Clift and Wright, 2000). Potential implications of ECEC/money ratio to outsourcing and sustainability and to adjust trade policy have been discussed further in Chapter 6 of this dissertation.

ECEC/money ratio is particularly useful in hybrid thermodynamic life cycle analysis of industrial systems. A hybrid analysis integrates process models or product systems with economy-scale input-output models, and in the process, combines accurate, process-specific data with more uncertain economy-scale data (Suh et al., 2004). Consequently, a hybrid analysis is more powerful as it combines the two critical attributes of an environmental decision tool, specificity and a broad system boundary. ECEC/money ratio can come in handy in this context as the interactions of a product system with the rest of the economy are routinely measured in monetary terms in normal accounting procedures.

4.7.3. ECEC/ICEC Ratio

ICEC analysis determines cumulative exergy consumption in the industrial links of a production chain. However, it does not consider ecological links of the production chain at all. Consequently, ICEC analysis assumes that all ecosystem products and services are identical, and have a constant transformity of unity. This is erroneous as ecosystem products and services are known to differ widely in their quality aspects. For instance, ICEC analysis does not differentiate between 1J of coal and 1J of sunlight, though it is well-known that ecosystems have to perform a lot more work in producing 1J of coal, whereas sunlight is practically free. ECEC analysis overcomes this shortcoming through the use of transformity values.

ECEC/ICEC ratio represents the degree to which ICEC analysis underestimates cumulative exergy consumption of a production chain by ignoring its ecological links. Since transformities of non-renewable resources are higher than those of renewable resources, ECEC/ICEC ratio is also higher for industry sectors that depend more on non-renewable resources. *Therefore ECEC/ICEC ratio is potentially useful as a proxy-indicator of "degree of non-renewability" of industry sectors* (Berthiaume et al., 2001), though a more rigorous analysis is required to propose any correlation.

As seen from Figure 4.9 and Table B.2 in the Appendix the sector of other agricultural products (SIC 2) has the lowest ECEC/ICEC ratio, while the sector of non-metallic minerals mining (SIC 9,10) has the highest. The median ECEC/ICEC ratio for all the sectors is approximately 1,860sej/J indicating that ecosystems have to expend 1,860J of energy to make 1J of an average ecological resource available to an average industrial activity. ECEC/ICEC ratios can be used in conjunction with ECEC/money ratios to determine ICEC/money ratios that are useful to quantify industrial cumulative exergy content of purchased inputs of industrial processes.

Resource considered in this analysis	Industry sector receiving direct input and its SIC code [Φ]	Material or Energy Flow (F)	Data Source for F	ICEC Flow (J/yr)	Transformity (τ)	Data Source for τ	ECEC Flow $c = \tau.F$ (sej/yr)
Lithosphere							
Crude petroleum field production	Crude Petroleum and natural gas (SIC 8)	1.31×10^{19} J/yr [a] [Ψ]	(USDOE, 2004a)	1.31×10^{19}	53000 sej/J	(Odum, 1996)	6.95×10^{23}
Iron-ore mining	Metallic ores mining (SIC 5,6)	181 MMT/yr	(Ayres and Ayres, 1998)	1.88×10^{16} [b]	1×10^{9} sej/g	(Odum, 1996)	1.81×10^{23}
Non-ferrous metal mining	Metallic ores mining (SIC 5,6)	576 MMT/yr	(USGS, 2004a)	4.71×10^{16} [c]	1×10^{9} sej/g	(Odum, 1996)	5.76×10^{23}
Crushed Stone	Nonmetallic minerals mining (SIC 9,10)	1118 MMT/yr	(Ayres and Ayres, 1998; USGS, 2004a)	1.48×10^{17} [d]	1×10^{9} sej/g	(Odum, 1996)	1.12×10^{24}
Sand	Nonmetallic minerals mining (SIC 9,10)	894 MMT/yr	(Ayres and Ayres, 1998)	1.18×10^{17} [e]	1×10^{9} sej/g	(Odum, 1996)	8.94×10^{23}
Raw coal excluding overburden	Coal mining (SIC 7)	878 MMT/yr	(Ayres and Ayres, 1998)	2.56×10^{19} [f]	1×10^{9} sej/g	(Odum, 1996)	8.78×10^{23}
Nitrogen from Mineralization	Other agricultural products (SIC 2)	3 MMT/yr	(Ayres and Ayres, 1998)	1.16×10^{15} [g]	4.19×10^{9} sej/g	(Odum, 1996)	1.26×10^{22}
Phosphorous from Mineralization	Other agricultural products (SIC 2)	2 MMT/yr	(Ayres and Ayres, 1998)	9.88×10^{14} [h]	2×10^{8} sej/g [i]	(Odum, 1996)	4×10^{21}
N-Deposition from Atmosphere [j]	Other agricultural products (SIC 2)	2 MMT/yr	(Ayres and Ayres, 1998)	7.76×10^{14} [k]	4.19×10^{9} sej/g	(Odum, 1996)	8.38×10^{21}
Return of decomposing detritus to agricultural soil	Other agricultural products (SIC 2)	-440 MMT/yr [l]	(Ayres and Ayres, 1998)	-8.91×10^{18} [m]	2.24×10^{8} sej/g of residue [n]	(Odum, 1996)	-9.87×10^{22}

Continued

Table 4.1: Data for Ecosystem Product Inputs to 1992 U.S Economy

Table 4.1 continued

Resource considered in this analysis	Industry sector receiving direct input and its SIC code [Φ]	Material or Energy Flow (F)	Data Source for F	ICEC Flow (J/yr)	Transformity (τ)	Data Source for τ	ECEC Flow $c = \tau.F$ (sej/yr)
Biosphere							
Wood production	Forestry and fishery products (SIC 3)	520 MMT/yr of roundwood	(Ayres and Ayres, 1998)	8.27×10^{18} [o]	5.55×10^{8} sej/g [p]	(Odum, 1996)	2.89×10^{23}
Pasture Grazing	Livestock and livestock products (SIC 1)	200 MMT/yr of wet grass	(Ayres and Ayres, 1998)	1.67×10^{18} [q]	5.83×10^{19} sej/MMT of wet grass [r]	(Odum, 1996)	1.17×10^{22}
Hydrosphere							
Water consumption	Water and sanitary services (SIC 68C)	1.47×10^{14} gallons/yr	(USGS, 2004b)	2.73×10^{18} [s]	7.67×10^{8} sej/gallon [t]	(Brown and Bardi, 2001)	1.13×10^{23}
Atmosphere							
CO_2 in 24-hr net photosyndissertation	Other agricultural products (SIC 2)	880 MMT/yr	(Ayres and Ayres, 1998)	0 [u]	6.19×10^{7}sej/g CO_2 [v]	(Odum, 1996)	5.45×10^{22}

[Φ] List of industry sectors and their SIC codes is given in Table A.1 of the Supplementary Material
[Ψ] Detailed calculations provided in Appendix C of the Supplementary Material

Ecosystem Service	Sector receiving direct input and corresponding SIC code	Energy or material flow (F)	Data Source for F	ICEC Flow (J/yr)	Transformity (τ) (sej/J)	Data Source for τ	ECEC flow ($C = F.\tau$) (sej/yr)
Sunlight for photosynthesis	Other agricultural products (SIC 2)	2.26×10^{22} J/yr	(USDOA, 2004; NASA 2004)	2.26×10^{22}	1	(Odum, 1996)	2.26×10^{21}
	Forestry and fishery products (SIC 3)	1.19×10^{22} J/yr	(ForestInfo, 2004; NASA 2004)	1.19×10^{22}	1	(Odum, 1996)	1.19×10^{21}
Hydropotential for power generation	Electric services (utilities) (SIC 68A)	9.11×10^{17} J/yr	(USDOE, 2004b)	9.11×10^{17}	27764	(Odum, 1996)	2.52×10^{22}
Geothermal heat for power generation	Electric services (utilities) (SIC 68A)	5.83×10^{16} J/yr	(USDOE, 2004b)	5.83×10^{16}	6055	(Odum, 1996)	3.53×10^{20}
Wind energy for power generation	Electric services (utilities) (SIC 68A)	1.02×10^{16} J/yr	(USDOE, 2004b)	1.02×10^{16}	1496	(Odum, 1996)	1.52×10^{19}
Soil erosion	Other agricultural products (SIC 2)	37.04×10^{8} ton/yr	(Adriaanse et al., 1997; Matthews et al., 2000)	3.35×10^{18}	4.43×10^{4}	(Brandt-Williams, 2002)	1.48×10^{23} †
	New construction (SIC 11)	36.59×10^{8} ton/yr	(Adriaanse et al., 1997; Matthews et al., 2000)	3.31×10^{18}	4.43×10^{4}	(Brandt-Williams, 2002)	1.47×10^{23}

† (37.04×10^{8} ton/yr topsoil loss) × (4% organics in soil) × (5.4Kcal/g energy content of organic soil) × (4186 J/Kcal) × (4.43×10^{4} sej/J) = 4.15×10^{23} sej/yr; transformity adjusted to 1996 base of 9.44×10^{24} sej/yr

Table 4.2: Data for Ecosystem Service Inputs to 1992 U.S Economy

Pollutant	Immediate Destination of emission	Impact category considered	DALY/kg of emission†	ECEC/kg of emission (sej/kg)
SO_2	Air	Respiratory Disorders	5.46×10^{-5}	1.86×10^{12} ‡
NO_2	Air	Respiratory Disorders	8.87×10^{-5}	3.03×10^{12}
PM10	Air	Respiratory Disorders	3.75×10^{-4}	1.28×10^{13}
CO_2	Air	Climate Change §	2.1×10^{-7}	7.17×10^{9}
Methanol	Air	Respiratory Disorders	2.81×10^{-7}	9.59×10^{9}
Ammonia	Air	Respiratory Disorders	8.5×10^{-5}	2.90×10^{12}
Toluene	Air	Respiratory Disorders	1.36×10^{-6}	4.64×10^{10}
1,1,1-TCE	Air	Ozone Layer Depletion	1.26×10^{-4}	4.30×10^{12}
Styrene	Air	Carcinogenic Effect	2.44×10^{-8}	8.33×10^{8}
Styrene	Water	Carcinogenic Effect	1.22×10^{-6}	4.16×10^{10}
Styrene	Soil	Carcinogenic Effect	2.09×10^{-8}	7.13×10^{8}

† DALY Values are based on Hierarchist Perspective

‡ Human Health Impact of emission per kg of SO_2 emission = (5.46×10^{-5}DALY/kg of SO_2 emission) × (365 days/yr) × (9.35×10^{13}sej emergy associated with unskilled labor/workday) = 1.86×10^{12} sej/kg; Emergy of unskilled labor is obtained from emergy literature (Odum, 1996), and is obtained by dividing total emergy budget of the US (7.85×10^{24} sej/yr) by the total population of the US (230×10^{6} people)

§ Impacts are potential impacts in future (Goedkoop and Spriensma, 1999)

Table 4.3: Pollutants, immediate destination of emission and impact category

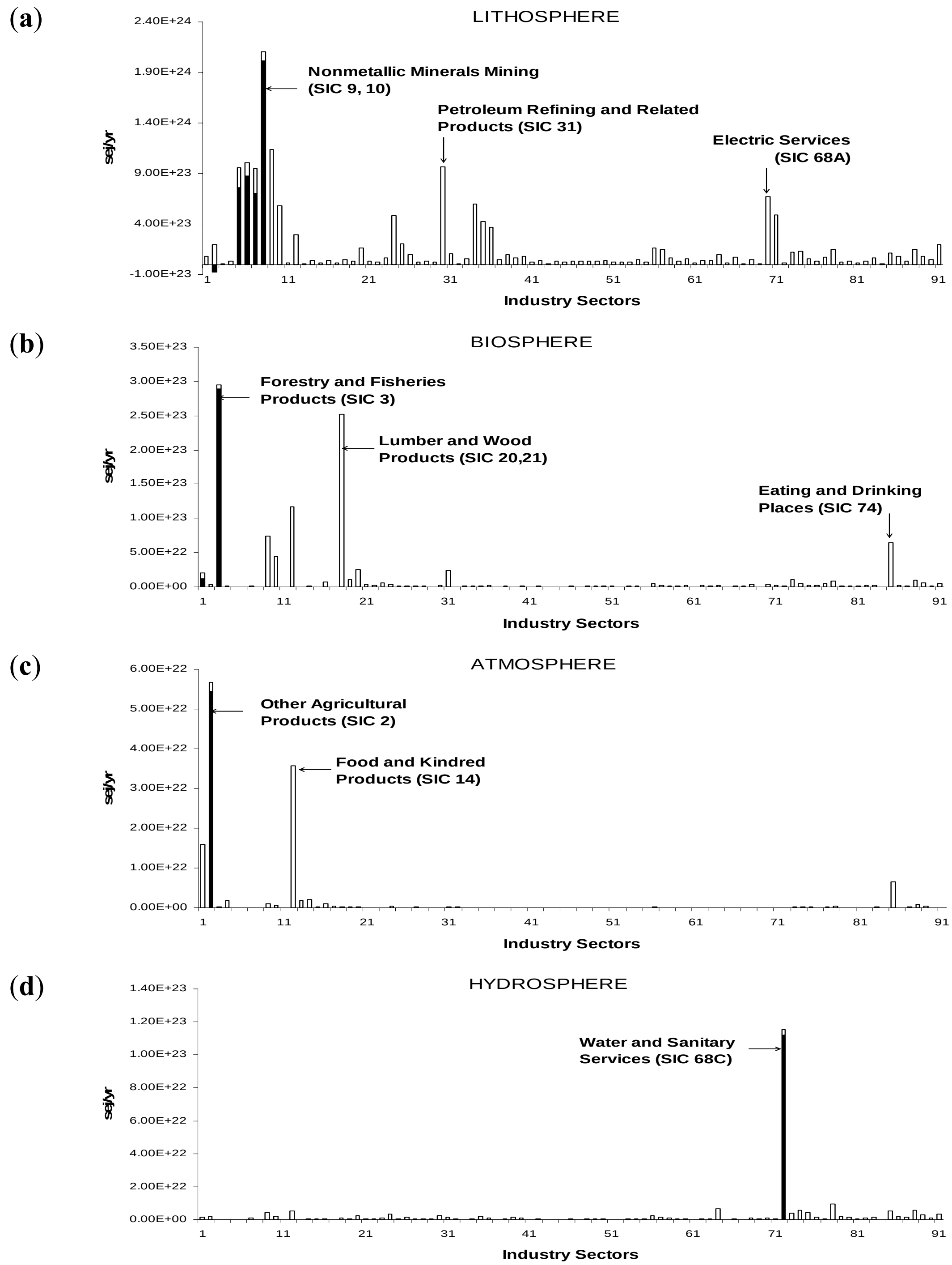


Figure 4.1. Contribution of ecological products to 91-sector 1992 US economic system from (a) lithosphere; (b) biosphere; (c) atmosphere; and (d) hydrosphere. The *y*-axis is ECEC in solar equivalent joules (sej) and *x*-axis is sector serial number (black part of each bar represents direct inputs and white part represents indirect inputs)

(a)

(b)

(c)

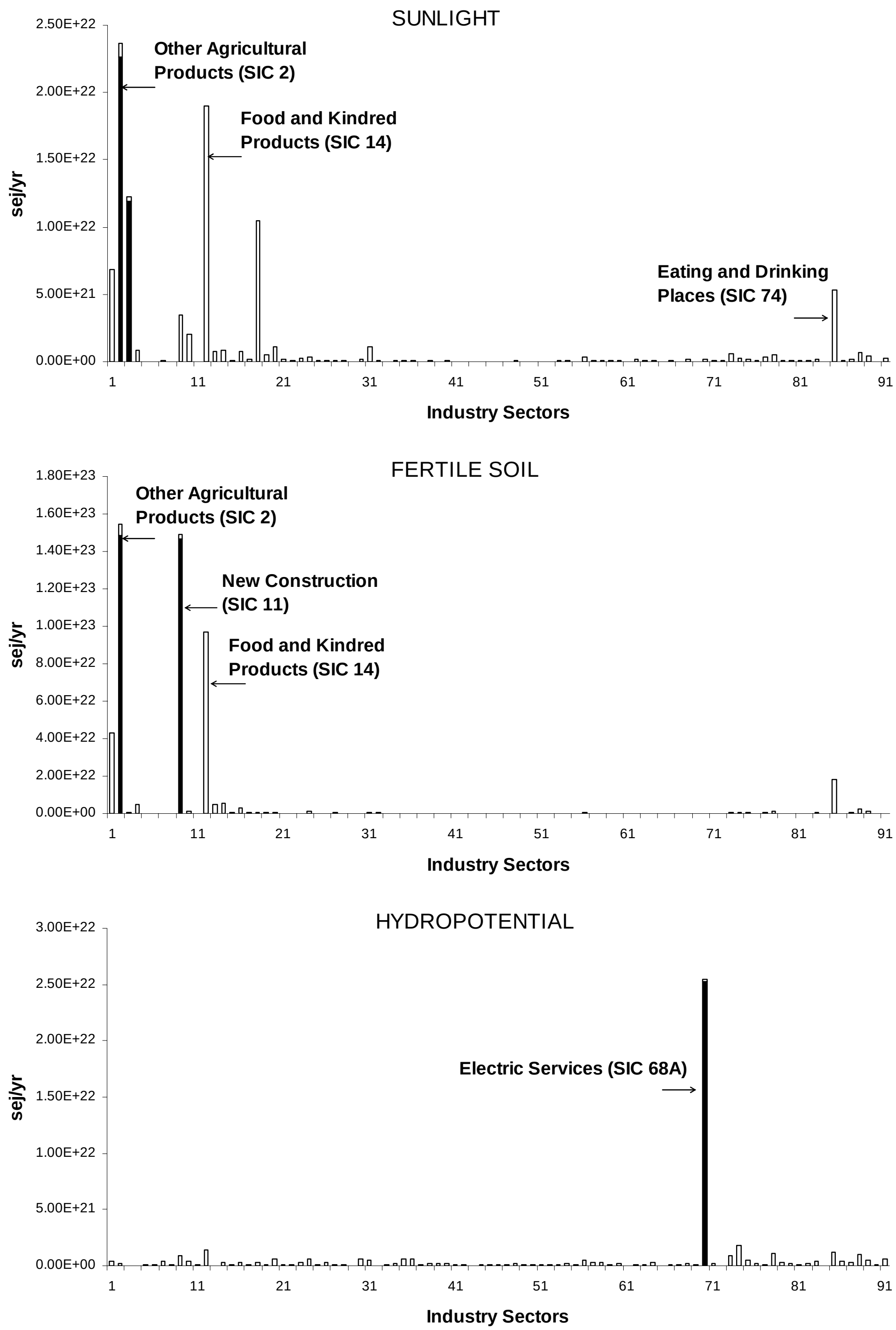


Figure 4.2: Contribution of direct ecosystem services to 91-sector 1992 US economic system from (a) sunlight; (b) fertile soil; and (c) hydropotential (black part of each bar represents direct inputs and white part represents indirect inputs)

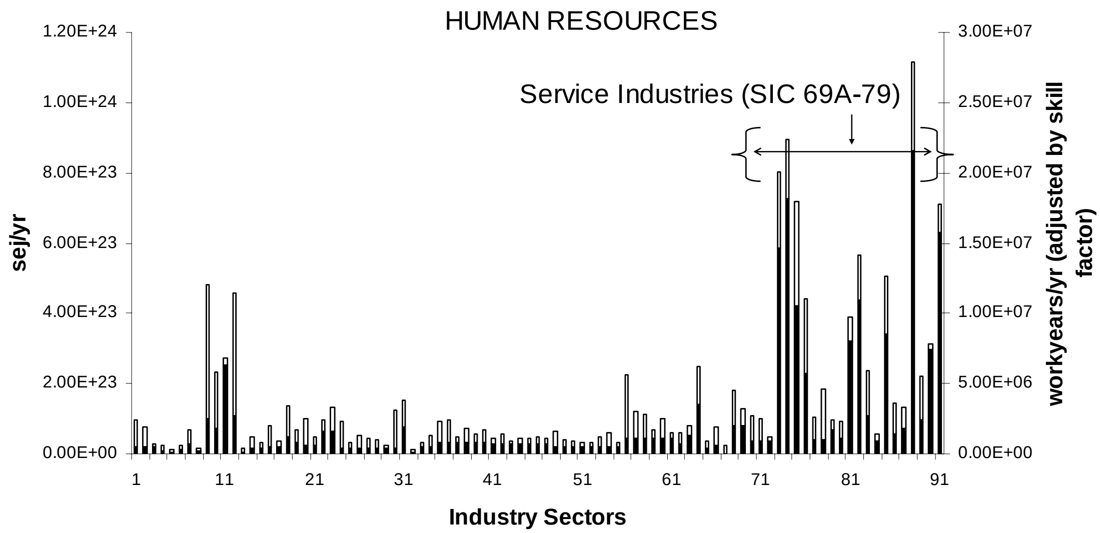


Figure 4.3: ECEC requirements from Human Resources for the 91-sector 1992 US economic system (Black part of each bar represents direct inputs, white part represents indirect inputs)

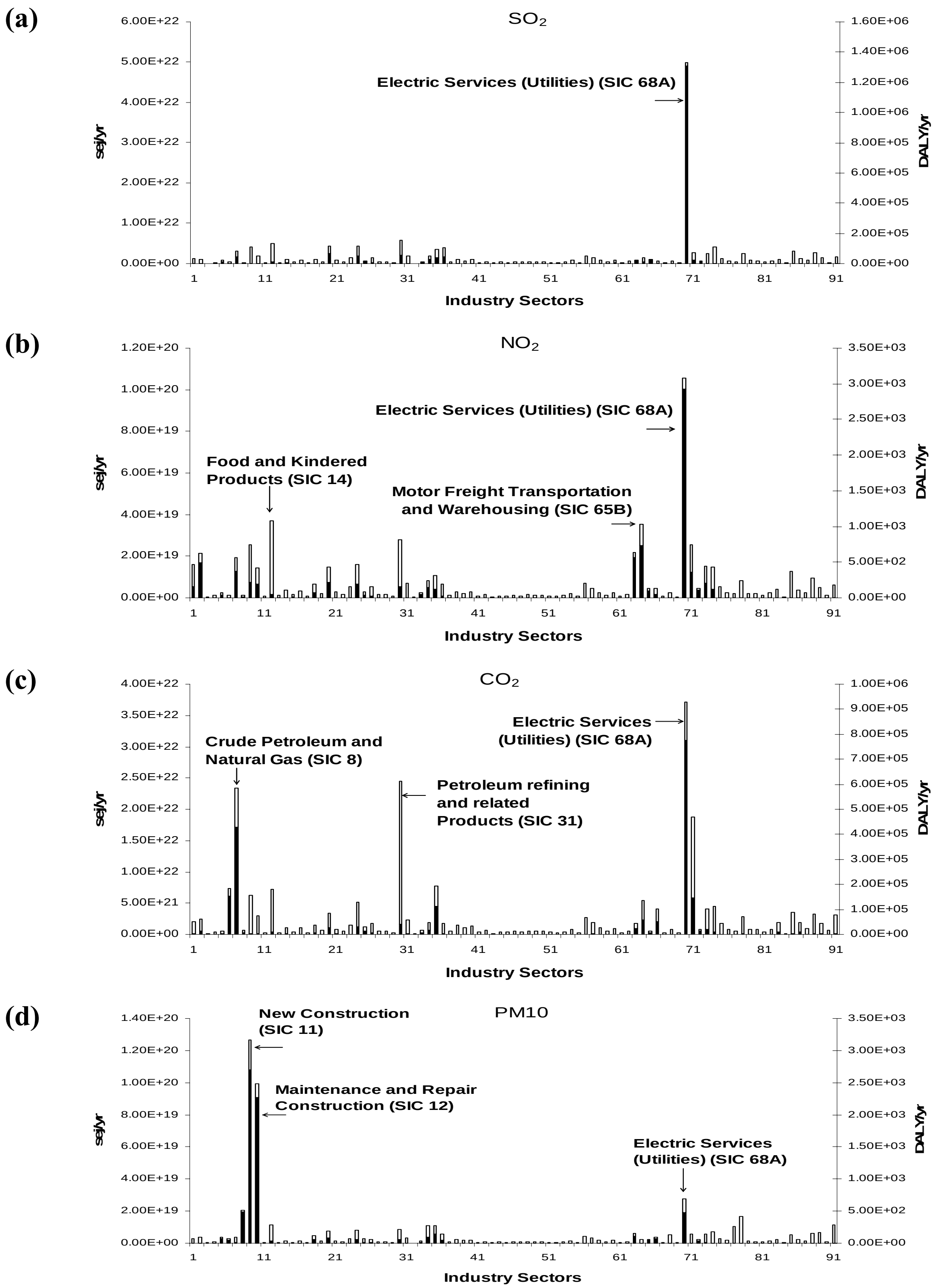


Figure 4.4: Impact of emissions on Human Health for the 91-sector 1992 US economic system from (a) SO_2; (b) NO_x; (c) CO_2; and (d) PM10 (black part of each bar represents direct inputs and white part represents indirect inputs)

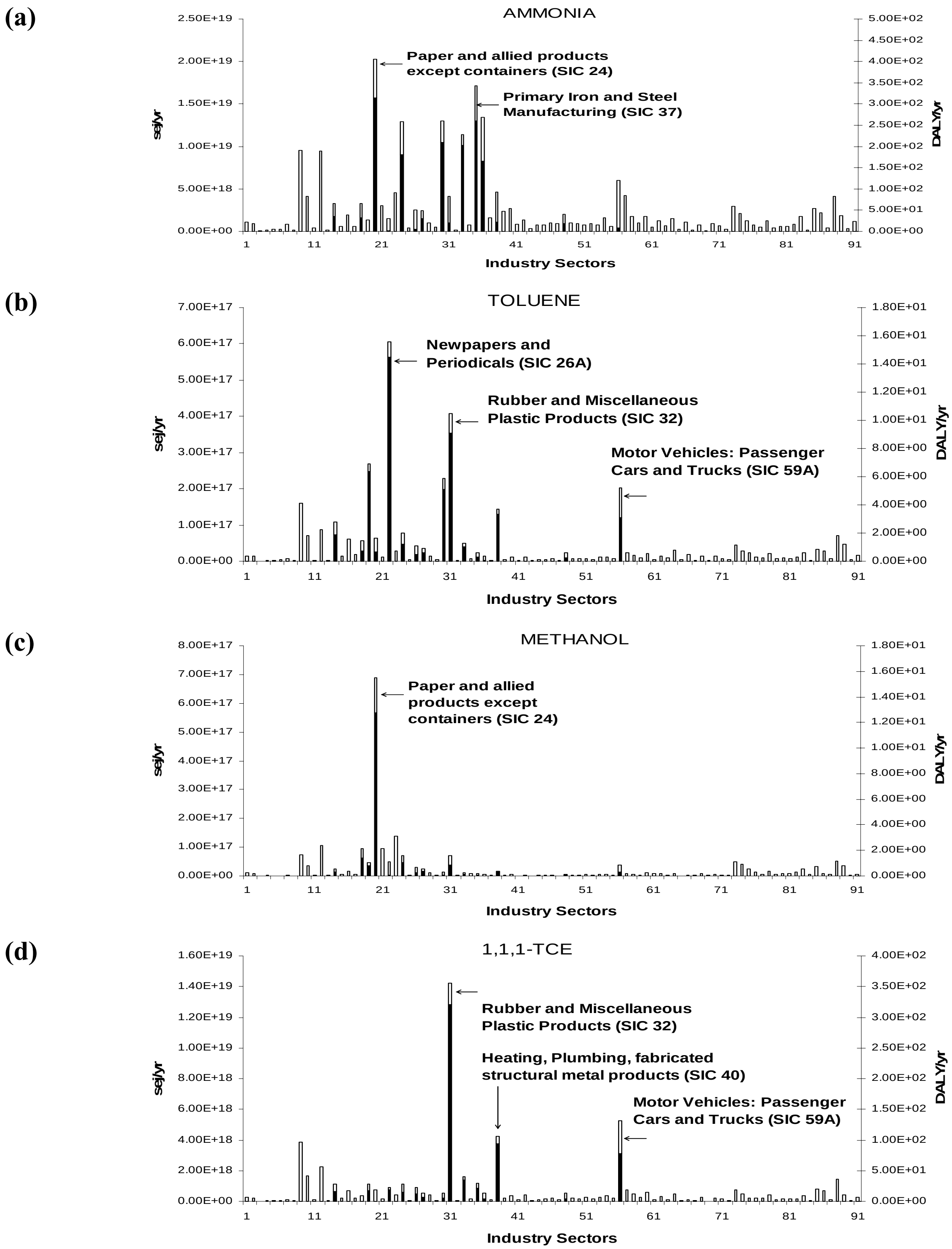


Figure 4.5: Impact of non-bulk pollutants on Human Health for 91-sector 1992 US economic system (a) Ammonia; (b) Toluene; (c) Methanol; (d) 1,1,1-Trichloroethane (Black part of each bar represents direct inputs, white part represents indirect inputs)

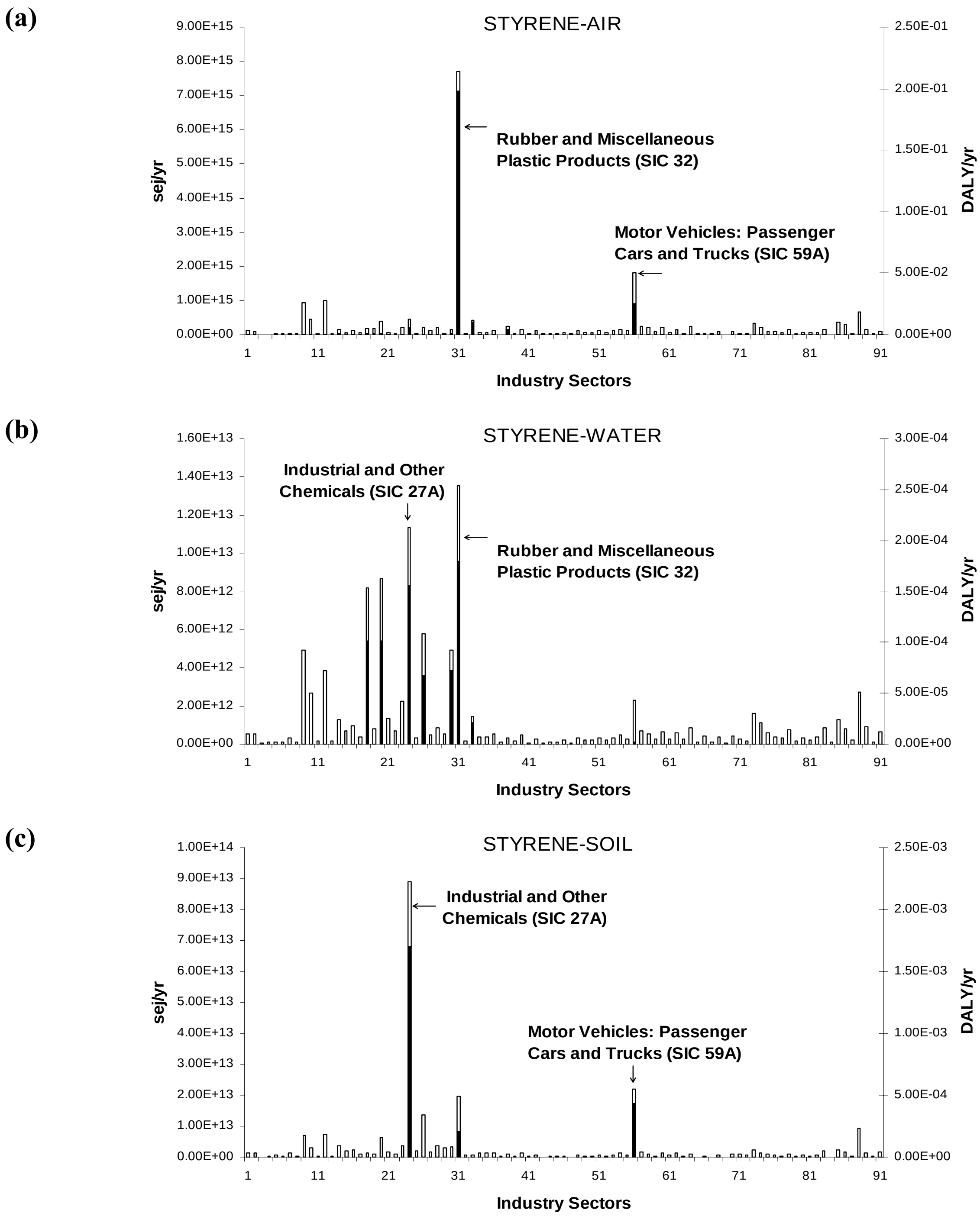


Figure 4.6: Impact of non-bulk pollutants on Human Health for 91-sector 1992 US economic system (a) Styrene emission to air; (b) Styrene emission to water; (c) Styrene emission to soil (Black part of each bar represents direct inputs, white part represents indirect inputs)

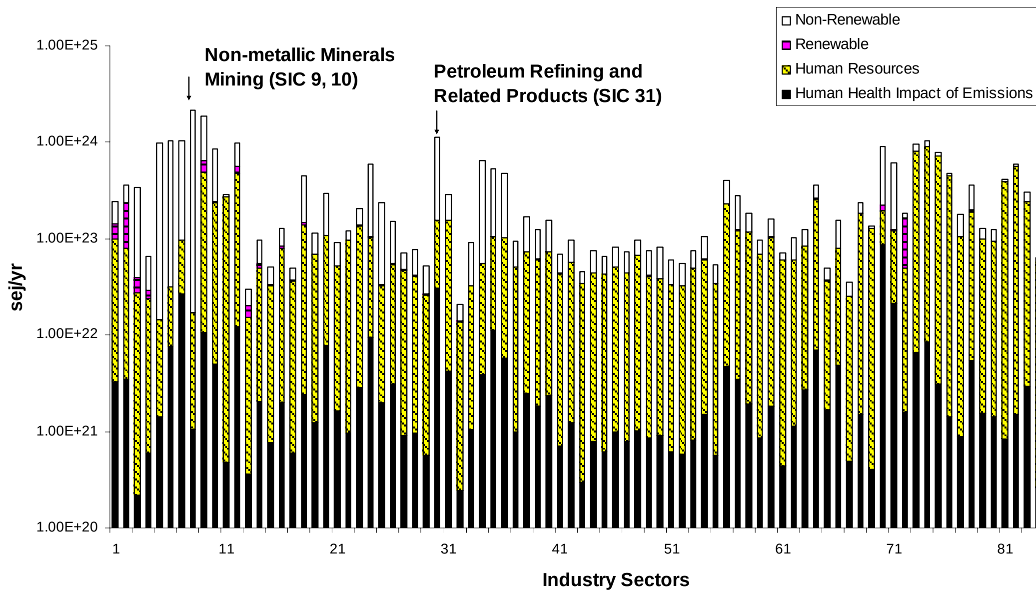


Figure 4.7: Total ECEC Requirements of Industry Sectors for 91-sector 1992 US Economy

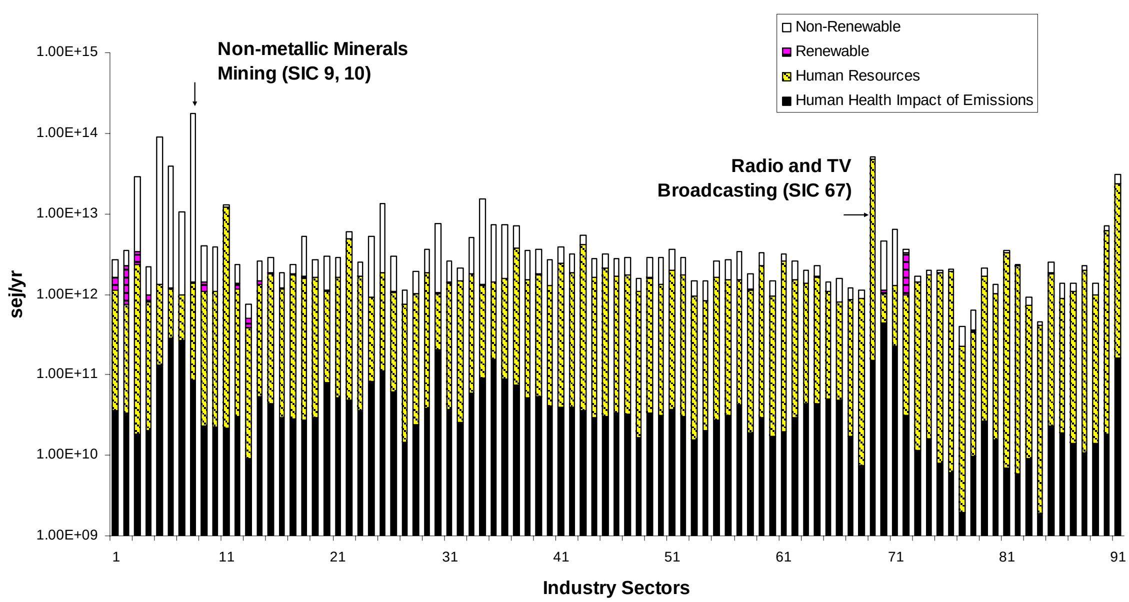


Figure 4.8: ECEC/Money Ratio for Industry Sectors for 91-sector 1992 US Economy

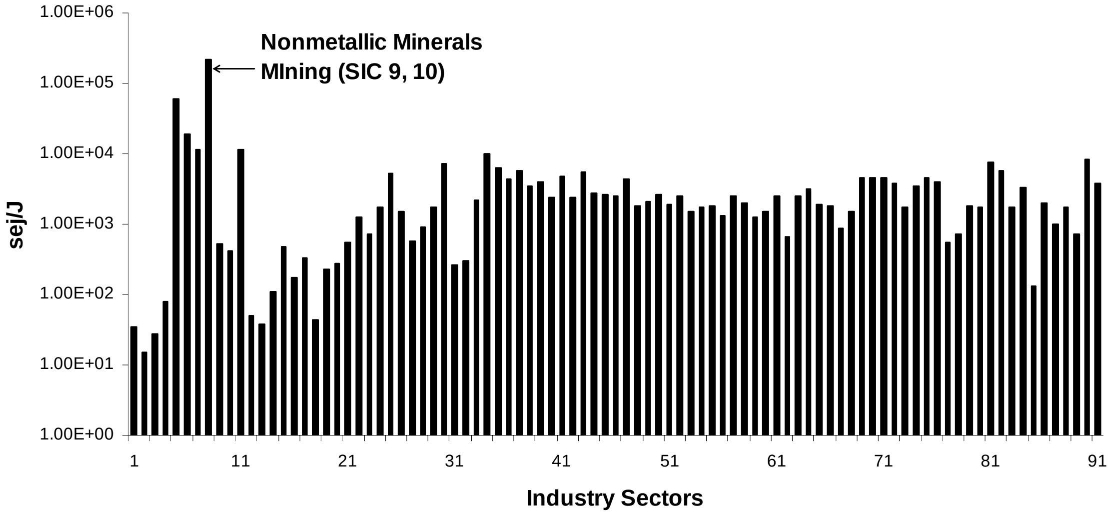


Figure 4.9: ECEC/ICEC Ratio of Industry Sectors for 91-sector 1992 US Economy

CHAPTER 5

RESULTS FOR 488-SECTOR 1997 US ECONOMY

Chapter 4 presented the results of Thermodynamic Input-Output Analysis of 91-sector 1992 US economic model. However, the 1992 model is quite aggregate and old, and hence has limited use for decision-making in the present context. Bureau of Economic Analysis, that operates under the aegis of US Department of Commerce (BEA, 2005a, b), compiles Input-Output Models for the US economy on a periodic basis. For instance, annual input-output accounts for 1998-2002 are available from BEA database. These accounts are based on North American Industrial Classification System codes at 65 industry sector level. These accounts, though more recent, are still quite aggregate. Benchmark accounts, on the contrary, are compiled less frequently but are more detailed than the annual accounts. The latest benchmark account available is based on 1997 US economic data. Benchmark accounts have a distinct advantage over annual accounts as they can distinguish between different industrial activities more accurately. For instance, while 1992 annual account aggregates all farming activity into a single sector, namely the sector of other agricultural products (SIC 2), the 1997 benchmark model separates all farming activity into 10 industry sectors (NAICS 1111A0-1119B0). The allocation matrix for 1997 benchmark model of US economy was obtained from Bureau of Economic Analysis (BEA, 2005b).

5.1. Contribution of Ecosystem Products to Industry Sectors

Figures 5.1 and 5.2 show the contribution of ecological products listed in Table 5.1 to the industry sectors in 1997 US industry benchmark model. The sector names, NAICS codes and serial numbers of the economic sectors are shown in Table A.2 of the supplementary material. The analysis of the 1997 benchmark model expanded the scope of the analysis of 1992 US economy by incorporating data about gold mining and natural gas consumption. Inputs to agricultural activities were also adjusted using data about number of farms and their average size during 1992 and 1997. Related calculations are shown in Appendix D of this dissertation.

5.1.1. Lithosphere

Figure 5.1 shows ECEC requirements of industry sectors from the lithosphere. Sectors of stone mining and quarrying (NAICS 212310), coal mining (NAICS 212100), sand, gravel, clay and refractory mining (NAICS 212320) and oil and gas extraction (NAICS 211000) have prominent peaks on account of direct inputs from lithosphere. Sectors of power generation and supply (NAICS 221100), petroleum refineries (NAICS 324110), iron and steel mills (NAICS 332111) and automobile and light truck manufacturing (NAICS 336110) also have prominent peaks on account of *indirect consumption* of lithospheric resources. Unlike mining sectors that extract resources from lithosphere, the agricultural sectors (NAICS 1111A0-1119B0) add to lithosphere on account of return of detrital matter to agricultural soil. Consequently, these sectors have *negative direct* ECEC requirements from lithosphere. This is shown with the aid of the embedded graph in Figure 5.1. The agricultural sectors, like other sectors in the economy, still have *positive indirect* ECEC requirements on account of consumption of fuels and electricity. Furthermore, the indirect requirements exceed the direct requirements making the agricultural sectors net consumers of lithospheric resources. Sector of greenhouse and nursery production (NAICS 111400) is found to be the only exception where direct requirements exceed indirect requirements, making it the net donor to lithosphere.

5.1.2. Biosphere

Figure 5.2(a) shows ECEC requirements from the biosphere. Sectors of logging (NAICS 113300) and cattle ranching and agricultural (NAICS 112100) get direct inputs from biosphere on account of timber harvesting and pasture grazing respectively. Sectors of sawmills (NAICS 321113), paper and paperboard mills (NAICS 3221A0), veneer and plywood manufacturing (NAICS 32121A) and new residential 1-unit structures (non-farm) (NAICS 230110) also have prominent peaks on account of indirect consumption. Sectors of all other petroleum and coal products manufacturing (NAICS 324199), military armored vehicles and tank part manufacturing (NAICS 336992) and ground or treated minerals and earths manufacturing (NAICS 327992) have the lowest ECEC inputs from biosphere.

5.1.3. Atmosphere

Figure 5.2(b) shows ECEC from atmosphere. The farming sectors (NAICS 1111A0-1119B0) get direct inputs from atmosphere on account of CO_2 consumption during 24-hr photosynthesis. As a result, Figure 5.2(b) shows prominent peaks for the farming sectors as well for those sectors that directly rely on farming sectors for their operation. This includes food and fabric manufacturing sectors (NAICS 311111-313240) and the sector of food services and drinking places (NAICS 722000). Sectors of industrial pattern manufacturing (NAICS 332997), military armored vehicles and tank part manufacturing (NAICS 336992) and saw blade and handsaw manufacturing (NAICS 332213) have the lowest requirements from atmosphere. As mentioned in Table 5.1, only CO_2 consumed during 24-hour photosynthesis has been considered in this analysis. As discussed in Section 4.2.3, other atmospheric gases, namely N_2 and O_2, have not been considered as their transformity values are unresolved in emergy analysis.

5.1.4. Hydrosphere

Figure 5.2(c) shows ECEC requirements from hydrosphere. Only the sector of water, sewage and other systems (NAICS 221300) that uptakes water from rivers and lakes is assumed to have a direct input from hydrosphere. Other sectors with prominent peaks in Figure 5.2(c) are real estate (NAICS 531000), retail trade (NAICS 4A0000) and wholesale trade (NAICS 420000). Sectors of software reproducing (NAICS 334611), industrial pattern manufacturing (NAICS 332997) and secondary processing of copper (NAICS 331423) have the lowest ECEC requirement from hydrosphere. Other functions of hydrosphere such as climate regulation and cleansing of air have not been considered in this analysis.

5.2. Contribution of Ecosystem Services to Industry Sectors

5.2.1. Sunlight

Figure 5.3(a) shows the contribution of sunlight. The agricultural sectors (NAICS 1111A0-1119B0) and the sector of forest nurseries, forest products and timber tracts (NAICS 113A00) are the direct recipients of sunlight. Sectors of sawmills (NAICS 321113) and food services and drinking places (NAICS 722000) have prominent peaks in Figure 5.3(a) on account of indirect consumption. In this work, solar inputs to the group of agricultural sectors and to the sector of forest nurseries, forest products and timber tracts are determined by multiplying average solar flux per unit area in the continental US by the total land area of the two (NASA 2004; USDOA, 2004). To allocate solar inputs within the group of agricultural sectors, economic data were used. If data about land areas in individual agricultural sectors were available, it could have been used for allocation as well. Furthermore, the use of transformity values in this analysis ensures consideration of indirect routes of solar inputs to industry sectors. These indirect routes include bio-geo-chemical cycles such as the hydrologic cycle and atmospheric circulation that are driven by solar insolation. In that regard, the analysis presented in this dissertation improves upon Costanza (1980) who considered only direct solar inputs to US economy to calculate energy intensities of industry sectors.

5.2.2. Fertile Soil

Figure 5.3(b) shows ECEC content of topsoil lost due to erosion. The agricultural sectors (NAICS 1111A0-1119B0) and the construction sectors (NAICS 230110-230250) are directly responsible for the loss of top organic soil. Sectors of animal, except poultry, slaughtering (NAICS 311611) and food services and drinking places (NAICS 722000) also have prominent peaks on account of indirect effects. Contribution of soil erosion is significantly larger than that of sunlight because top organic soil is a more concentrated form of resource than sunlight. Sectors with the lowest contribution from fertile soil are industrial pattern manufacturing (NAICS 332997), military armored vehicles and tank parts manufacturing (NAICS 336992) and saw blade and handsaw manufacturing (NAICS 332213). In this analysis fertile soil is assumed to be a renewable, and hence, non-additive resource. The assumption is based on the fact that the carbonaceous content of top organic soil, as used in this analysis, is regenerated from the dead biomass in a renewable fashion.

5.2.3. Hydropotential.

Figure 5.3(c) shows the contribution of hydropotential to industry sectors. Hydropotential refers to the potential energy in water streams that is converted to kinetic energy and then to electrical energy in hydroelectric power plants. Naturally the sector of power generation and supply (NAICS 221100) is the only sector with direct input. Sectors of real estate (NAICS 531000), retail trade (NAICS 4A0000) and wholesale trade (NAICS 420000) also have prominent peaks on account of high electricity consumption which can be explained considering their high economic throughputs. These results also match those obtained for the 91-sector 1992 US economic system (Ukidwe and Bakshi, 2004). Sectors of software reproducing (NAICS 334611), industrial pattern manufacturing (NAICS 332997) and lessors of nonfinancial intangible assets (NAICS 533000) have the lowest contribution from hydropotential. Contributions of wind energy and geothermal energy are also calculated but not shown. Their graphs can be obtained by multiply the y-axis of Figure 5.3(c) by 4.99×10^{-4} and 9×10^{-3} respectively.

5.3. Contribution from Human Resources

Figure 5.4 shows ECEC requirements of industry sectors from human resources. Unlike other resources, human resources are directly consumed by all industry sectors through employment of labor. Service sectors, in particular, have higher direct inputs than the rest of the economy. Sectors of other state and local government enterprises (NAICS S00203), retail trade (NAICS 4A0000), wholesale trade (NAICS 420000) and home health care services (NAICS 621600) have the highest consumption of human resources. These results also conform to those obtained for 91-sector 1992 US economy. Other non-service sectors with prominent peaks include automobile and light truck manufacturing (NAICS 336110), motor vehicle parts manufacturing (NAICS 336300), new residential 1-unit structures, non-farm (NAICS 230110) and commercial and institutional buildings (NAICS 230220). In this analysis, contribution of human resources is determined from economic data that includes the number of people employed and their average annual payrolls.

5.4. Human Health Impact of Bulk Pollutants

Figure 5.5 show the human health impact of the four bulk pollutants considered in this analysis. These are SO_2, NO_2, PM10 and CO_2. Figure 5.5 show human health impact in terms of DALY/yr based on a hierarchist perspective as well as corresponding ECEC values. To convert human health impact from DALY/yr to ECEC/yr, the former is multiplied by a factor of 3.42×10^{16}sej/yr (Ukidwe and Bakshi, 2004a).

5.4.1 Sulfur Oxides

Figure 5.5(a) shows the impact associated with SO_2. Power plants are the major emitters of SO_2. Consequently, the sector of power generation and supply (NAICS 221100) has the most significant peak in Figure 5.5(a). Other sectors with prominent peaks include petroleum refineries (NAICS 324110), real estate (NAICS 531000) and retail trade (NAICS 4A0000). Sector of petroleum refineries is one of the major suppliers to the sector of power generation and supply, whereas sectors of real estate and retail trade are major consumers of electricity due to their large economic throughputs.

5.4.2. Nitrogen dioxide

Figure 5.5(b) shows impact associated with NO_2 emissions. Like SO_2, power plants are also the major emitters of NO_2. Consequently, the sector of power generation and supply (NAICS 221100) has the most significant peak in Figure 5.5(b). Other major emitters of NO_2 include sectors of natural gas distribution (NAICS 221200) and truck transportation (NAICS 484000). Sectors of petroleum refineries (NAICS 324110), retail trade (NAICS 4A0000), wholesale trade (NAICS 420000), food services and drinking places (NAICS 722000) and oil and gas extraction (NAICS 211000) also have prominent peaks on account of indirect effects. Some of the agricultural and husbandry sectors, namely sectors of grain farming (NAICS 1111B0) and cattle ranching and farming (NAICS 112100), also have noticeable peaks due to high usage of nitrogenous fertilizers whose production is a source of NO_2.

5.4.3. Carbon dioxide

Figure 5.5(c) shows impact associated with CO_2 emission. CO_2 is emitted in combustion processes such as furnaces and internal combustion engines, and affects human health through climate change and global warming. Sectors of power generation and supply (NAICS 221100) and oil and gas extraction (NAICS 211000) have the highest CO_2 emissions amongst all sectors. Other sectors with prominent peaks include natural gas distribution (NAICS 221200), petroleum refineries (NAICS 324110) and retail trade (NAICS 4A0000). These sectors are either directly involved in extraction and consumption of fossil fuels or are major consumer of electricity. Impact of CO_2 emissions, as reported in eco-indicator 99, is the potential impact in future (Goedkoop and Spriensma, 1999).Among the bulk pollutants, impact associated with SO_2 and CO_2 is two orders of magnitude higher than that for NO_2 and PM10.

5.4.4. Particulate matter (PM10)

Figure 5.5(d) shows impact associated with emission of PM10. PM10 is primarily responsible for respiratory disorders. Particulate matter is primarily emitted during construction activities. Sectors of maintenance and repair of nonresidential buildings (NAICS 230320), commercial and institutional buildings (NAICS 230220) and new residential 1-unit structures, non-farm (NAICS 230110) have prominent peaks in Figure 5.5(d) on account of direct emission of particulate matter. Other sectors with prominent peaks include real estate (NAICS 531000) and iron and steel mills (NAICS 332111).

5.5. Human Health Impact of Non-Bulk Pollutants

Figure 5.6 show impact associated with selected non-bulk pollutants. Their immediate destinations and the impact category they belong to are listed in Table 4.4.

5.5.1. Ammonia

Figure 5.6(a) shows impact associated with emission of ammonia. Ammonia is primarily emitted by the sectors of paper and paperboard mills (NAICS 3221A0) petroleum refineries (NAICS 324110) and iron and steel mills (NAICS 331111). As a result, these sectors also have the tallest peaks in Figure 5.6(a). Sectors of motor vehicles part manufacturing (NAICS 336300) and automobile and light truck manufacturing (NAICS 336110) also have significant peaks on account of indirect effects.

5.5.2. Toluene

Figure 5.6(b) shows impact associated with emission of toluene. Sectors of software publishers (NAICS 511200), petroleum refineries (NAICS 324110) and plastic plumbing fixtures and all other plastics products (NAICS 32619A) are the major emitters of toluene. Other sectors with prominent peaks include automobile and light truck manufacturing (NAICS 336110), newspaper publishers (NAICS 511110) and periodical publishers (NAICS 511120).

5.5.3. Methanol

Figure 5.6(c) shows impact associated with emission of methanol. Sectors of paper and paperboard mills (NAICS 3221A0), coated and laminated paper and packaging materials (NAICS 32222A) and sanitary paper product manufacturing (NAICS 322291) are some of the major emitters of methanol. Other sectors with prominent peaks include other paperboard container manufacturing (NAICS 322210), commercial printing (NAICS 32311A) and retail trade (NAICS 4A0000).

5.5.4. 1,1,1-Trichloroethane

Figure 5.6(d) shows impact associated with 1,1,1-Trichloroethane. 1,1,1-TCE is primarily responsible for the depletion of ozone layer. Sectors of plastic plumbing fixtures and all other plastic products (NAICS 32619A), automobile and light truck manufacturing (NAICS 336110) and plastics packaging materials, film and sheet (NAICS 326110) are some of the major emitters of 1,1,1-TCE. Sectors of commercial and institutional buildings (NAICS 230220), new residential 1-unit structures, non-farm (NAICS 230110), glass and glass products, except glass containers (NAICS 32721A) and motor vehicle part manufacturing (NAICS 336300) also have substantial impact due to indirect effects.

5.5.5. Styrene

Figure 5.7 show impact associated with emission of styrene. Styrene is a carcinogenic substance that is released to soil, water and air. Depending on the immediate destination of Styrene emission human health impact could be very different. This is demonstrated in Figure 5.7. Impact of Styrene emission to air is two orders of magnitude higher than that to water or soil. Sectors of plastic plumbing fixtures and all other plastic products (NAICS 32619A) and plastic packaging materials, film and sheet (NAICS 326110) are the major emitters of styrene to air. Sectors of automobile and light truck manufacturing (NAICS 336110) and motor vehicle parts manufacturing (NAICS 336300) also have significant peaks in Figure 5.7. Compared to styrene emissions to air, styrene emissions to water is fairly small. Sectors of plastic plumbing fixtures and all other plastic products (NAICS 32619A) and plastic material and resin manufacturing (NAICS 325211) have the highest emission of styrene to water. Other sectors with significant styrene emissions to water include petroleum refineries (NAICS 324110) and paperboard mills. Sectors with highest styrene emissions to soil include other basic organic chemical manufacturing (NAICS 325190) and automobile and light truck manufacturing (NAICS 336110).

5.6. Aggregate Metrics

One of the fortes of Thermodynamic Input-Output Analysis is its ability to combine the results obtained for individual resources in Sections 5.2-5.6 into aggregate metrics. Such aggregation is facilitated by the fact that all results obtained for individual resources in Section 5.2-5.6 are expressed in a single consistent thermodynamic unit of solar equivalent joules.

For combining results obtained in Figures 5.1-5.7, the algorithm of ECEC analysis discussed in Section 2.5.4 has been used. Such algorithm avoids across-the-board addition which could lead to double counting. Rather, it divides the resources into two groups, additive and non-additive, depending on whether they originate from dependent or independent sources. Renewable resources such as wind and rain originate as co-products from the same source, namely sunlight, and hence cannot be added. On the contrary, non-renewable resources such as coal and petroleum originate from independent stocks, and hence can be added without double-counting. More lucid and in-depth discussion on allocation rules in ECEC analysis has been provided in Section 2.5.4 and in Hau and Bakshi (2004b) and Odum (1996). To calculate aggregate metrics, inputs from atmosphere, hydrosphere and ecosystem services are considered to be non-additive whereas the rest are considered to be additive. This is consistent with the allocation rules used for 1992 dataset in Chapter 4.

5.6.1. Total ECEC

Total ECEC of each industry sector is shown in Figure 5.8(a)-(d) which is a semi-log plot that shows relative contributions of renewable resources, non-renewable resource, human resources and human health impact of emissions to the total ECEC of each sector. The sector of stone mining and quarrying (NAICS 212310) is found to have the highest ECEC. Other sectors with high ECEC values are coal mining (NAICS 212100), power generation and supply (NAICS 221100) and sand, gravel, clay and refractory mining (NAICS 212320). Sectors with the smallest ECEC are industrial pattern manufacturing (NAICS 332997), malt manufacturing (NAICS 311213) and tortilla manufacturing (NAICS 311830). Sectors with the smallest ECEC requirements are also among the sectors with the smallest economic activity.

Total ECEC requirement captures the cumulative exergy consumption in all the links of the production network, and in principle, is equivalent to the concept of ecological cost. Unlike ecological cost that focuses only on industrial stages of the production network and non-renewable resources, total ECEC considers renewable resources along with non-renewable resources, and exergy consumed in the ecological links along with the industrial links of a production network. Figure 5.8(a) can be useful in determining industry-specific pro-ecological tax as proposed by Szargut and others (Szargut, 2002). ECEC by itself is of limited use for sustainable decision making. A normalized metric that compares ecosystem contribution to economic activity is more insightful, and is discussed next.

5.6.2. ECEC/Money Ratio

ECEC/money ratio compares ecological and economic throughputs of industry sectors. Figure 5.9 shows ECEC/money ratio of each of the 488 industry sectors on a semi-log plot. It is calculated by dividing total ECEC throughput of each sector shown in Figure 5.8 by its total economic throughput. Additional details about ECEC/money ratios for the 488 sectors can be found in Table B.3 of the Supplementary Information. The ECEC/money ratio is analogous to the emergy/money ratio used in emergy analysis, and similar ratios suggested in exergy analysis. However, unlike the single ratio in emergy or exergy analysis for the entire economy, Figure 5.9 provides a separate ratio for each sector. Moreover, ratios presented in Figure 5.9 are more disaggregate than those presented for 1992 economy in Figure 4.8. The ratio of the direct ecological inputs to the 1997 GDP of the US is 2.53×10^{12} sej/\$. This is higher than the similar ratio for 1992 US economy that stands at 2.10×10^{12} sej/\$. As seen from Figure 5.9, the mining sectors have the high ECEC/money ratios. Sectors of stone mining and quarrying (NAICS 212310), sand, gravel, clay and refractory mining (NAICS 212320) and iron ore mining (NAICS 212210) have some of the highest ECEC/money ratios. Sectors with the smallest ECEC/money ratios are lessors of non-financial intangible assets (NAICS 533000), owner-occupied dwellings (NAICS S00800) and all other miscellaneous professional and technical services (NAICS 5419A0).

Sectors such as primary smelting and refining of copper (NAICS 331411) that rely on mining sectors also have high ECEC/money ratio. In general, more specialized sectors have lower ECEC/money ratios than the basic infrastructure sectors. For instance, the median ECEC/money ratio of finance, insurance, real estate, rental and leasing sectors (NAICS 522A00-533000) is approximately one tenth of that of mining and utilities (NAICS 211000-221300) sectors. Amongst sectors receiving direct inputs from ecosystems, agriculture, forestry, fishing and hunting sectors (NAICS 1111A0-115000) have a median ECEC/money ratio that is 14% of that of the mining and utilities (NAICS 211000-221300) sectors. Agriculture, forestry, fishing and hunting sectors also depend more on renewable resources than the mining and utilities sectors that are primary fossil-based.

5.6.3. ECEC/ICEC Ratio

ECEC calculates cumulative exergy consumption in the industrial as well as ecological stages of a production chain, whereas ICEC only focuses on the industrial stages and ignores the ecological stages. Consequently, ECEC/ICEC ratio indicates the extent to which ICEC analysis underestimates the contribution of ecological resources. Figure 5.10 depicts ECEC/ICEC ratios for industry sectors from the 1997 benchmark model of the US economy. As seen from Figure 5.10, forest nurseries, forest products and timber tracts (NAICS 113A00) have the lowest, whereas sand, gravel, clay and refractory mining (NAICS 212320) have the highest ECEC/ICEC ratio amongst all sectors. In general, agricultural and forestry sectors have lower ECEC/ICEC ratios due to their reliance on renewable resources such as sunlight. Mining and extraction sectors, on the contrary have higher ratios due to their reliance on non-renewable resources. These results conform to those obtained for the 1992 US economy in Chapter 4. Furthermore, the average ECEC/ICEC ratio for the 1997 US economy is 2,873sej/J as against a ratio of

1,860sej/J for the 1992 US economy. This plausibly indicates that the 1997 economy had a higher reliance on non-renewable resources than the 1992 US economy. A detailed uncertainty analysis would, however, be required to determine confidence bounds on these results.

5.6.4. Performance Metrics

Based on the aggregate metrics obtained in Figure 5.8(a)-(d), various performance metrics can also be calculated. Definitions of these metrics are provided in Table 3.5 which also illustrates their calculation for the hypothetical example of Figure 3.3. Figure 5.11(a) shows the yield ratio for the 488 industry sectors. Yield ratio is defined as the ratio of total ECEC requirements to indirect ECEC requirements. Consequently, a peripheral sector that derives a large portion of its ECEC requirements directly fro ecosystems or human resources has a higher yield ratio and vice versa. This is evident from Figure 5.11(a) which shows high peaks for non-metallic mineral mining sectors (NAICS 212310 and 212320) and water sewage and other systems sector (NAICS 221300). Other federal government enterprises (NAICS S00102) and home health care services (NAICS 621600) also have prominent peaks as they rely heavily on human resources. Sectors with lowest yield ratios include veterinary services (NAICS 541940), automotive repair and maintenance, except car washes (NAICS 8111A0) and religious organizations (NAICS 813100). These are service industries that are embedded in the economic network and have relatively lower direct reliance on ecological or human resources. Figure 5.11(b) shows environmental loading ratio for the 488 industry sectors. Environmental loading ratio is defined as the ratio of total ECEC requirements from nonrenewable resources to those from renewable resources. It is higher for the sectors relying more on nonrenewable resources and vice versa. As seen from Figure 5.11(b), sectors of stone mining and quarrying (NAICS 212310), asphalt paving mixture and block manufacturing (NAICS 324121) and cut stone and stone product manufacturing (NAICS 327991) have some of the tallest peaks. These are the sectors that are involved either in mining of non-metallic minerals or in their downstream processing. Sectors with the lowest environmental loading ratios are water, sewage and other systems (NAICS 221300), forest nurseries, forest products and timber tracts (NAICS 113A00), vegetable and melon farming (NAICS 111200), tree nut farming (NAICS 111335) and oilseed farming (NAICS 1111A0). These sectors along with other agricultural sectors have environmental loading ratios of less than unity indicating that they rely on renewable resources more than nonrenewable resources. All other sectors in the economy have environmental loading ratios of higher than unity due to heavy reliance on metallic and non-metallic minerals and fossil energy sources. Figure 5.11(c) shows the yield-to-loading (YLR) ratios for the 488 sectors. YLR is called the index of sustainability in emergy analysis, though it only represents the resource consumption side of the sustainability riddle. YLR is less than unity for all sectors of the economy except the agricultural sectors (NAICS 1111A0-1119A0), forest nurseries, forest products and timber tracts (NAICS 113A00), water sewage and other systems (NAICS 221300), soybean processing (NAICS 311222), other oilseed processing (NAICS 311223) and other federal government enterprises. Sectors with the lowest YLR are clay refractory and other structural clay products (NAICS 32712A), ready-mix concrete manufacturing

(NAICS 327320) and cut stone and stone product manufacturing (NAICS 327991). Thus sectors relying on nonmetallic minerals, in general, have some the lowest YLR values.

Resource considered in this analysis	Industry sector receiving direct input and its NAICS code [a]	Material or Energy Flow (*F*)	Data Source for *F*	ICEC Flow (J/yr)	Transformity (τ)	Data Source for τ	ECEC Flow $c = \tau.F$ (sej/yr)
Lithosphere							
Crude petroleum field production	Oil and Gas Extraction (NAICS 211000)	1.06×10^{19}J/yr [b]	(USDOE, 2004a)	1.06×10^{19}	53000 sej/J	(Odum, 1996)	5.61×10^{23}
Natural Gas	Oil and Gas Extraction (NAICS 211000)	18.9MMCuF/yr	(USDOE, 2004b)	1.99×10^{19}	48000sej/J	(Odum, 1996)	9.58×10^{23}
Iron-ore mining	Iron ore mining (NAICS 212210)	202 MMT/yr	(USGS, 2004a)	2.08×10^{16} [c]	1×10^{9} sej/g	(Odum, 1996)	2.02×10^{23}
Copper mining	Copper, nickel, lead and zinc mining (NAICS 212230)	342 MMT/yr [d]	(USGS, 2004a)	2.80×10^{16} [e]	1×10^{9} sej/g	(Odum, 1996)	3.42×10^{23}
Gold mining	Gold, silver and other metal mining (NAICS 2122A0)	217 MMT/yr [f]	(USGS, 2004a)	5.63×10^{16} [g]	1×10^{9} sej/g	(Odum, 1996)	2.17×10^{23}
Crushed Stone	Stone mining and quarrying (NAICS 212310)	1390 MMT/yr	(USGS, 2004a)	1.83×10^{17} [h]	1×10^{9} sej/g	(Odum, 1996)	1.39×10^{24}
Sand	Sand, gravel, clay and refractory mining (NAICS 212310)	961 MMT/yr	(USGS, 2004a)	1.27×10^{17} [i]	1×10^{9} sej/g	(Odum, 1996)	9.61×10^{23}
Raw coal excluding overburden	Coal mining (SIC 212100)	988 MMT/yr	(USGS, 2004a)	5.73×10^{19} [j]	1×10^{9} sej/g	(Odum, 1996)	9.88×10^{23}
Nitrogen from Mineralization	Farming sectors (NAICS 1111A0-1119B0)	2.96 MMT/yr [k]	(Ayres and Ayres, 1998)	1.15×10^{15} [l]	4.19×10^{9} sej/g	(Odum, 1996)	1.24×10^{22}
Phosphorous from Mineralization	Farming sectors (NAICS 1111A0-1119B0)	1.97 MMT/yr [m]	(Ayres and Ayres, 1998)	9.75×10^{14} [n]	2×10^{9} sej/g [o]	(Odum, 1996)	3.94×10^{21}
N-Deposition from Atmosphere [p]	Farming sectors (NAICS 1111A0-1119B0)	1.97 MMT/yr [q]	(Ayres and Ayres, 1998)	7.76×10^{14} [r]	4.19×10^{9} sej/g	(Odum, 1996)	8.25×10^{21}

Continued

Table 5.1: Data for Ecosystem Product Inputs to 1997 U.S Economy

Table 5.1 continued

Resource considered in this analysis	**Industry sector receiving direct input and its NAICS code**	**Material or Energy Flow (*F*)**	**Data Source for *F***	**ICEC Flow (J/yr)**	**Transformity (*τ*)**	**Data Source for *τ***	**ECEC Flow** $c = \tau.F$ (sej/yr)
Lithosphere							
Return of decomposing detritus to agricultural soil	Farming sectors (NAICS 1111A0-1119B0)	-433 MMT/yr [s]	(Ayres and Ayres, 1998)	-8.77×10^{18} [t]	2.24×10^{8} sej/g of residue [u]	(Odum, 1996)	-9.70×10^{22}
Biosphere							
Wood production	Logging (NAICS 113300)	520 MMT/yr of roundwood	(Ayres and Ayres, 1998)	8.27×10^{18} [v]	5.55×10^{8} sej/g [w]	(Odum, 1996)	2.90×10^{23}
Pasture Grazing	Cattle Ranching and Farming (NAICS 112100)	200 MMT/yr of wet grass	(Ayres and Ayres, 1998)	1.67×10^{18} [x]	5.83×10^{19} sej/MMT of wet grass [y]	(Odum, 1996)	1.17×10^{22}
Hydrosphere							
Water consumption	Water, sewage and other systems (NAICS 221300)	1.47×10^{14} gallons/yr	(USGS, 2004b)	2.73×10^{18} [z]	7.67×10^{8} sej/gallon [α]	(Brown and Bardi, 2001)	1.13×10^{23}
Atmosphere							
CO_2 in 24-hr net photosynthesis	Farming sectors (NAICS 1111A0-1119B0)	867 MMT/yr [β]	(Ayres and Ayres, 1998)	0 [γ]	6.19×10^{7}sej/g CO_2 [δ]	(Odum, 1996)	5.37×10^{22}

Ecosystem Service	**Sector receiving direct input and corresponding NAICS code**	**Energy or material flow (*F*)**	**Data Source for *F***	**ICEC Flow** (J/yr)	**Transformity (τ)** (sej/J)	**Data Source for τ**	**ECEC flow ($C = F.\tau$)** (sej/yr)
Sunlight for photosynthesis	Farming sectors (NAICS 1111A0-1119B0)	2.23×10^{22} J/yr [(a)]	(USDOA 2004, NASA 2004)	2.23×10^{22}	1	(Odum, 1996)	2.23×10^{22}
	Forest nurseries, forest products and timber tracts (NAICS 113A00)	1.19×10^{22} J/yr	(USDOA 2004, NASA 2004)	1.19×10^{22}	1	(Odum, 1996)	1.19×10^{22}
Hydropotential for power generation	Power generation and supply (NAICS 221100)	1.28×10^{18} J/yr	(USDOE 2004c)	1.28×10^{18}	27764	(Odum, 1996)	3.55×10^{22}
Geothermal heat for power generation	Power generation and supply (NAICS 221100)	5.3×10^{16} J/yr	(USDOE 2004c)	5.3×10^{16}	6055	(Odum, 1996)	3.21×10^{20}
Wind energy for power generation	Power generation and supply (NAICS 221100)	1.18×10^{16} J/yr	(USDOE 2004c)	1.18×10^{16}	1496	(Odum, 1996)	1.77×10^{19}
Soil erosion	Farming sectors (NAICS 1111A0-1119B0)	34.49×10^{8} ton/yr	(Adriaanse et al., 1997; Matthews et al., 2000)	3.12×10^{18}	4.43×10^{4}	(Brandt-Williams, 2002)	1.38×10^{23} [(b)]
	Construction sectors (NAICS 230110-230250)	35.65×10^{8} ton/yr	(Adriaanse et al., 1997; Matthews et al., 2000)	3.22×10^{18}	4.43×10^{4}	(Brandt-Williams, 2002)	1.43×10^{23}

[(a)] Sunlight for photosynthesis: (2.26×10^{22}J/yr 1993 flux) × (1.91×10^{6} farms in 1997) × (487acres average size of farm in 1997) / (1.93×10^{6} farms in 1993) / (491acres average size of farm in 1993) = 2.23×10^{22}J/yr 1997 flux

[(b)] (34.49×10^{8} ton/yr topsoil loss) × (4% organics in soil) × (5.4Kcal/g energy content of organic soil) × (4186 J/Kcal) × (4.43×10^{4} sej/J) = 1.38×10^{23} sej/yr; transformity adjusted to 1996 base of 9.44×10^{24} sej/yr

Table 5.2: Data for Ecosystem Service Inputs to 1997 U.S Economy

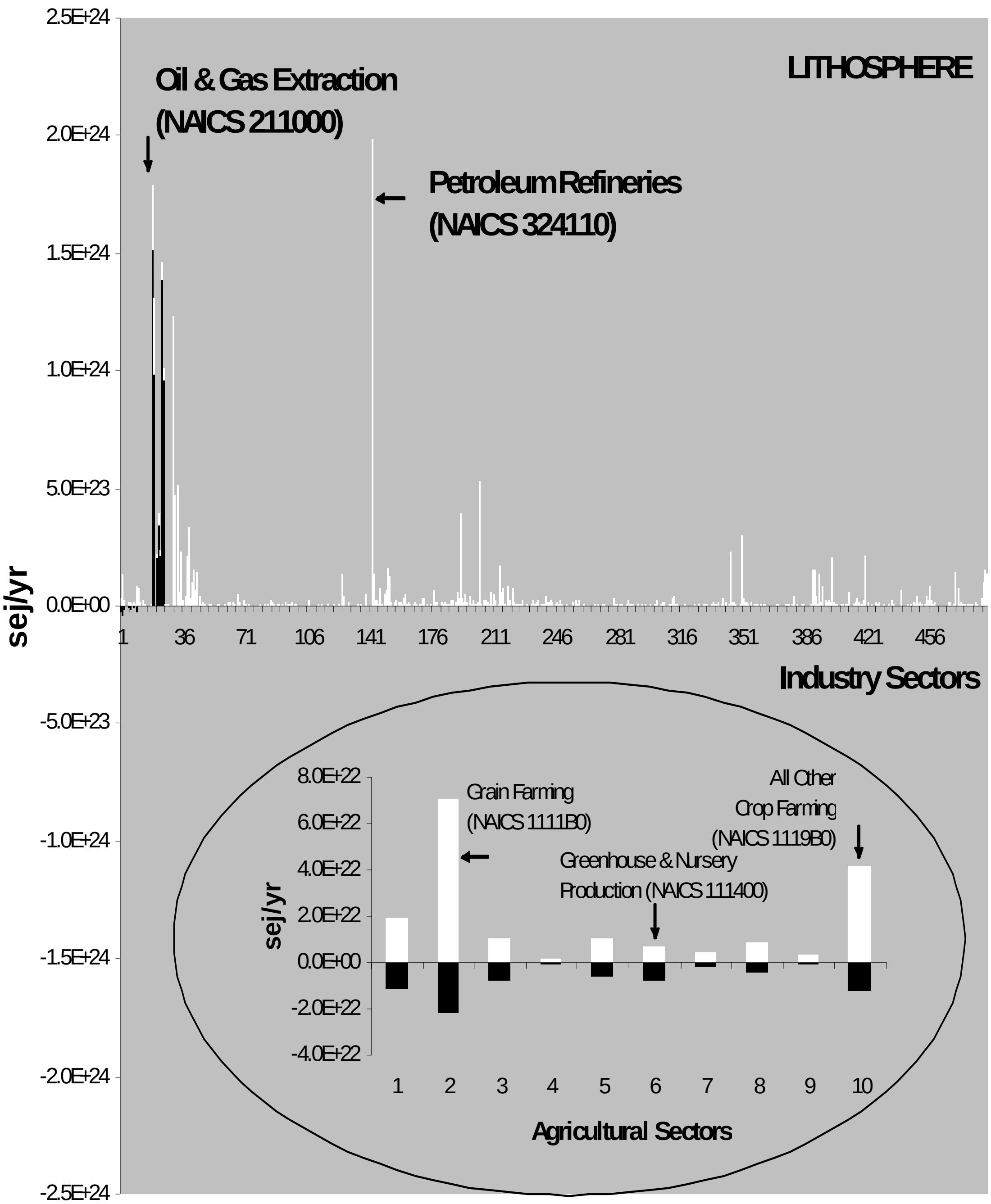
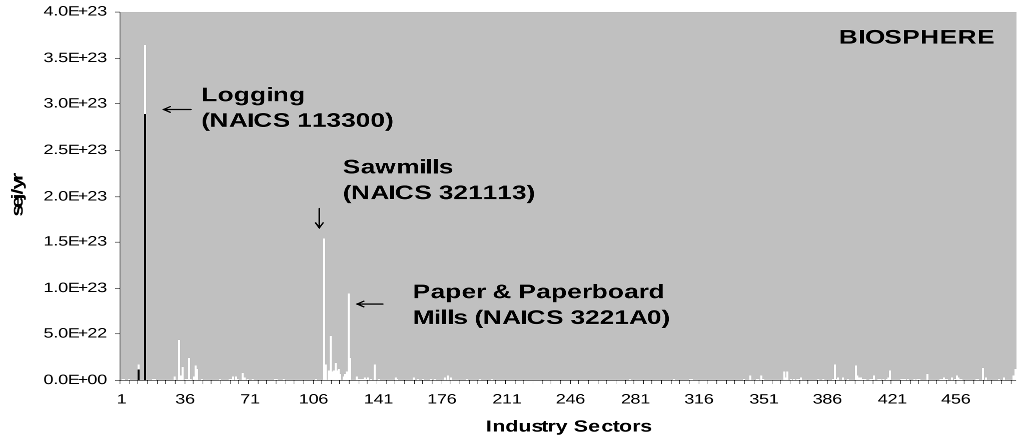
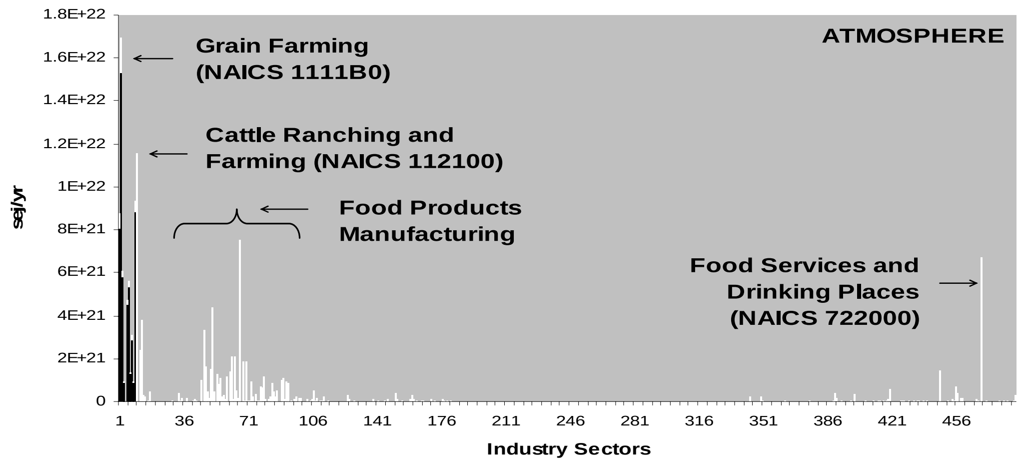


Figure 5.1: Contribution from Lithosphere to US economic sectors; *y*-axis is annual flows of ECEC in solar equivalent joules (sej/yr), and *x*-axis is sector serial number (ref: Table A.2) (black part of each bar represents direct inputs and white part represents indirect inputs)

(a)



(b)



(c)

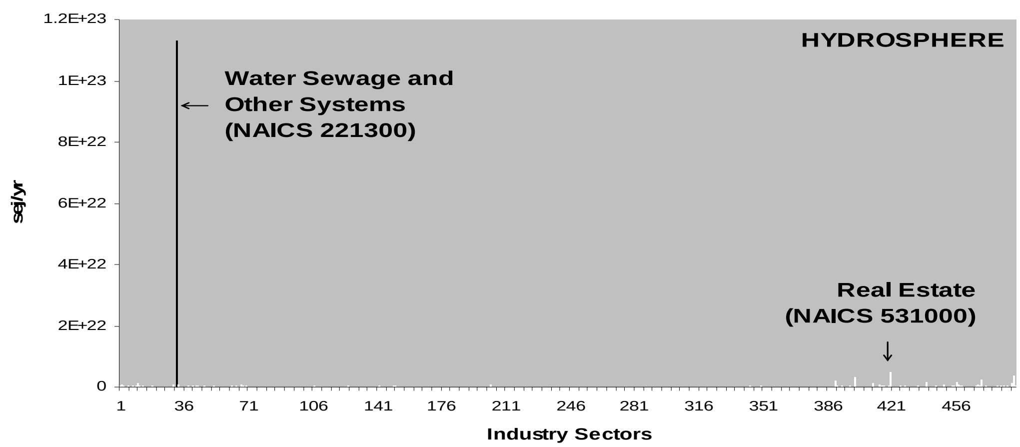


Figure 5.2: Contribution of ecological products US economic sectors from (a) Biosphere; (b) Atmosphere; (c) Hydrosphere; *y*-axis is annual flows of ECEC in solar equivalent joules (sej/yr), and *x*-axis is sector serial number (ref: Table A.2) (black part of each bar represents direct inputs and white part represents indirect inputs)

(a)

(b)

(c)

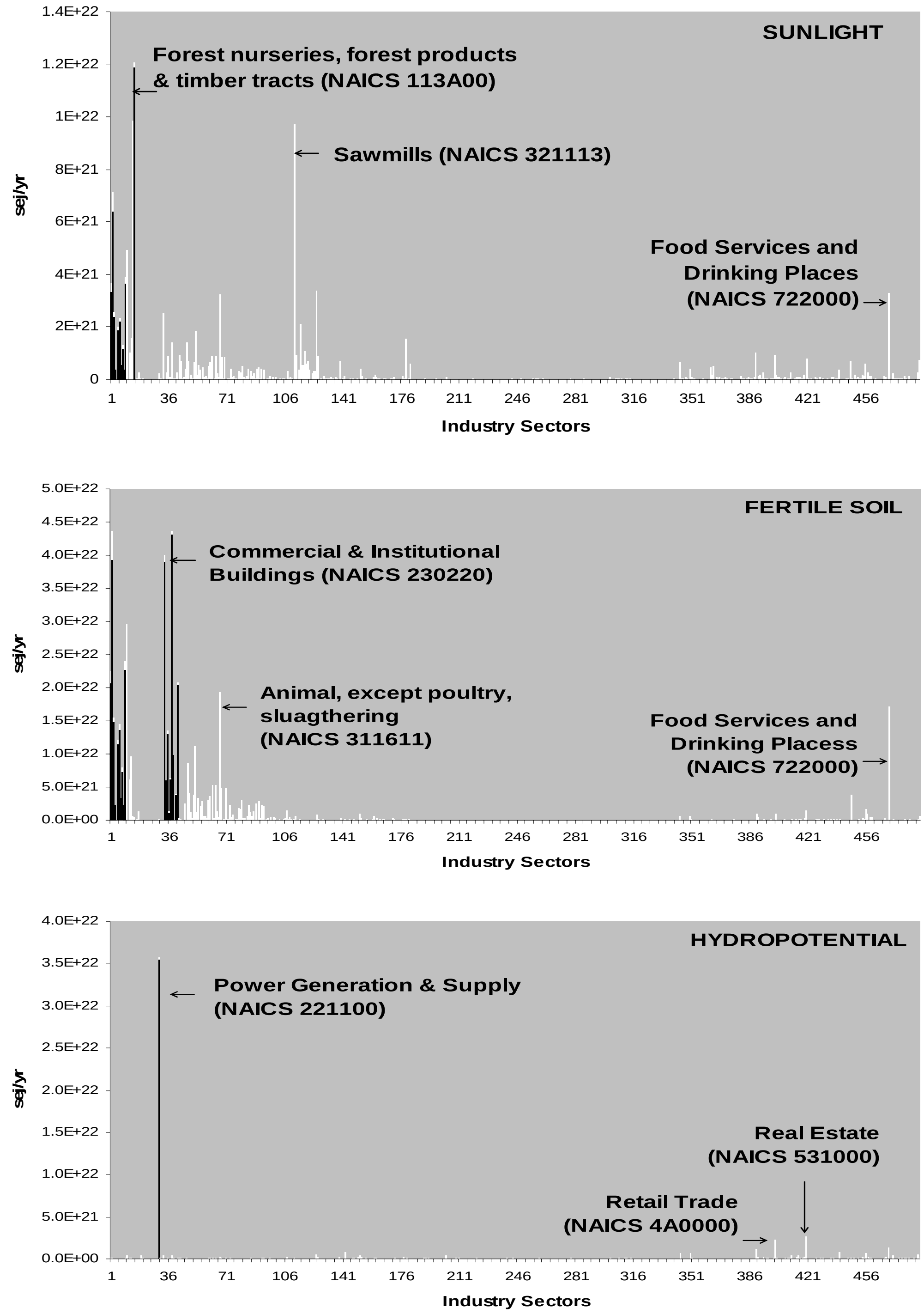


Figure 5.3: Contribution of direct ecosystem services. (a) Sunlight; (b) Fertile soil; (c) Hydropotential *y*-axis is annual flows of ECEC in solar equivalent joules (sej/yr), and *x*-axis is sector serial number (ref: Table A.2) (black part of each bar represents direct inputs and white part represents indirect inputs)

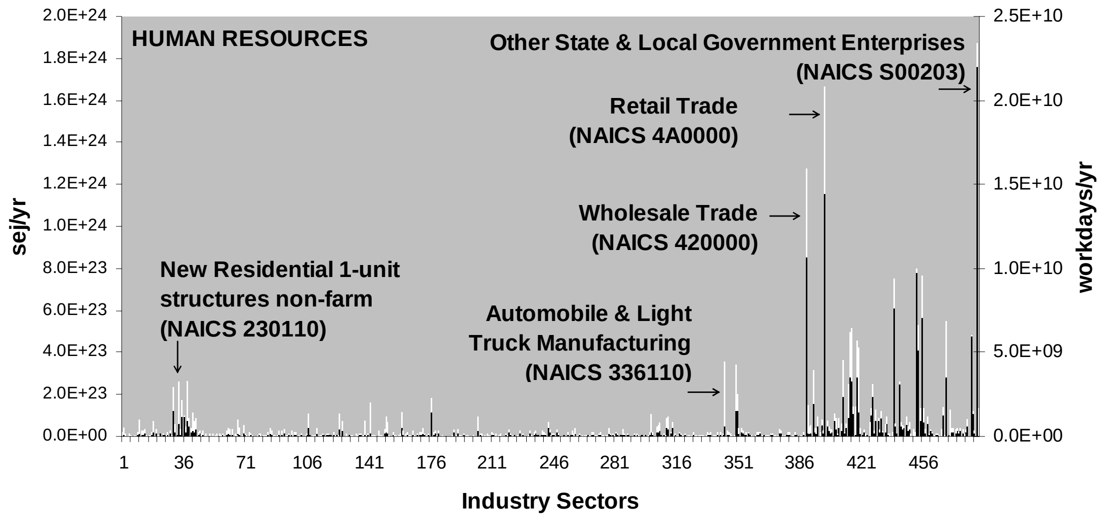


Figure 5.4: ECEC requirements from human resources; y-axes are annual ECEC flows in sej/yr and corresponding flows in workdays/yr; x-axis is sector serial number (ref: Table A.2) (black part of each bar represents direct inputs and white part represents indirect inputs)

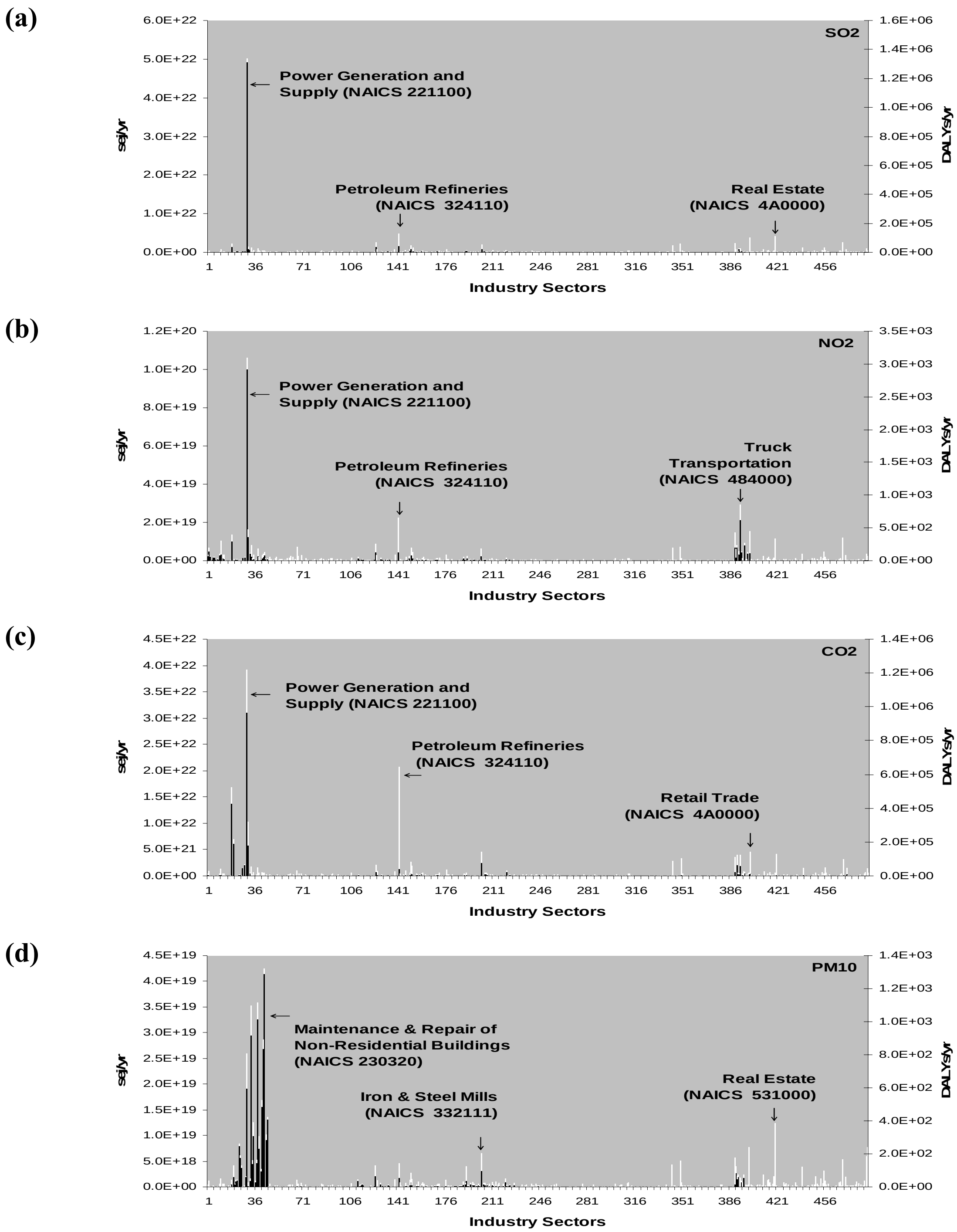


Figure 5.5: Human Health Impact of Bulk-Pollutants (a) SO_2; (b) NO_2; (c) CO_2; (d) PM10; *y*-axes are annual ECEC flows in sej/yr and corresponding impact in DALYs/yr; *x*-axis is sector serial number (ref: Table A.2) (black part of each bar represents direct inputs and white part represents indirect inputs)

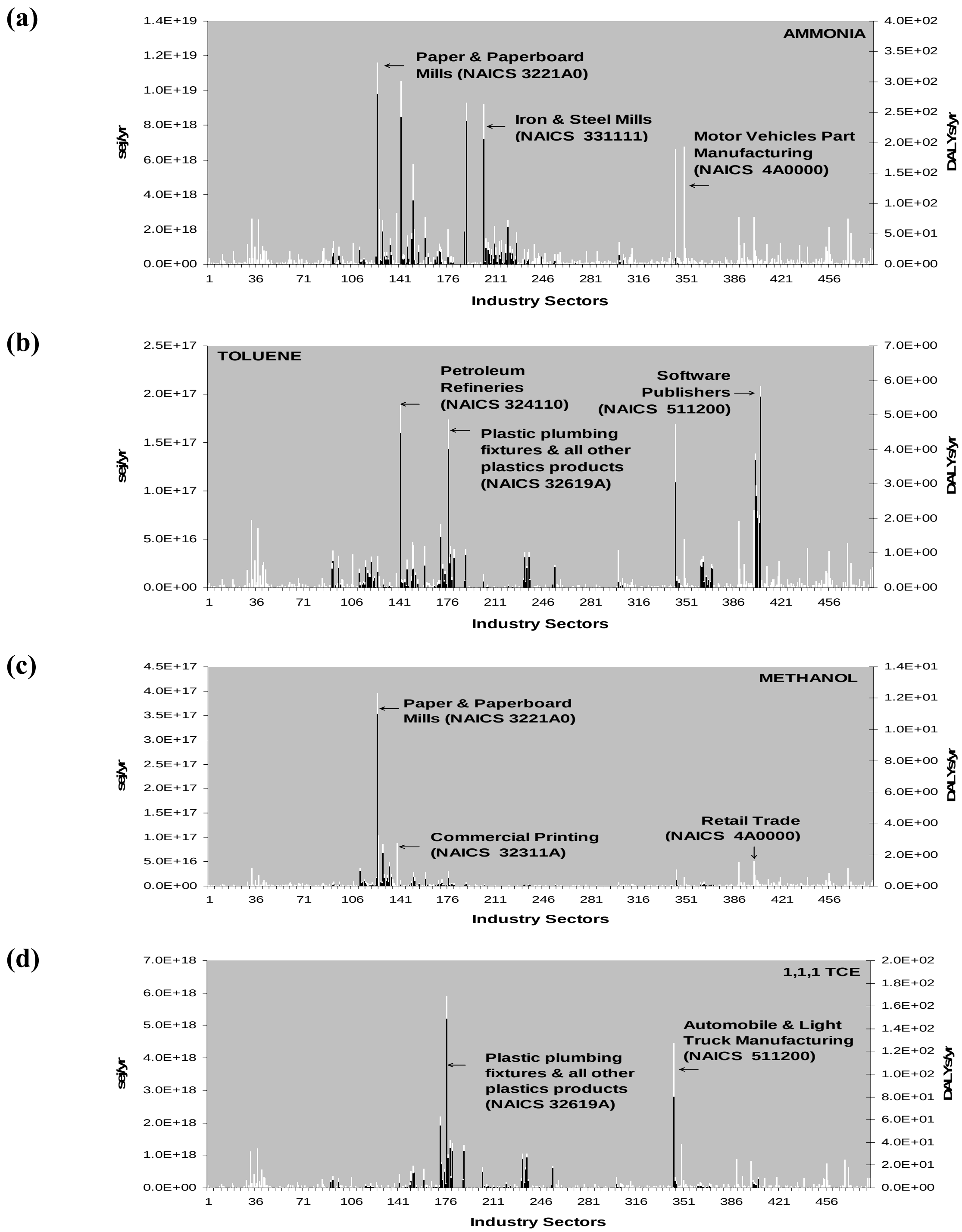


Figure 5.6: Impact of non-bulk pollutants. (a) Ammonia; (b) Toluene; (c) Methanol; (d) 1,1,1-Trichloroethane; *y*-axes are annual ECEC flows in sej/yr and corresponding impact in DALYs/yr; *x*-axis is sector serial number (ref: Table A.2) (black part of each bar represents direct inputs and white part represents indirect inputs)

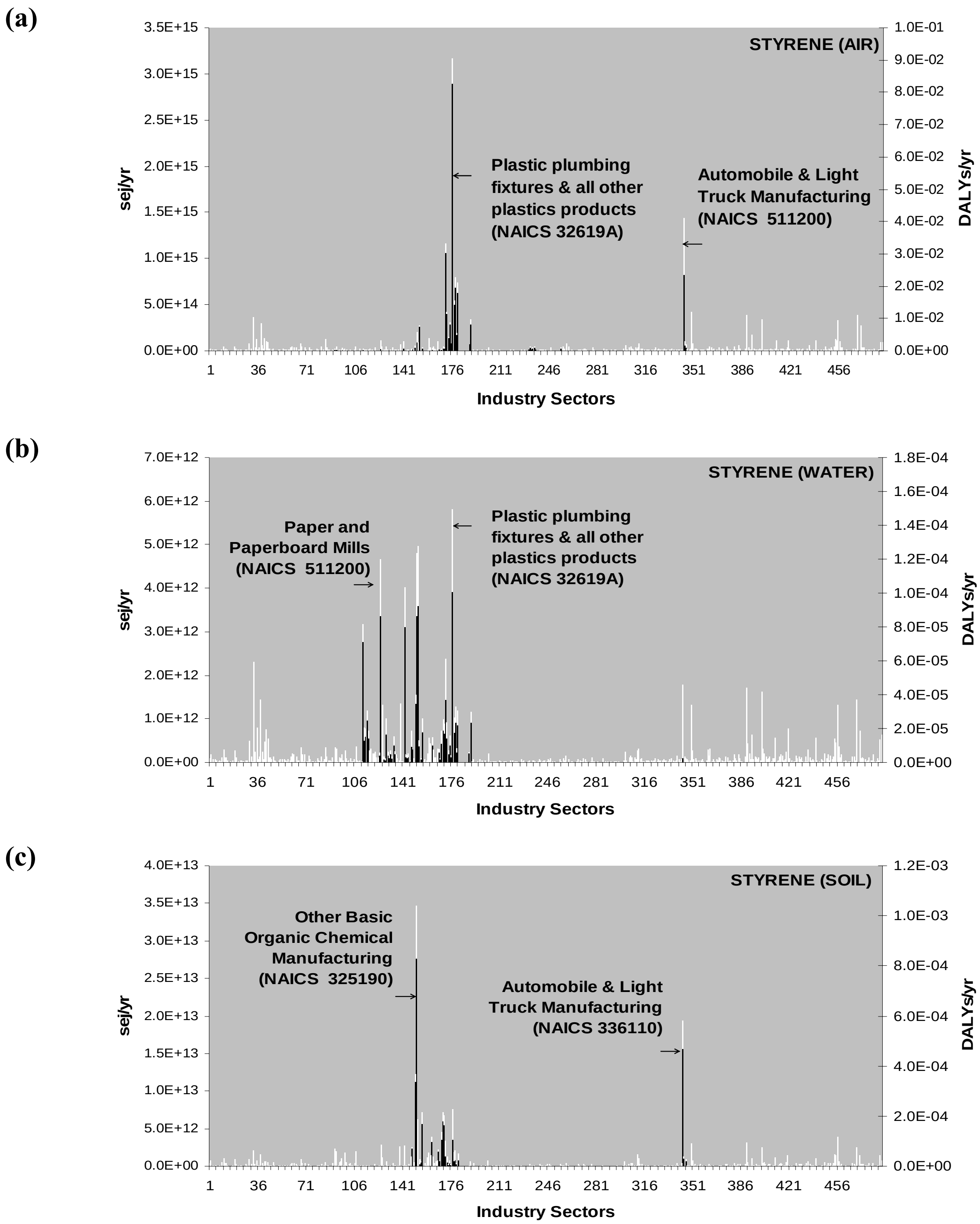


Figure 5.7: Impact of non-bulk pollutants. (a) Styrene emission to air; (b) Styrene emission to water; (c) Styrene emission to soil ; *y*-axes are annual ECEC flows in sej/yr and corresponding impact in DALYs/yr; *x*-axis is sector serial number (ref: Table A.2) (black part of each bar represents direct inputs and white part represents indirect inputs)

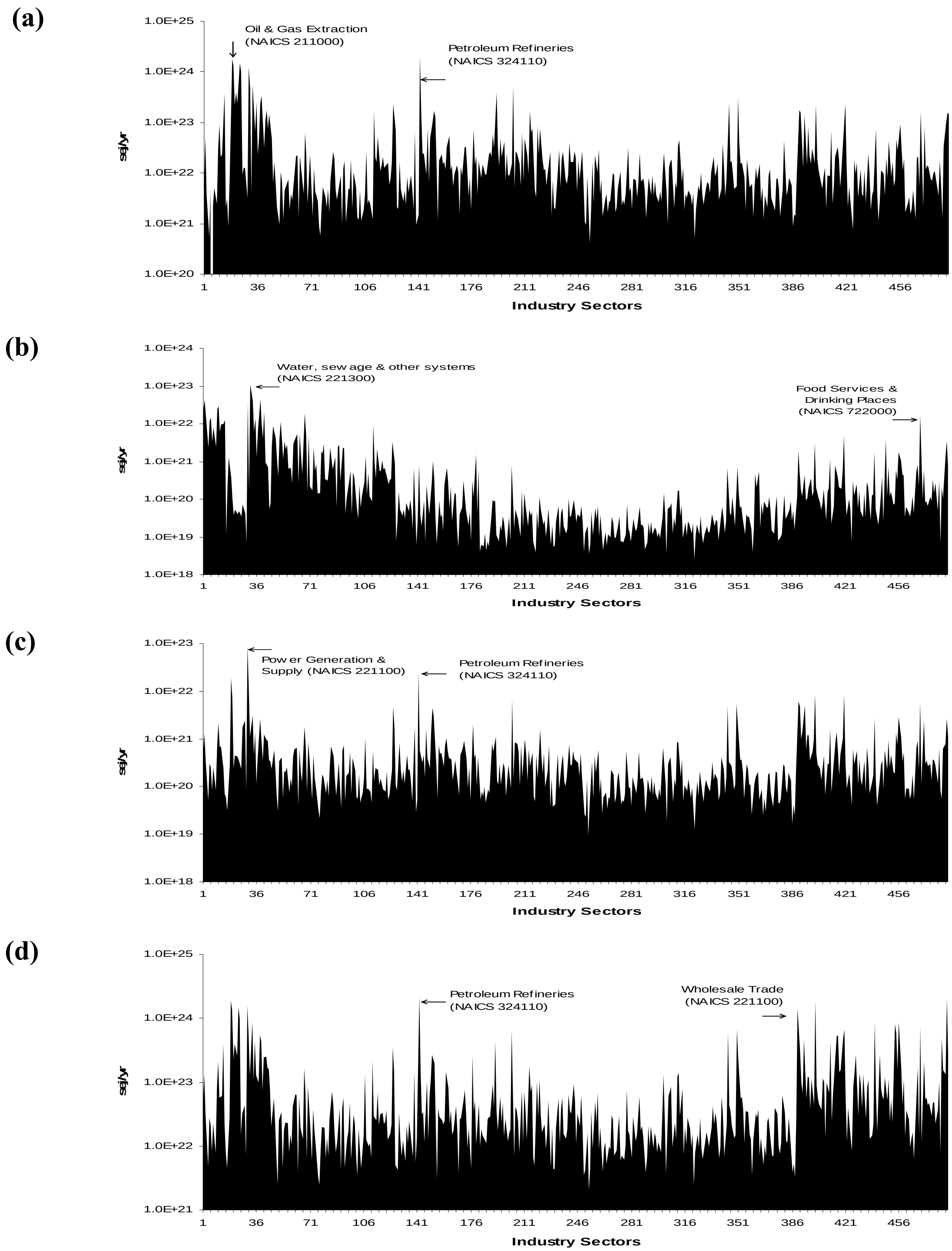


Figure 5.8: ECEC Requirements of Industry Sectors (a) non-renewable resources; (b) renewable resources; (c) human health impact of emissions; (d) total; *y*-axes are annual ECEC flows in sej/yr; *x*-axis is sector serial number (ref: Table A.2)

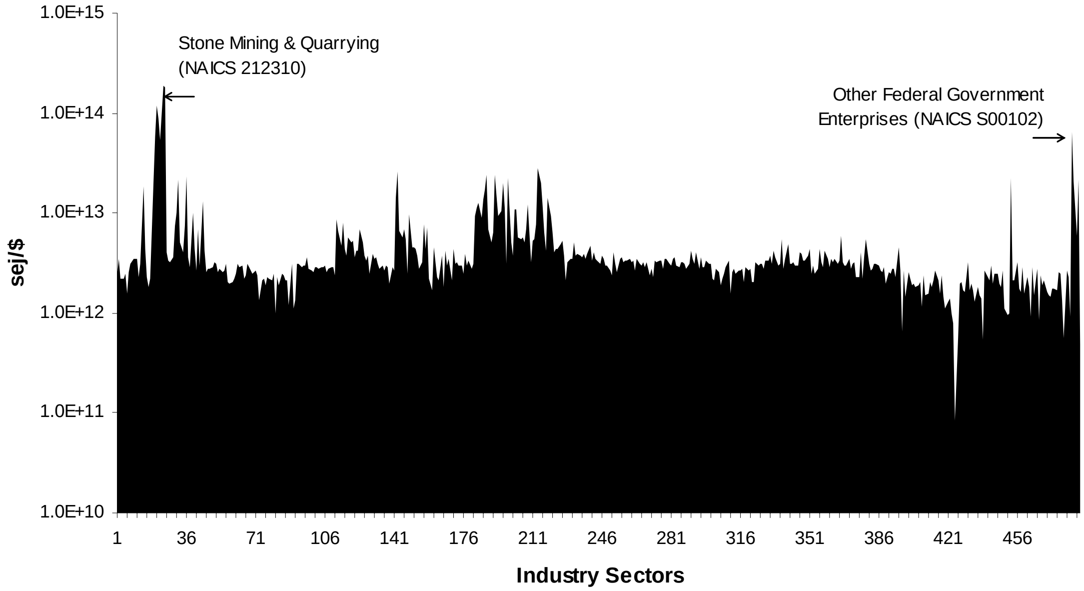


Figure 5.9: ECEC/$ Ratios for Industry Sectors of 1997 US economy; y-axis is sej/$; *x*-axis is Sector Serial Rank (for Sector Serial Rank (SR) refer to Table A.2 in the Supplementary Material)

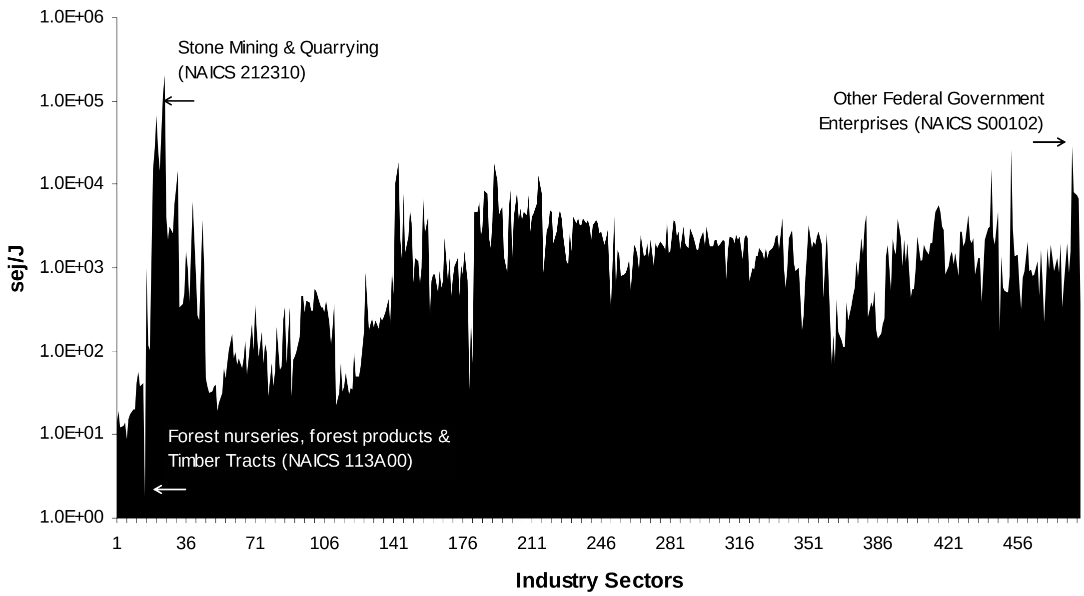


Figure 5.10: ECEC/ICEC ratios for 488-sector 1997 US economic model; *y*-axis is sej/J, *x*-axis is Sector Serial Rank (for Sector Serial Rank (SR) refer to Table A.2 in the Supplementary Material)

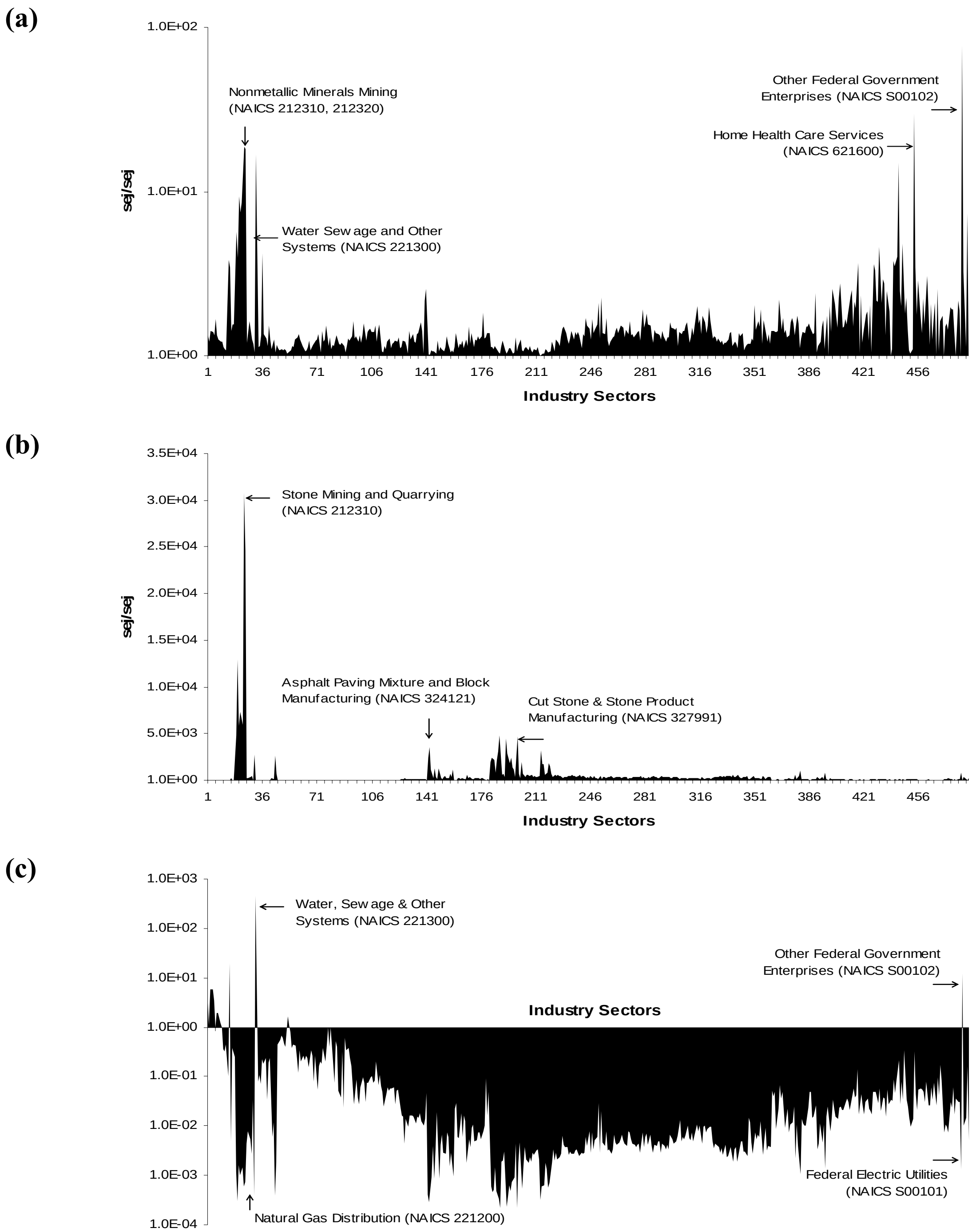


Figure 5.11: Performance Metrics of Industry Sectors (a) Yield Ratio; (b) Environmental Loading Ratio; (c) Yield-to-Loading Ratio; *x*-axis is sector serial number (ref: Table A.2), for Definitions of performance metrics refer to Table 3.5

CHAPTER 6

APPLICATIONS OF THERMODYNAMIC INPUT-OUTPUT ANALYSIS FOR ENVIRONMENTALLY CONSCIOUS DECISION MAKING

6.1. Introduction

This chapter presents the applications of Thermodynamic Input-Output Analysis as a tool for environmental decision-making. ICEC/money and ECEC/money ratios obtained in Chapters 4 and 5 can be used to evaluate environmental objectives of alternative products and processes at the micro-scale. They can also be used at a macro-scale to understand accumulation of economic and natural capitals in industrial networks. Such insight is potentially useful in rationalization of economic policies and in addressing issues related to sustainable international trade, corporate restructuring and industry-specific pro-ecological taxes. This chapter presents four case studies. The first two use results for 91-sector 1992 model of the US economy, whereas the last two use results for the 488-sector 1997 model. Section 6.2 presents comparison of coal-based thermoelectric and geothermal electricity generation systems. This case study compares environmental implications of the two systems using thermodynamic efficiencies at process-scale (exergetic efficiency), economy-scale (ICDP) and ecosystem-scale (ECDP). It also calculates performance metrics listed in Table 3.4 for the two systems. Section 6.3 presents the application of ICEC/money and ECEC/money ratios to construct hierarchical thermodynamic metrics of sustainability. These metrics have many desirable attributes of ideal sustainability metrics. They are easy to calculate, robust, stackable, non-perverse in indicating progress towards sustainability and protective of proprietary information. Construction of these metrics and their interpretation has been illustrated via an ammonia production example. Section 6.4 builds on the case study presented in Section 6.2 by considering four additional electricity systems. These additional system are oil- and NG-based thermoelectric, hydroelectric and wind-based systems. Finally Section 6.5 uses ECEC/money ratios to determine accumulation of economic and natural capitals along supply chains of industrial processes. Economic and natural capitals are two of the three constituents of the productive capital base of a country. The results reveal a hierarchical organization of the US economy that resembles an ecological food chain. These results have significant implications to macro-scale phenomena such as outsourcing and sustainable international trade.

6.2. Comparison of Coal- and Geothermal Electricity Generation Systems based on Results for 91-sector 1992 US model

The purpose of this case study is to demonstrate how accounting for ecosystem contribution in thermodynamic analysis offers a different perspective than the existing methods such as emergy analysis, exergy analysis and Industrial Cumulative Exergy Consumption (ICEC) analysis. This case study illustrates how results obtained in Section 4.7 can be used for environmental decision making. The electricity generation systems considered here have already been studied in emergy analysis (Ulgiati and Brown, 2002) allowing comparison of the results with those obtained in the past.

For the purpose of this case study, data were obtained for two electricity generation systems in Italy (Ulgiati and Brown, 2002). The first was a geothermal electricity generation system located at Castelnuovo V.C., Pisa, and the second was a conventional coal-fueled, thermoelectric generation facility located at Vado Ligure, Savona. Data included direct environmental inputs, direct human resource inputs and economic inputs during construction and operation phases. Data were also obtained for process outputs including net electricity production and emissions during operation phase. All inputs were expressed on a yearly basis by dividing total amount of fixed capital equipment, buildings etc. by their estimated useful life of 25 years. For the purpose of this analysis, electricity generation systems in Italy were assumed to be technologically similar to their American counterparts so that results obtained for the US economy could be used. Information about transformity values of direct ecological inputs were obtained from the systems ecology literature (Odum, 1996; Brown and Bardi, 2001; Brandt-Williams, 2002), whereas, data about exergy content of ecological and purchased inputs were obtained from Szargut et al. (1988). Data about prices of purchased inputs were obtained from various government databases (USDOE, 2004a; USGS, 2004a). Detailed calculations are provided in Appendix E of the Supplementary Material. Since details of machineries used during the construction and the operation phases were not available, prices of machineries were assumed to be those of the metals from which they were made. ICEC/$ ratios calculated in Section 4.7.3 were used to perform a traditional ICEC Analysis, whereas, ECEC/$ ratios were used to account for ecosystem contribution.

The ICEC and ECEC flows associated with a purchased input were calculated by assigning the purchased input to appropriate industry sector, determining the monetary transaction by multiplying purchased quantity by market price, and finally multiplying the monetary transaction by ICEC/$ and ECEC/$ ratios for the previously chosen industry sector. For the inputs purchased from the Sector of Petroleum Refining and Related Products (SIC 31) the ratios were augmented by a factor of 2.1 to account for imports of crude oil, since in 1992, total consumption of refinery products in the US was 2.1 times the domestic production of crude oil (USDOE, 2004c). Detailed mathematical algorithms for performing hybrid thermodynamic analysis on a process system are presented in Appendix H of the Supplementary Material. Table 6.1 shows the thermodynamic efficiencies for the two systems at different scales. Table 6.1 also shows several performance metrics to compare environmental implications of the two electricity generation systems. These metrics have been defined in Chapter 3 and the algorithm for their calculation has been provided in Appendix H.

Geothermal electricity production facility, Castelnuovo V.C., Pisa. Total annual electricity production from this facility was 3.28×10^{14}J. Total exergetic inputs, total ICEC requirements and the total ECEC requirements of the process were 2.38×10^{15}J/yr, 2.42×10^{15}J/yr and 3.85×10^{19}sej/yr respectively. Total ECEC requirement calculated in this case was comparable to the total emergy cost of 4.83×10^{19}sej/yr calculated by Ulgiati and Brown. The difference between total ECEC requirement and total emergy cost may arise as the two are calculated in different ways. Total emergy cost is based on transformity values whereas total ECEC requirements are based on economic prices and ECEC/money ratios. The second law efficiency and ICDP of this process are close because the process derives 98.9% of its exergetic requirements directly from ecosystems. These direct inputs include geothermal heat as the primary source of energy. Direct renewable resource input to the process is 3.35×10^{19}sej/yr which is equal to that calculated by Ulgiati and Brown (2002).

Coal-fueled, thermoelectric production facility; Vado Ligure, Savona. Total annual electricity production from this facility was 2.44×10^{16}J/yr. Total exergetic inputs, total ICEC requirements and total ECEC requirements were 1.11×10^{17}J/yr, 1.17×10^{17}J/yr and 3.22×10^{21}sej/yr respectively. Unlike geothermal facility that relies heavily on direct ecological inputs, this facility derives only 38.7% of its total exergetic inputs from ecosystems. The two primary sources of energy, namely coal and combustion oil, are purchased from the Sectors of Coal Mining and Petroleum refinery and related products respectively. Total ECEC content of direct fuel inputs is 2.88×10^{21}sej/yr which is close to the emergy value of 3.01×10^{21}sej/yr calculated by Ulgiati and Brown (2002). The difference is again attributable to different analyses techniques adopted in the two approaches.

As seen from Table 6.1, accounting for ecosystem contribution gives a different perspective on thermodynamic efficiencies of industrial processes. For instance, according to exergy analysis and ICEC analysis, the thermoelectric alternative is more efficient than the geothermal alternative, but according to ECEC analysis it is the other way around. The primary reason for this is the *ability of ECEC analysis, and the failure of exergy analysis and ICEC analysis, to incorporate exergy expended in ecological processes*. Geothermal Heat being a renewable resource is readily available to industrial activity, whereas coal being a non-renewable resource requires significant contribution from ecosystems. Because of this ability to account for ecosystem products and services, ECEC analysis is a more suitable technique for environmental decision making than the existing thermodynamic techniques such as exergy analysis and ICEC analysis.

Table 6.1 also calculates metrics for comparing the two alternatives. These metrics have been defined along the lines of those used in emergy analysis (Ulgiati et al., 1995; Odum, 1996). The major difference is in the way resources are categorized. For instance, unlike emergy analysis, the analysis presented in this dissertation does not have to distinguish between purchased inputs and direct ecological inputs. Since the Thermodynamic Input-Output Analysis can consider the entire economic network, ecological inputs embodied in purchased inputs can also be quantified. Accordingly, direct ecological inputs in emergy analysis correspond to direct ECEC inputs in TIOA and purchased inputs in emergy analysis correspond to indirect ECEC inputs in TIOA. The higher yield ratio for geothermal alternative indicates that it derives a larger portion of its ECEC inputs directly from ecosystems. Similarly a higher loading ratio for the thermoelectric alternative indicates that it consumes relatively more non-renewable resources than the geothermal alternative. As a result, the index of sustainability of the geothermal option is 6919 times that of the thermoelectric alternative. Moreover, human health impact of emissions per unit electricity production is 15 times higher for the thermoelectric alternative. A significant portion of this impact arises from direct SO_2 and NO_x emissions from the thermoelectric alternative as shown in Table E.2 in the Supplementary Material.

Like ECEC analysis, emergy analysis can also determine ecosystem contribution to economic activity. However, to do so it either needs to know the entire industrial network which is infinitely long and practically intractable or has to use a single emergy/$ ratio to represent the entire economy. ECEC/$ ratios calculated in Chapters 4 and 5 and used in this case study are easier to use since the required monetary information about purchased inputs is routinely gathered by businesses for their financial accounts. Moreover, unlike emergy analysis, Thermodynamic Input-Output Analysis does consider the entire economic network through the use of economic input-output models. ECEC/$ ratios are also more accurate than a single emergy/$ ratio because they are more disaggregated and can reflect differences between industry sectors. At this point, it is necessary to note that the use of a single emergy/$ ratio is not a theoretical limitation of emergy analysis. Emergy analysis can use different industry-specific ratios if they are available. The analysis presented in this dissertation is the first systematic effort to make such ratios available. ICEC/$ and ECEC/$ ratios are also particularly useful in hybrid thermodynamic analysis of industrial processes (Suh et al., 2004). Since the interactions of a process or a *product system* with the rest of the economy are typically measured in monetary units ICEC/$ and ECEC/$ ratios can be readily used to determine efficiencies at coarser economic and ecological scales respectively.

6.3. Hierarchical Thermodynamic Metrics of Sustainability

ECEC/$ and ICEC/$ ratios calculated in Section 4.7 can be used to evaluate hierarchical thermodynamic metrics of sustainability. As businesses are continuing to realize the strategic advantages of sustainable operations and the tangible as well as intangible benefits they bring about to the business enterprise (Fiksel, 2003; Thomas and Harris, 2004), there is a great need for reliable, robust and practical metrics that can determine the progress towards sustainability. A vast variety of sustainability metrics have been proposed in the past to quantify ecological, economic and social aspects of industrial systems (Azapagic and Perdan, 2000; Schwarz et al., 2002; Marteel et al., 2003; Sikdar, 2003; Wirdak, 2003; AIChE, 2004; IChemE, 2004). These metrics typically include measures of pollutant output, process performance and direct and indirect effects of an activity on the environment and the society.

These approaches, in general, categorize the environmental effects of industrial processes into input side and output side metrics as shown in Figure 6.1. Material intensity, energy intensity, water consumption, toxic emissions, pollutant emissions and carbon dioxide emissions are a few examples of metrics commonly used for industrial applications (Schwarz et al., 2002). The input- and output-side metrics may also be normalized by some measure of performance such as mass of product, dollars of value added, or dollars of revenue.

Additional metrics for specific types of impact categories, land use, and social aspects may also be developed. The sustainability metrics mentioned above posses many desirable attributes. These metrics are simple to calculate, useful for decision making, understandable to different audiences, cost-effective, robust and non-perverse in indicating progress towards sustainability, stackable to permit combination with metrics for other processes, and protective of proprietary information (Schwarz et al., 2002). The calculations for these metrics are relatively straightforward, and have been carried out for a large number of chemical processes by Schwarz et al (2002). However, these metrics also face numerous shortcomings that hinder their wide-spread use. Some of these shortcomings are as follows.

- *Curse of Dimensionality.* A large number of, often conflicting, metrics and variables make the decision-making task quite challenging.
- *Perverse Results due to Lack of Theoretical Rigor.* Adding mass or energy of different streams to compute material or energy intensities focuses only on the first law of thermodynamics and ignores the second law. This can lead to perverse results such as improvement in metrics by switching to a higher quality, but scarce, energy source. Furthermore, mass and energy usually cannot be separated for any stream, and the separate consideration of both streams may introduce redundancy and double counting.
- *Challenge of Multiple Scales.* A rigorous and comprehensive method for considering inputs and impacts of the selected process at multiple spatial scales is crucial. Otherwise, use of a narrow spatial boundary may improve sustainability by simply shifting the impacts outside the boundary.

Thermodynamic Input-Output Analysis proposed in Chapter 3 and ECEC/$ and ICEC/$ ratios calculated in Section 4.7 can assist in overcoming these shortcomings while retaining the attractive features of practical sustainability metrics. Exergy can be used for reducing dimensionality on the input side by combining material and energy streams in a theoretically rigorous manner (Szargut et al., 1988; Ayres, 1994; Seager and Theis, 2002). The dimensionality on the output side can be reduced by representing the impact of emissions in terms of exergy loss of the impacted system. The approach for determining cumulative exergy associated with human health impact of emissions has been discussed in Section 3.3.3. A similar approach can be developed for assessing cumulative exergy associated with impact of emissions on ecosystems. Finally, the input- and output-side metrics may be combined to yield a single aggregate metric. This procedure results into a hierarchy of metrics at different levels of aggregation, and addresses the first two shortcomings listed above in a scientifically rigorous fashion. Use of ICEC/$ and ECEC/$ ratios also enables expansion of the system boundary beyond the scale of the process, and to the scale of the economy and ecosystems respectively. The ultimate result is a doubly-nested hierarchy, consisting of multiple spatial scales and different levels of aggregation encapsulated at each scale. The concept of a multiscale system comprising process-, life-cycle, economy- and ecosystem-scales has been elaborated further in the next section.

6.3.1. Multiscale System

Figure 6.2 shows the conceptual diagram of flows between industrial and ecological processes (Odum, 1996; Bakshi, 2002). Industrial processes consume non-renewable resources, N, renewable ecosystem services and products, R_1, and input from economy, F. Economic inputs represent goods and services that are valued by the economy, and that involve a monetary transaction. The outputs of industrial processes include main products that are sold to the market, Y, and emissions that are returned to the environment, W. The ecosystem output, R_2, represents nature's services needed to dissipate the emissions, and to absorb their impact. The box representing "industrial processes" in Figure 6.2(a) may actually include a single process or an ensemble of processes capturing the life cycle of a product or service. The economy scale includes economic sectors represented by the box of "economic resources" in Figure 6.2(a). Finally, the ecosystem scale includes ecological processes that lie outside the market.

6.3.2. Single Scale Hierarchy

The structure of the hierarchical metrics developed by Yi et al. (2004) is depicted in Figure 6.3 for any system at a selected scale. At the base level, that is Level 1a, the left and right halves contain data about inputs and outputs respectively. These data may be in a variety of units such as mass, energy, or money. At Level 1b, all the data are converted into a consistent thermodynamic unit using exergy or ECEC analysis as described in Chapter 3. At this level, details about all input and output streams are available without any aggregation resulting in a high dimensional space. Performance parameters such as productivity, profitability or value-added are not shown in Figure 6.3 since these parameters are usually incorporated in the metrics via normalization. A popular approach is to normalize the metrics by the economic value of the output (Schwarz et al., 2002).

At the next level of the hierarchy (Level 2), the multitude of inputs and outputs are combined to yield more aggregate but separate metrics for the inputs and the impact of emissions. Impact of different emissions in level 1a cannot be aggregated without translating them into a consistent thermodynamic unit. Thus, the exergy loss by emissions is calculated in level 1b and aggregated in level 2. This aggregation could be done in a few different ways. Exergy of outputs may be classified as products (*Y*) and waste (*W*), and inputs may be classified as direct renewable (R_1), direct nonrenewable (*N*), and direct economic (*F*). The impact of emissions represents exergy required for dissipation of emissions, and the loss of exergy due to ecological and human health impact of emissions. At Level 3, a single metric may be obtained to represent the sustainability of the selected system. Many different types of metrics may be defined by combining the variables at Level 2.

The simplest and potentially most useful among these is the thermodynamic efficiency (or its reciprocal), which may be defined with or without including the impact of emissions. Alternatively, exergy consumption of the system can be normalized by economic value added or some other measure of productivity. In the hierarchical metrics developed by Yi et al. (2004), exergy values of input streams and exergy loss by the impact of emissions are aggregated for a single metric at level 3, which represents the exergy change of the environment by the consumption of raw materials and the release of pollutants. The proposed hierarchical structure eases the curse of dimensionality by aggregating multiple variables in a scientifically sound manner, while ensuring that details are still available.

6.3.3. Multi-Scale Hierarchy

Since it is widely recognized that sustainable development cannot be addressed by taking a narrow, process-centric view, techniques and data are required for expanding the system boundary beyond a process or equipment, to the entire life cycle, economy or ecosystem (Bakshi and Fiksel, 2003). Conversely, data and metrics at coarser scales alone cannot be used for engineering decision-making, but need to be fused with finer process- or equipment-scale data and models. The hierarchy presented in Section 6.3.2 focused on a system at a single scale, but can be expanded and connected with similar hierarchies at multiple spatial scales, as described in this section.

Information for developing the hierarchy at the *process scale* may be readily obtained from mass and energy balances and cost information about the process from computer simulations, literature, or company-logs and standard operating procedures. Gate-to-gate inventory modules developed for specific processes may also provide useful information at the scale of the process (Jimenez-Gonzales et al., 2000). Such information also forms the basis of the metrics developed by AIChE-CWRT and others.

Expanding the analysis to the *life cycle scale* would involve selection of the most important processes in the life cycle. This approach is analogous to that used for process LCA, and may utilize the extensive life cycle inventory databases included in various software packages. Converting the results of a process LCA into thermodynamic terms is quite straightforward if information about physical and chemical properties of various streams is available. Thermodynamic parameters such as cumulative exergy consumption (CEC) and cumulative degree for perfection (CDP) have been calculated for many common industrial processes, and may be used to calculate life cycle exergetic requirements of selected products or services (Szargut et al., 1988; Sussman, 1980). However, analysis at this scale still ignores a large number of processes in the life cycle network, which together may introduce a significant error in the results.

The coarser *economy scale* considers activity in the entire economy required to sustain the selected process or the ensemble of processes. Such analysis relies on combining economic input-output LCA (EIO-LCA) with process LCA, resulting in an approach analogous to a tiered hybrid LCA (Suh et al., 2004). EIO-LCA is applied to the streams that enter the process LCA based on their economic value, resulting in the material, energy and emissions information due to the economic inputs considered at the life cycle scale. These may be converted into exergy values at Level 1b and Level 2 according to the approach described in Section 6.3.2. The same result may also be obtained more conveniently by using ICEC/$ ratios for individual economic sectors (Ukidwe and Bakshi, 2004a). As discussed in Section 4.7, this ratio indicates cumulative exergy consumption of an industry sector normalized by its corresponding monetary throughput. Therefore, ICEC of each economic input may be calculated according to Equation 6.1.

$$ICEC_i = m_i \cdot C_i \cdot R_{ICEC,i} \tag{6.1}$$

Here, $R_{ICEC,i}$ is the ICEC/$ ratio of the industry sector that supplies product i, m_i is the mass or energy flow of product i, C_i is the price of product i, and $ICEC_i$ is the industrial cumulative exergy of product i. This analysis implicitly considers all natural resources to be thermodynamically identical by ignoring the contribution of ecological goods and services for making various natural resources.

At the *ecosystem scale*, analysis boundary is expanded further to account for the contribution of ecological goods and services. Determining ecological cumulative exergy consumption in the life cycle of a selected process or process ensemble is facilitated via the ECEC/$ ratios derived in Section 4.7 (Ukidwe and Bakshi, 2004a). As discussed earlier, this ratio provides information about how much exergy is consumed from the generation of natural resources in ecosystems to the production of industrial goods and services per unit monetary throughput in each industry sector. It is represented in solar equivalent joules (sej) following the approach of emergy analysis (Odum, 1996). ECEC of each economic input may be calculated according to Equation 6.2.

$$ECEC_i = m_i \cdot C_i \cdot R_{ECEC,i} \tag{6.2}$$

Here, $R_{ECEC,i}$ is the ECEC/$ ratio of the industry sector that supplies product i, m_i is the mass or energy flow of product i, C_i is the price of product i, and $ECEC_i$ is the ecological cumulative exergy of product i. Unlike Equation 6.1, Equation 6.2 does acknowledge quality differences between natural resources.

The appropriate level of detail can be left to the practitioner according to the type of decision-making task. For example, upper level management may prefer using the most aggregate numbers, while process engineers may prefer details provided by the bottom levels of the hierarchy. More aggregate metrics may be used for quick screening between alternatives. Combination of the single-scale and multi-scale hierarchy results into a doubly-nested hierarchy. This is illustrated with the help of a case study focusing on ammonia production in the next section.

6.3.4. Case Study – Ammonia Process

This case study evaluates the hierarchical sustainability metrics for an ammonia process. It provides the detailed procedure for the calculation of metric values for process scale, life cycle scale, economy scale, and ecosystems scale.

<u>Process Scale</u>. Figures 6.4(a) and 6.4(b) show material and exergy flows of an ammonia process based on data from Shreve and Brink (1977). From these diagrams, the hierarchical metrics at the process scale can be constructed quite readily as shown in Figure 6.5. These numbers are not normalized to permit easier interpretation. For a metric to be meaningful and permit comparison across alternatives it must be normalized by an appropriate output measure such as monetary value or exergy content. Normalized metrics may be readily obtained by dividing the numbers in Figures 6.4(a) and 6.4(b) by mass of ammonia (38 t/h) or its exergy (212 MW). The normalized metric value at Level 1a for the ammonia process is 1.6t/h because it only includes natural gas and air. Fuel is not included as material consumption but as energy metric in the Level 1a. The metric value for energy consumption at Level 1a is 4.3MW, which is the sum of net calorific value of fuel and electric power. The value for water consumption at Level 1a is 3.1t/h based on assuming 10% loss of process water in cooling tower. Exergy values for material, water and fuel are calculated using standard exergy values from Szargut et al. (1988), but exergy of electricity is assumed equal to its energy content. The values of emission of toxics, pollutants and carbon dioxide are based on the work of US

Department of Energy's Office of Industrial Technology (Pellegrino, 2000). These emissions are converted into exergy via Equation 3.2. Although mass of emissions is much smaller than that of raw materials, exergy loss due to impact is thrice the exergy of input streams. The single metric in Level 3 is the sum of input and output exergies in Level 2.

Life Cycle Scale. The system boundary for sustainability metrics is expanded using process-based life cycle analysis. The expanded system includes a refinery process for generation of natural gas from crude oil and a power plant for generating electricity from coal. Data about material and exergy flows for this system were obtained from Maple (2000) and Taftan Database (Taftan, 2005). Figure 4.6 shows material and exergy flows between the three processes at the life-cycle scale. Hierarchical sustainability metrics for the power plant, refinery and ammonia plant are shown at the process scale in Figure 6.6. The procedure for calculating these metrics for the refinery and the power plant is similar to that for the ammonia plant (Yi et al., 2004). Sustainability metrics without normalization at the process-based life cycle scale are also shown in Figure 6.7. Material metric value in Level 1a for the life cycle scale is 32.2 t/h, which is calculated from the flow rates of crude oil, *i*-butane, MTBE and air. The corresponding energy value at Level 1a for the life cycle scale is 0.7MW, which corresponds to net calorific value of 0.12t/h of coal. Water metric value at Level 1a for the life cycle scale is about 11.7t/h with 10% loss of cooling water. Emission flow rates at process life cycle scale are the sums of emissions flow rates for individual processes. Exergy values of input streams and exergy loss due to impact are calculated as for the ammonia plant. Not surprisingly, exergy consumption at the life cycle scale is larger than that for the single ammonia process. The input side metric at the life cycle scale of the ammonia process is about thirty times larger than that for the ammonia process only. The output side metric at the life cycle scale is also twenty times larger than that for the ammonia process alone. However, the analysis is still incomplete as only a small fraction of the life cycle is actually considered at the life-cycle scale. The rest of the life cycle can be considered by expanding the system boundary to the economy scale.

Economy Scale. The incompleteness of process-based LCA may be addressed via a thermodynamic hybrid life cycle analysis based on ICEC/$ ratios discussed in Section 4.7.3. The metric values at Level 1a of the economy scale are obtained by adding the metric values at Level 1a of the Process Life Cycle Scale to the results obtained by applying EIO-LCA to the cut-off streams in the process-based life cycle scale. These cut-off streams represent interactions of the process ensemble shown in Figure 6.6 with the rest of the economy. This approach results in information about consumption of energy, water, and ores and production of pollutants, green house gases, toxics etc. associated with each cut-off stream. These results are added to those from process-based LCA to produce metric values at Level 1a of the economy scale. To determine "exergy of input" at Level 2 of the economy-scale, exergy of input at Level 2 of the process life-cycle scale is added to the exergy consumption in the rest of economy. The later is calculated according to Equation 6.1. For instance, the ICEC/$ ratio for the sector of coal mining is 2.03×10^{9}J/$. This is used to estimate the total ICEC consumption in the economy ascribed to the coal consumption of 0.12 t/h at $5/t. Exergy loss attributed to impact is calculated using DALY values of emitted substances. For instance, flow rate of CO_2 emission is 5.8t/h, the DALY value of CO_2 is 2.1×10^{-7} DALY/kg, and the converting factor, ξ, that represents ICEC of human labor is 3.1×10^{14} J/DALY. Therefore, exergy loss due to emission of carbon dioxide is about 104.9MW. The exergy losses for other streams can be calculated in the same way. The exergy of input streams at the economy scale is larger than exergy loss due to impact, suggesting that cumulative exergy consumption by all processes to make ammonia is larger than the potential exergy changes in the environment due to waste emissions. In addition, energy consumption, water consumption and carbon dioxide emissions are much increased compared with the metric values at the process life cycle scale. Including the entire economy in the life cycle analysis is not complete because ecological products and services are indispensable for industrial and economic activities and need to be included in the analysis.

Ecosystem Scale. ECEC analysis expands the boundary of ICEC analysis even further to include all ecological processes required to make natural resources available to industrial activities (Hau and Bakshi, 2004b). The ECEC values for inputs and impact of emissions may be readily obtained via an approach similar to that used at the economy scale. The primary difference is that ECEC/$ ratios are used at the ecosystem scale instead of ICEC/$ ratios used at the scale of the economy. Alternatively, ECEC/ICEC ratios of industry sectors can also be used. ICEC consumption of 0.12t/h of coal is 0.18MW. It can be converted to corresponding ECEC flow by multiplying by ECEC/ICEC ratio of 19,001sej/J, resulting into ECEC of about 3,420Msej/s. Cumulative exergy values at ecosystem scale are much larger compared with those at the economy scale because energy is required to make natural products or services, and ecological processes tend to be exergetically quite inefficient. This is especially true in case of non-renewable lithospheric resources such as fossil fuels and minerals that are made available via geological cycle that is sluggish and accompanied by significant exergy losses. Therefore, exergy consumption during ecological processes is not negligible when sustainability of industrial processes is to be evaluated.

The hierarchical thermodynamic metrics have many distinct advantages that make them useful for industrial decision making. In summary, the hierarchical thermodynamic metrics overcome three major shortcomings faced by other conventional metrics of sustainability, namely the curse of dimensionality, lack of adequate scientific rigor due to ignorance of material and energy balance constraints and the second law of thermodynamics and failure to address the multiscale nature of environmental issues. Consequently, these metrics are more powerful and scientifically sound than their state-of-the-art counterparts.

6.4. Comparison of Coal-, Oil- and NG-based Thermoelectric and Hydro-, Wind- and Geothermal Electricity Systems based on 488-sector 1997 model of US Economy.

In this case study results obtained for the 488-sector 1997 model of the US economy were used to analyze environmental implications of six electricity generation systems. Amongst these, coal- and geothermal- systems have already been dealt with in Section 6.1 using results for 91-sector 1992 model of the US economy. Case study presented in this section extends the scope of that analysis by considering four additional electricity generation systems, namely NG- and Oil-based thermoelectric and hydroelectric and wind-based systems. In that context this case study is more comprehensive than that presented in Section 6.2. Furthermore, this case study uses results for 1997 benchmark model of US economy that are more accurate and recent than those for the 1992 US economy. The six electricity systems considered in this analysis are listed below.

- *Wind*: The production facility was located at Casone Romano, Foggia, Italy. The plant composed of 10 250kW generators with a total installed generation capacity of 2.5MW. The net electricity production from the facility was 1.35×10^{12}J/yr
- *Geothermal*: The plant with a net installed production facility of 20MW was located at Castlenuovo V.C., Pisa, Italy. The net electricity generation from the plant was 3.28×10^{14}J/yr.
- *Hydro*: The Hydro-electric plant with a net installed capacity of 85MW was located at Castrocucco, Italy. The annual electricity yield from the plant was 3.94×10^{14}J.
- *Natural Gas*: The cogeneration, gas powered electricity generation power plant had an installed capacity of 171MW with annual electricity yield of 1.86×10^{15}J. The plant was located in Italy.
- *Oil*: The oil-based thermoelectric facility was located at Piombino, Italy. It had an installed capacity of 1280MW with annual electricity yield of 2.35×10^{16}J.
- *Coal*: The coal-based thermoelectric facility was located at Vado Ligure, Savona, Italy. It had an installed capacity of 1280MW with annual electricity yield of 2.44×10^{16}J.

Data about material and energy inputs and emissions during construction and operation phases for all the six systems were obtained through personal communication with Prof. Ulgiati. These data are provided in Appendix G of the Supplementary Material.

Environmental implications of the six systems were determined by performing exergy, ICEC and ECEC analyses. Along the lines of results presented in Section 6.2, thermodynamic efficiencies of the six systems were determined at different scales and various performance metrics were calculated. Figure 6.8 shows the exergetic efficiency, ICDP and ECDP values for the six systems. Furthermore, Figure 6.9 shows yield ratio, loading ratio, yield-to-loading ratio and impact per value added for the six systems. Based on the results obtained in Figure 6.8 and 6.9 following conclusions can be drawn.

- Hydroelectric system has the highest exergetic efficiency, whereas wind power plant has the lowest. This observation also matches the work of Tonon et al. (2006). In general power plants based on fossil sources of energy have higher exergetic efficiencies than those based on wind and geothermal energy because fossil fuels represent a more concentrated form of resource than wind or geothermal heat.
- As the system boundary is expanded through ICEC and ECEC analyses, efficiency values of oil-, coal- and NG-based power plants decrease to a larger degree than the efficiency values of geothermal, hydro and wind-based power plants. This is evident from Figure 6.8(b) that shows lower ICDP values for power plants based on non-renewable resources. Furthermore, ECDP values in Figure 6.8(c) show a different ordering than that based on exergetic efficiencies in Figure 6.8(a). In particular wind-based power plant has a higher ECDP than that of any plant based on non-renewable energy resource. This is so because ECDP, unlike exergetic efficiency or ICDP, can

acknowledge quality differences between energy resources such as their degree of renewability.

- Yield ratio shown in Figure 6.9(a) shows a clear distinction between power plants based on renewable and non-renewable resources. Plants based on renewable resources have an order of magnitude higher yield ratio than those based on non-renewable resources. The reason behind this is the fact that power plants based on renewable resources derive a major fraction of their energy requirements directly from the environment, and consequently rely relatively less on economic activities. In other words, these plants have relatively short industrial supply chains. On the contrary, power plants based on non-renewable resources derive a significant portion of their energy requirements from other industry sectors and have relatively longer industrial supply chains.
- Environmental loading ratio shown in Figure 6.9(b) also shows a clear distinction between power plants based on renewable and non-renewable resources. Power plants based on non-renewable resources have a loading ratio of greater than one whereas those based on renewable resources have a loading ratio of less than one.
- Yield-to-loading ratio, projected in emergy analysis as the index of sustainability, indicates that power plants based on renewable resources are much more sustainable than those based on non-renewable resources. The term "index of sustainability" must be used with caution, however, because it only reflects the resource consumption side of the sustainability riddle. Other attributes such as the economics of these plants and their impact on society must also be considered before determining their sustainability.

- Impact per value added shows that coal-based power plant has the highest human health impact per unit electricity generation, whereas hydroelectric power plant has the lowest. Power plants based on non-renewable fossil energy sources emit CO_2 which affects human health via global warming and climate change. Combustion of coal, in particular, also emits SO_2 and NO_x that cause acidification and photochemical smog formation. Barring indirect emissions, power plants based on renewable resources do not have this problem, and have a much lower impact on human health. At this point it is necessary to note that other impact categories such as impact on ecosystem health and land use have not been considered in this analysis. Land use in particular is likely to be significant in case of hydroelectric power plant that involves dam construction, and consequent loss of habitat due to retained water stream. These effects must be considered to make a more comprehensive appraisal of the six electricity generation systems.
- The results obtained in this case study are potentially useful in understanding a plausible correlation between ECDP and impact of emissions, that has been hypothesized but is yet unproven. Such correlation is of great practical significance as it would enable decision-makers to get an approximate idea about the impact of emissions from a process based on its material and energy inputs. This is especially useful in assessing emerging technologies and novel products for which emission information and toxicological studies are not readily available. The results obtained in Figure 6.8(c) and 6.9(d) suggest that such correlation may exist. However, a lot more research is required to validate this hypothesis.

6.5. Natural versus Economic Capital in Industrial Supply Networks

Sustainability of human activities requires that at least as large a *productive capital base* is available for its future operations as it inherited from its past (Dasgupta, 2002). Productive capital base or the capital stock of a region is made up of *economic*, *natural* and *social capitals* (Faber et al., 1995; Lutz, 2003). Economic capital includes assets such as buildings, machinery, and infrastructure. Natural capital includes various environmental functions such as provision of natural resources like coal, water, petroleum, timber and air to production activities, and dissipation and absorption of wastes from the production activities (Ekins et al., 2003, Ekins and Simon, 2003). Social capital includes human resources, labor productivity, value systems and social organizations through which contributions of individuals are mobilized and coordinated. All three forms of capital are equally important, and must be considered simultaneously to address sustainability issues. The criterion of *weak sustainability* (Neumayer, 1999) assumes that different types of capital are substitutable, implying that sustainability may be maintained by converting one type of capital into another. In contrast, *strong sustainability* rejects the notion of complete substitutability since many ecosystem goods and services cannot be replaced by human-made capital. It requires preservation of natural capital in itself, in addition to other capital stocks. The implications of the results presented in this section have been discussed considering both paradigms of sustainability, without supporting or debunking either.

Since natural capital usually lies outside the market, many efforts have been made for quantifying its importance. These include monetary valuation (Costanza et al., 1997;

Balmford et al., 2002) and analysis of material and energy flows (Odum, 1996; Adriaanse et al., 1997; Matthews et al., 2002). A variety of methods and metrics have been devised for evaluating sustainability at different spatial scales. These range from national measures of genuine investment which account, at least partially, for economic and natural capitals (WB, 2001) to corporate measures of sustainability and eco-efficiency that are being used in annual sustainability reports and for evaluating socially responsible investments (GEMI, 1998; Biswas et al., 1998). However, systematic analysis of the flow of natural capital through the economy and the corresponding economic activity is missing. Such analysis can provide useful insight into the reliance of economic activity on natural capital, and guide the development of effective policies and corporate decisions. It can also complement existing techniques for sustainability metrics, environmental life cycle assessment and for greening the industrial supply chain. Thermodynamic Input-Output Analysis proposed in this dissertation can be used to evaluate natural and economic capital flows in supply chains of industrial processes. ECEC/money ratios, for instance, compare natural and economic capital throughputs of industry sectors. The numerator of such ratio captures the thermodynamic basis of an industry sector and can be considered as a measure of natural capital, whereas the denominator captures monetary basis and is a measure of economic capital.

Environmental and economic aspects of supply networks have also been studied in the past (Russel, 1998; USEPA, 1998; Walton et al., 1998). However, most of these studies have focused on either of the two aspects in isolation, and comparative studies juxtaposing natural and economic capital flows are rare (Behmanesh et al., 1993; Petrie and Raimondo, 1997; Clift and Wright, 2000). Clift and Wrights' study of the relationship between supply chain environmental burdens and value added is a notable exception that tries to compare economic and environmental aspects of industrial supply chains. However, their analysis is based on proprietary data, and analyzes too few supply chains to derive any general conclusions. Moreover, the analysis focuses only on impact of emissions, and does not consider other components of natural capital such as ecosystem goods and services. On the economic side, Clift and Wrights' study considers only value added, and ignores the remaining component of economic capital, namely intermediate inputs from other industry sectors. The analysis presented in this section is more comprehensive as it considers supply networks of a large number of industry sectors belonging to different hierarchical levels of the economy, and is based on non-proprietary data. Moreover, it considers total throughputs of natural capital including renewable and non-renewable ecological goods, ecosystem services and impact of emissions on human health, and total throughputs of economic capital including intermediate inputs to industry sectors besides value added.

6.5.1. Approach for Supply Chain Analysis

The first task in analyzing the supply chain of a process is the selection of an appropriate supply chain from the many possibilities. This is a non-trivial task because, in reality, for any process there exists an infinitely long supply network rather than just a solitary supply chain of finite length. In this analysis this task is accomplished by using economic information from EIOLCA. The components of the supply chain are chosen from the supply network in such way that the most significant supplier at each stage could be included in the analysis and the supply chain loops could be avoided. This is explained with the help of Figure 6.10 which illustrates the selection of a supply chain from a supply network for a hypothetical process A.

The supply chain of the process A is assumed to consist of four stages. Stage 4 represents process A at the top of the supply chain tree. Stage 1 represents primary resource extraction process at the bottom of the supply chain tree and stages 2 and 3 are the intermediate processes. Process A has three suppliers B, C and D with B being the most dominant. Hence at Stage 3 process B is selected for further investigation. Process B has three suppliers, namely A, E and F with A being the most dominant, followed by F and E in that order. Since choice of process A at Stage 2 would lead to a loop, namely A-B-A, in the supply chain, the next most dominant process is chosen instead. In a similar way, process G is chosen at Stage 1 resulting in the complete supply chain, A-B-F-G. This is equivalent to finding an elementary dipath in a digraph (Ahuja et al., 1993; Tennenbaum, 1997; Ban-Jensen and Gutin, 2001) or the most important first-order path at each stage in *Structural Path Analysis* (Treloar, 1997; Treloar et al., 2000). This technique of choosing nodes from a graph resembles the depth first search (DFS) algorithm from graph theory. Other graph searching algorithms such as breadth first search, though equally applicable, have not been used because of higher computational requirements.

After selecting a supply chain for further investigation, the next task to determine economic and natural capital flows along the selected supply chain. In this analysis economic capital flows have been estimated using eio-LCA database. Natural capital flows, in turn, have been calculated by multiplying economic capital flows by ECEC/money ratios of corresponding industry sectors discussed in Section 5.7 and presented in Table B.3 in the Supplementary Material. This has been explained in greater detail with the aid of an illustrative example shown in Table 6.2 and Figure 6.11.

Figure 6.12(a) depicts the relation between cumulative ecosystem contribution and cumulative economic activity in graphical form. At each stage i the ratio $(e_i - e_{i-1})/(m_i - m_{i-1})$ represents the ECEC/money ratio for that stage. Ratio e_4/m_4, also the slope of the reference line, is the resultant ECEC/money ratio for the entire supply chain. Figure 6.12(b) shows the variation in ECEC/money ratio along the various stages of the supply chain. The relation between Cumulative Ecosystem Contribution and Cumulative Economic Activity in Figure 6.12(a) is convex in nature. Mathematically a set is said to be convex if given any two points p_1 and p_2 in the set, a linear combination $a \times p_1 + (1-a) \times p_2$ with $a \in [0,1]$ is also contained in the set. This implies that, in this analysis, the correlation between cumulative ecosystem contribution and cumulative economic activity will be convex if and only if $(e_i - e_{i-1})/(m_i - m_{i-1}) \leq (e_{i-1} - e_{i-2})/(m_{i-1} - m_{i-2})$ for $i = 2, 3, \ldots, n$ with n being the number of supply chain stages considered. In other words, a convex correlation between Cumulative Ecosystem Contribution and Cumulative Economic Activity translates into a monotonic decrease in the ECEC/money ratio and vice versa.

6.5.2. Analysis of Aggregate Sectors

The 488-sector 1997 US economy may be aggregated into 28 major subdivisions as listed in Table 6.3. These subdivisions are defined by the Bureau of Economic Analysis (BEA, 2005b), and have been used in economic input-output life cycle assessment (EIOLCA, 2004). This aggregation scheme is preferred as it provides a more concise overview of the economy than the 3-digit NAICS codes, and yet is more detailed than the 2-digit NAICS codes. Figure 6.13 shows median ECEC/money ratio of each of the 28 subdivisions along with ratios of the constituent sectors in each subdivision. The resultant organization of the “economic food chain” resembles hierarchical organization commonly observed in ecosystems, wherein primary producers constitute the base of the hierarchy and carnivores constitute the top. For the economic hierarchy, median ECEC/money ratio decreases from the base to the top. Basic extractive and infrastructure subdivisions such as Mining and Utilities, Plastic, Rubber and Nonmetallic Mineral Products and Ferrous and Nonferrous Metal Products constitute the base, whereas more specialized subdivisions such as Finance, Insurance, Real Estate and Professional and Technical Services constitute the top. Manufacturing sectors such as, Vehicles and other Transportation Equipment, Textiles and Leather Products, and Semiconductor Manufacturing occupy the middle. This general trend is maintained even for other aggregation schemes. Figure 6.13 leads to following notable observations.

Mining and utilities subdivision (Position 1, NAICS 21, 22) has the highest ECEC/$ ratio whereas Finance, Insurance, Real Estate, Rental and Leasing subdivision (Position 28, NAICS 52, 53) has the lowest ECEC/$ ratio. In general, the advanced manufacturing and service subdivisions have lower ECEC/$ ratios than the resource extraction and basic manufacturing subdivisions. A lower ECEC/money ratio indicates lower consumption of natural capital vis-à-vis generation of economic capital. Therefore from the standpoint of weak sustainability paradigm that presumes substitutability between economic and natural capitals, lower ECEC/money ratio translates into a higher improvement in the productive capital base and indicates more sustainable operations. A plausible reason behind higher ECEC/money ratios of basic infrastructure industries is that these industries are technologically less efficient due to having to process a relatively dilute resource and, consequently, have to consume a lot of raw material to produce finished product or service. This gives rise to large *overburdens*, defined in Material Flow Analysis (MFA) as the material moved by extraction that does not enter the economic system or, alternatively, the difference between *Total Domestic Output* (TDO) and *Domestic Processed Output* (DPO) (Adriaanse et al., 1997; Matthews et al., 2000; Eurostat, 2001; Williams et al., 2002). Other reasons for high ECEC/money ratio for the extractive industries could be economic subsidies and failure of market prices to fully appreciate the contribution of ecological resources and the environmental impact of these activities. People tend to value services and finished products much more than intermediate items, while ecosystem goods and services become economic externalities and are rarely reflected in prices.

Figure 6.14 shows median ECEC/money ratios for the 28 subdivisions for four resource categories, namely contribution from non-renewable resources, renewable resources, human resources and impact of emissions on human health. Figure 6.14 leads to several notable observations, some of which are discussed below along with their interpretation:

- ECEC/$ ratios for non-renewable resources are higher than those for renewable resources for all subdivisions except for Agriculture, Forestry, Fishing and Hunting subdivision (Position 19, NAICS 11). Agricultural and forestry activities convert sunlight and fertile soil into organic biomass, and rely primarily on renewable resources. Other subdivisions, on the contrary, rely more on non-renewable resources that include metallic and non-metallic minerals and fossil fuels.

- The coefficient of variation, defined as the ratio of standard deviation to mean, for ECEC/money ratios for human resources is an order of magnitude smaller than that for renewable and non-renewable ecological resources and human health impact of emissions. This is not surprising, as human resources are likely to be better internalized in economic prices than ecological resources. For instance, human resources are paid wages commensurate with their skill level, but ecological resources are obtained for free. The ECEC/$ ratios for natural capital consumed via the contribution of human resources is based on economic data that includes number of people employed, their average annual payroll, and the average human consumption of economic goods and services (Ukidwe and Bakshi, 2004a). Relatively small variation in these ratios may be due to the reliance on monetary data for partitioning of inputs between multiple outputs in the economic system, and may simply reflect the increase in consumption of economic products with increasing income along the economic food chain. Furthermore, Government and Special subdivision (NAICS S00100-S00500) has the highest ECEC/$ ratio for human resources. This is so because state, local and federal government enterprises together employ the maximum number of people amongst all industry sectors.

ECEC/$ ratios for non-renewable resources dominate the total for resource extraction and infrastructure subdivisions such as Mining and Utilities (NAICS 21, 22), Petroleum, Coal and Basic Chemicals (NAICS 324, 3251) and Plastic, Rubber and Nonmetallic Mineral Products (NAICS 326, 327). On the contrary, ECEC/$ ratios for human resources dominate the total for advanced manufacturing and service subdivisions. This corroborates the understanding that resource extraction and infrastructure industries rely more on natural capital whereas advanced manufacturing and service industries that represent the modern-age knowledge economy rely more on intellectual capital (Stewart, 1997). Whether growth of intellectual capital can be decoupled from the use of natural capital, and to what extent, and are there limits to this decoupling are all relevant and interesting questions that are beyond the scope of this analysis.

If the contribution of human resources is excluded from total ECEC/money ratios, the order of the 28 subdivisions listed in Table 6.3 does not change drastically. In such case, Government and Special (NAICS S00101-S00500) and Agriculture, Forestry, Fishing and Hunting (NAICS 11) subdivisions show the maximum shift. Government and Special subdivision moves further up the economic food chain, , from position 2 to position 16, because it depends on contribution from human resources the most. On the contrary, Agriculture, Forestry, Fishing and Hunting (NAICS 11) subdivision relies on contribution from human resources the least, and consequently, shows the maximum shift down the economic food chain, from position 19 to position 10.

6.5.3. Analysis of Selected Supply Chains

Analysis of supply chains of individual industry sectors also reveals similar trends. For this analysis, industry sectors were chosen so as to cover manufacturing and service subdivisions of the economy. These industries being away from the economy-ecosystem interface have relatively long supply chains. A linear supply chain was obtained from the complex supply network according to the algorithm discussed in Section 6.5.1.

Figure 6.15 shows the variation in ECEC/money ratios along supply chain stages of 12 typical industry sectors. These ratios are shown for renewable and non-renewable resources, human health impact of emissions, contribution of natural capital via human resources, and their total. Additional details about supply chain components of these sectors, and economic and natural capital flows through them are provided in Appendix F of the Supporting Information. In general, all supply chains exhibit a decreasing trend for the ECEC/money ratios. Graphs for Sectors of Plastic Material and Resin Manufacturing (Graph 6.15(b)), Copper Wire, except mechanical, drawing (Graph 6.15(d)), Machinery Equipment Rental and Leasing (Graph 6.15(h)), Legal Services (Graph 6.15(i)), Waste Management and Remediation Services (Graph 6.15(j)) and Colleges, Universities and Junior Colleges (Graph 6.15(k)) show a monotonic decrease in ECEC/money ratio for total resource consumption, indicating a consistently disproportionate increase in natural capital flows vis-à-vis economic capital flows along the supply chain. In these cases, relationship between natural and economic capital flows can be considered to be convex as hypothesized by Clift and Wright (2000).

For sectors of Pharmaceutical and Medicine Manufacturing (Graph 6.15(c)), Semiconductor and Related Device Manufacturing (Graph 6.15(e)), Wholesale Trade (Graph 6.15(f)) and Air Transportation (Graph 6.15(g)), such monotonic decrease is violated by a relatively small ECEC/money ratio for the sector of real estate. This small ratio indicates that, considering its position in the supply chain, real estate may have an uncharacteristically high economic valuation as compared to other sectors at a similar level in the supply network. Graphs for ECEC/money ratios for *renewable resources* for sectors of Pharmaceutical and Medicine Manufacturing (Graph 6.15(c)), Semiconductor and Related Device Manufacturing (Graph 6.15(e)), Wholesale Trade (Graph 6.15(f)), Air Transportation (Graph 6.15(g)), Machinery Equipment Rental and Leasing (Graph 6.15(h)), Legal Services (Graph 6.15(i)), Colleges, Universities and Junior Colleges (Graph 6.15(k)) and Spectator Sports (Graph 6.15(l)) show a prominent peak for the sector of Power Generation and Supply. This is so because, in comparison to its most significant first order supplier, the sector of Oil and Gas Extraction, the sector of Power Generation and Supply relies more on renewable ecosystem services such as wind, hydropotential and geothermal heat. In contrast, Oil and Gas Extraction relies predominantly on non-renewable fossil fuels and has hardly any contribution from renewable resources. In general, the contribution of non-renewable resources to each sector is much larger than that of renewable resources due to the greater reliance of the modern economy on non-renewable resources and lower thermodynamic efficiency of creating these resources in nature. The ECEC/$ ratios for natural capital consumed via the contribution of human resources is based on economic data that includes number of people employed and their average annual payroll (BLS, 2004). These ratios exhibit relatively little variation along supply chain stages, which may be due to the reliance on monetary data for partitioning of inputs between multiple outputs, and may simply reflect the increase in consumption of economic products along the economic food chain. Furthermore, graphs of non-renewable resources and human resources intersect in most cases, suggesting that basic infrastructure industries such as rely more on non-renewable ecological resources whereas value-added service industries rely more on human resources. These results conform to the results presented in Figure 5.13 for the 28 subdivisions of the US economy.

If contribution of human resources is ignored from this analysis, graphs of total ECEC/$ ratios follow those for non-renewable resources (blue circles in Figure 6.14), and the monotonic decrease in ECEC/$ ratios is much more consistent for all supply chains. Moreover, certain industry sectors, namely Real Estate, Power Generation and Supply and Wholesale Trade, appear in supply chains of a large variety of industry sectors. Consequently, these sectors can be considered as the critical nodes or the *keystone sectors* of the economy (Fisk, 2004). A marginal improvement in natural capital valuation in these sectors would have much greater impact on the economy than a similar improvement in a relatively remote sector of the economy.

6.5.4. Implications to Sustainability

The variation in ratios of natural to economic capitals along supply chains has significant implications for sustainability, corporate reorganization and outsourcing. Since basic infrastructure industries are the underperformers of the economy in relation to the high value-added service and advanced manufacturing industries, corporations have often sold off or outsourced such assets to gain a strategic advantage. Such actions may also allow them to move to trajectories of higher growth by switching to emerging markets and new technologies, and positioning themselves favorably in market cycles of creative-destruction (Hart and Milstein, 1999; Hall and Christensen, 2002). For example, DuPont spun off Conoco, and Monsanto divested its commodity chemicals business with this objective in mind (Hedstrom et al., 2000). The higher ECEC to money ratio for these basic industries means that getting rid of them will also improve commonly used sustainability and eco-efficiency metrics, at least for as long as natural capital remains under valued. The approach used in this dissertation provides a more holistic and multi-dimensional approach, which may be used for full cost accounting and corporate sustainability metrics by considering the broader implications of corporate decisions over multiple scales.

Replacement of less value-added industries by more value-added ones is also evident on a macroeconomic scale, wherein business enterprises in developed countries are increasingly outsourcing extractive and manufacturing-related activities abroad, and are replacing them by service industries that are better at value-addition, have higher growth prospects and returns on investment and lower risk perceptions and environmental costs. For instance, 50% of the manufactured goods bought by American people today are produced abroad, up from 31% in 1987 (Uchitelle, 2003). Even activities such as software writing and customer help desks that are being outsourced seem to have relatively less value-addition in comparison to the activities that are higher up in their supply chains, namely finance, health care services, banking, insurance etc. As industrial activity in developed countries shifts towards the more value-added end of the spectrum, the result is reduced consumption of natural capital per unit of economic capital. The exact opposite situation occurs in developing countries where absorption of the outsourced activity leads to creation of economic capital at the expense of natural capital. This is shown with the help of a hypothetical example in Figure 6.16. In either case, sustainability limit based on *weak sustainability paradigm* would follow the theory of comparative advantages and would coincide with the point where marginal changes in the net sum of economic, natural and social capitals turn negative (Turner, 1993; Bartelmus, 2003; Ekins et al., 2003).

In Figures 6.16(a) and (b) this coincides with the point where marginal benefit and marginal cost curves intersect. At this equilibrium point the Net Capital Base also reaches a maximum. Furthermore, the equilibriums for outsourcees and outsourcers may not coincide as valuation of economic and natural capitals may differ from region to region. Figures 7(a) and 7(b) also show equilibrium points for outsourcees and outsourcers when natural capital is undervalued. In such case the marginal ecological cost curve for outsourcees and the marginal ecological benefit curve for outsourcers shift downward. Consequently, the new equilibrium points represent a higher sustainability limit for absorption of outsourced activity in outsourcees and a lower sustainability limit for outsourcing of industrial activity in outsourcers.

From the view of strong sustainability, outsourcing may reduce sustainability of the outsourcees if their lost natural capital is irreplaceable or falls below a critical limit. This loss of natural capital is likely to be even more than what is indicated by the ratios calculated in our work if environmental regulations are weak or not enforced. Identification and quantification of critical components of natural capital that make a unique contribution to welfare and cannot be substituted by other forms of capitals is an important and active area of research (Ekins et al., 2003, de Groot et al., 2003). Similarly criticality of natural capital also depends on various economic, ecological, political and social aspects that differ in space and time (MacDonald et al., 1993).

Most of the existing methods for quantifying industrial sustainability normalize the environmental burden by monetary value added (Biswas et al., 1998), and do not consider effects on economic and natural capitals at larger scales. This can create an illusion of sustainable development since such sustainability indicators can be improved by simply becoming more profitable or moving up the economic food chain, while actually eroding the net productive capital base they rely on for their future operations. Consideration of marginal changes in economic and natural capitals coupled with identification and quantification of critical natural capital can be a more rigorous way of addressing sustainability issues. The data and approach used in this analysis may be combined with process and life cycle information to enable the development of more holistic and hierarchical sustainability metrics (Graedel and Allenby, 2002, Yi et al., 2004). For the outsourcees to enhance their sustainability, they must use the economic capital available from outsourced activities to quickly move up the economic food chain towards more economically value-added industries, without sending natural capital below its critical limit. Similarly, compensating for any loss of economic capital and jobs for outsourcers also requires them to move further up the economic food chain via new innovations. In the short run, the sustainability of an existing economy may be improved by small changes in the valuation of natural capital in sectors that appear frequently in most supply chains. Such keystone sectors include Real Estate, Wholesale Trade, and Power Generation and Supply. However, from a global perspective, adjustment in market prices to reflect the contribution of natural capital is ultimately necessary for sustainability. This will require combination of the type of analysis presented in this section with economic principles and knowledge about the crucial role of natural capital.

	Geothermal	Coal-fueled thermoelectric
Annual electricity production (J/yr)	3.28×10^{14}	2.44×10^{16}
Total ECEC requirement (sej/yr)	3.85×10^{19}	3.22×10^{21}
EFFICIENCIES		
Exergetic efficiency	1.38×10^{-1}	2.20×10^{-1}
Industrial Cumulative Degree of Perfection (ICDP)	1.09×10^{-1}	1.09×10^{-1}
Ecological Cumulative Degree of Perfection (ECDP) (J/sej)	8.52×10^{-6}	7.59×10^{-6}
METRICS		
Yield Ratio (total ECEC requirement/ECEC inputs from economy)	11.5	1.1
Loading Ratio (ECEC from nonrenewable resources/ECEC from renewable resources)	0.08	52
Impact/value added (ECEC of human health impact/annual electricity production)	7.53×10^{2}	1.15×10^{4}

Table 6.1: Comparison of Geothermal and coal-fueled thermoelectric alternatives (Ukidwe and Bakshi, 2004a)

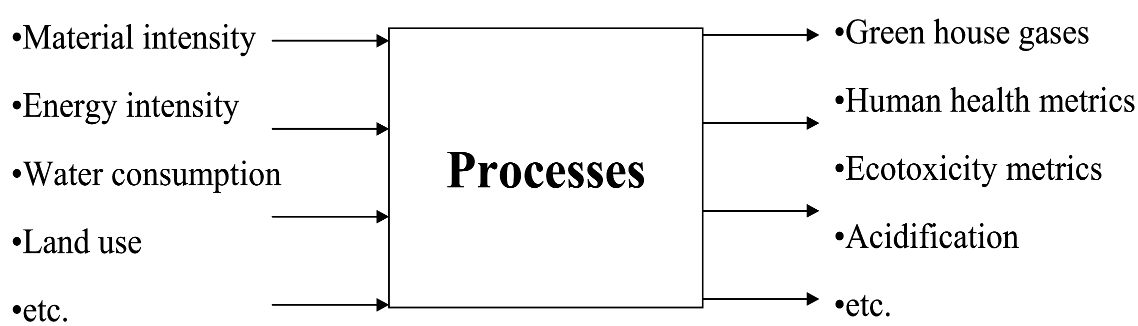


Figure 6.1: Sustainability metrics of AIChE-CWRT (Schwarz et al., 2002).

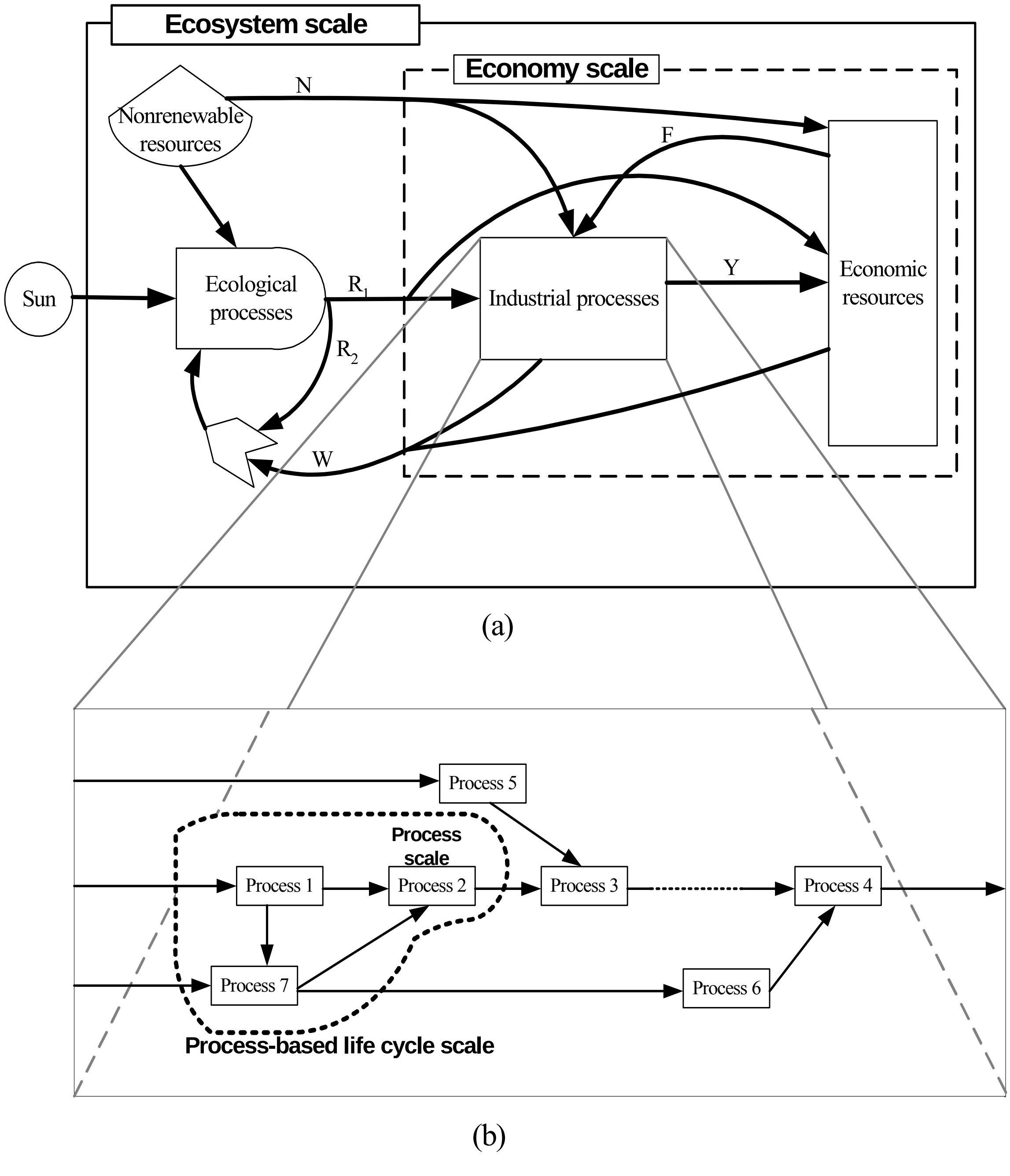


Figure 6.2: Energy flow diagram at multiple spatial scales. (a) Flow diagram for economy and ecosystem scales, (b) Industrial processes considered for process and life cycle scales (Yi et al., 2004).

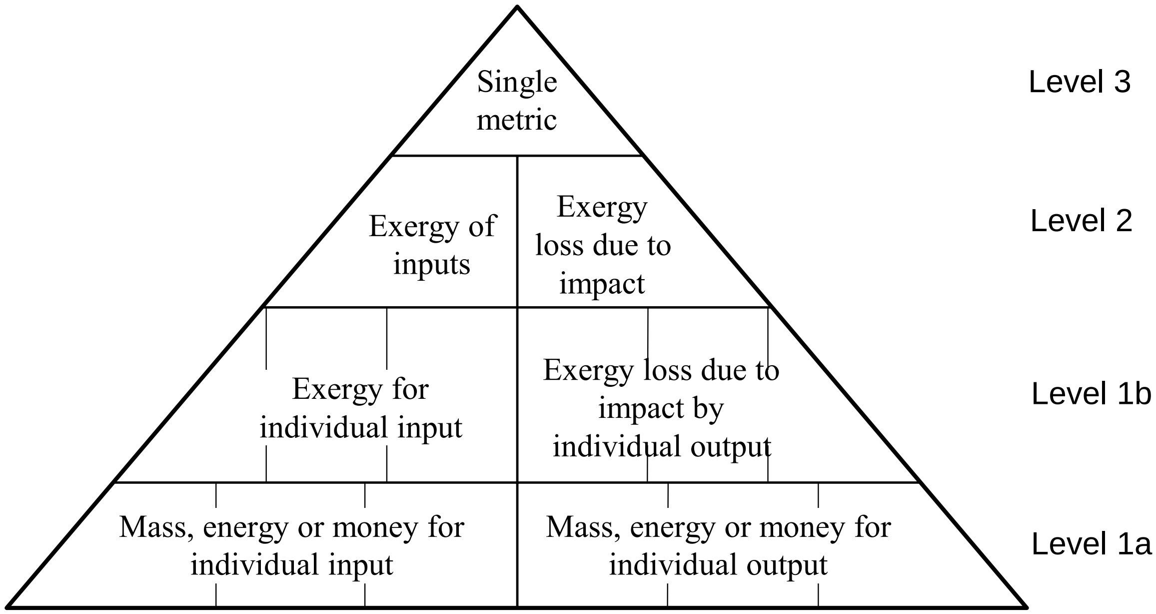
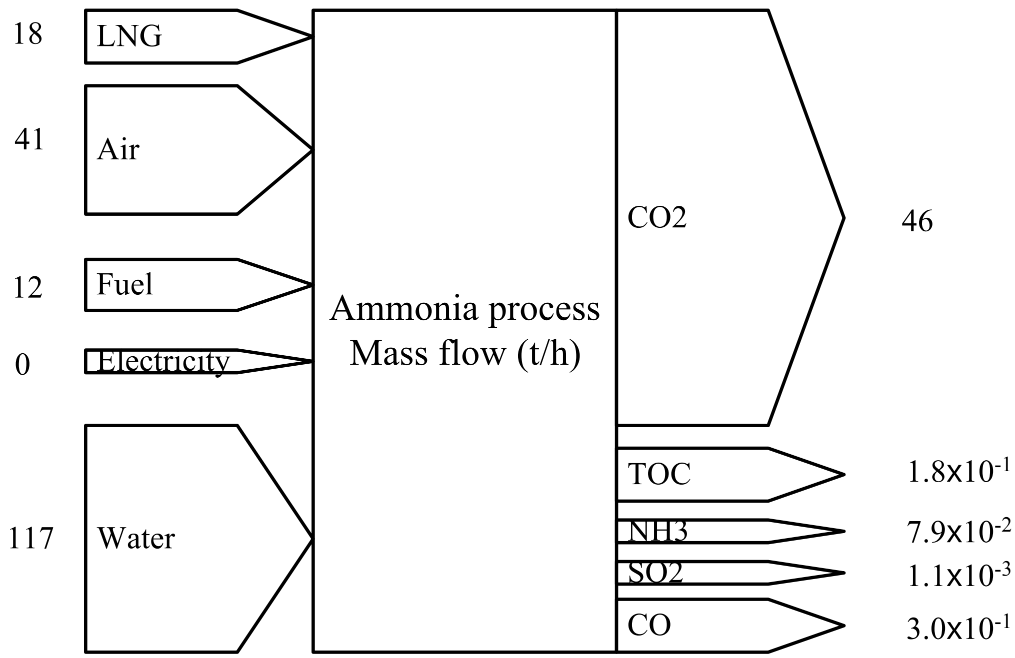
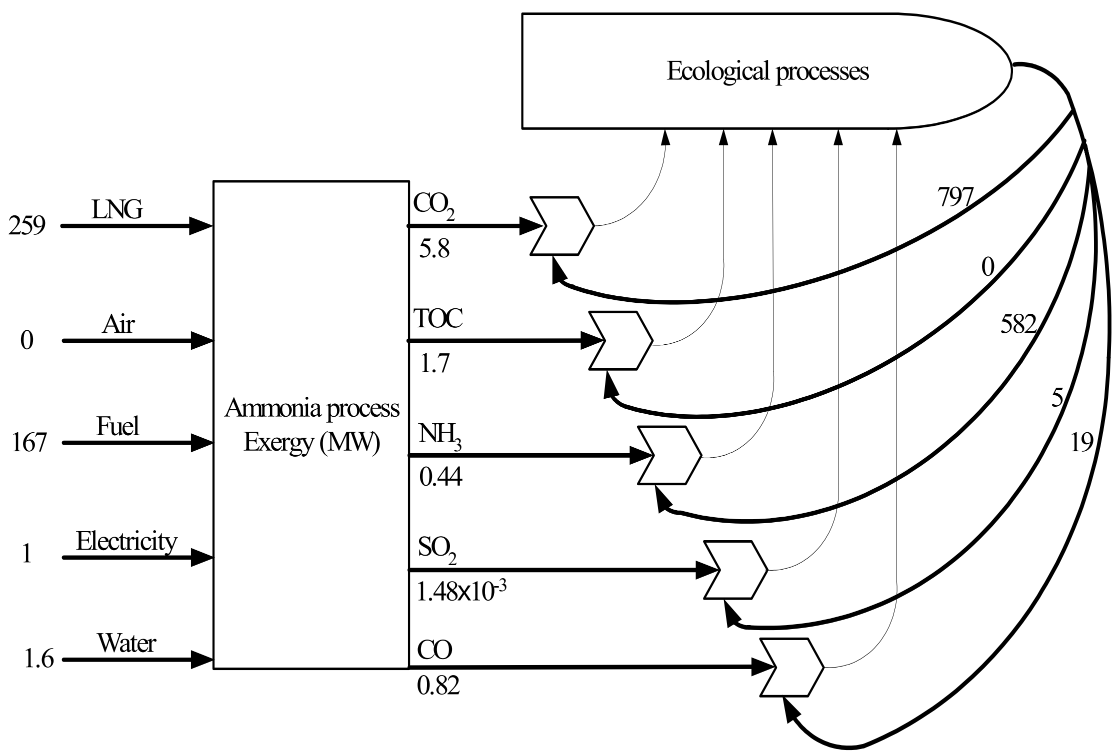


Figure 6.3: Hierarchical structure of sustainability metrics for a selected system (Yi et al., 2004).



(**a**)



(**b**)

Figure 6.4: (a) Mass flow diagram for an ammonia process. The energy value for 12 t/h of fuel is 160 MW. (b) Exergy flow diagram for an ammonia process (Yi et al., 2004).

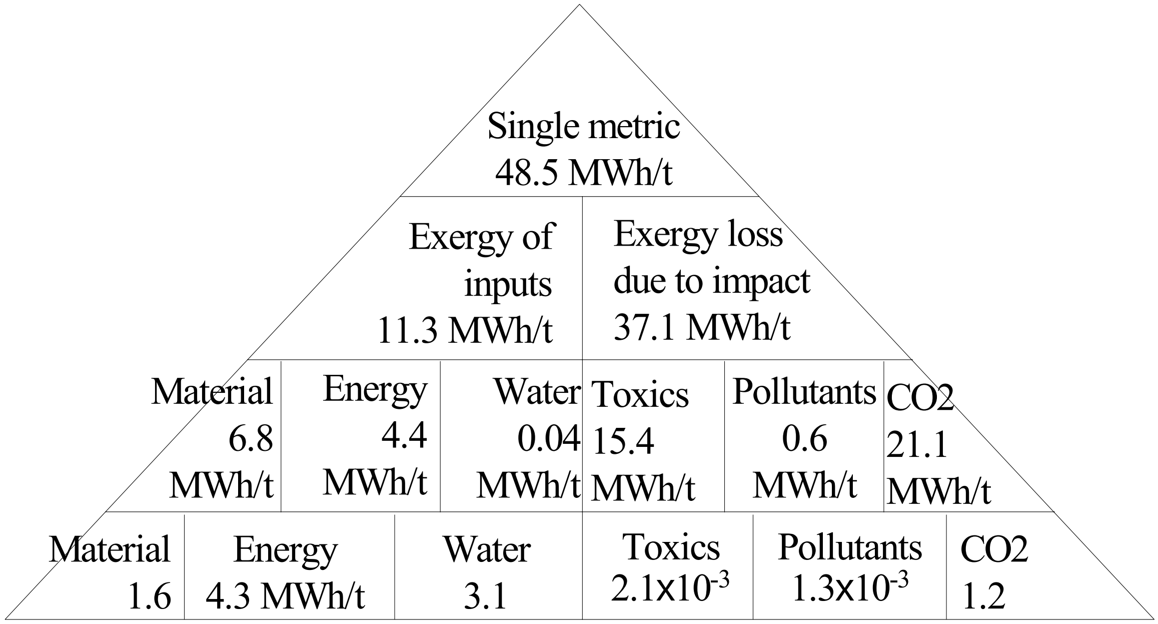


Figure 6.5: Hierarchy of metrics for ammonia process. The values of metrics are normalized by the production rate of ammonia. (Yi et al, 2004).

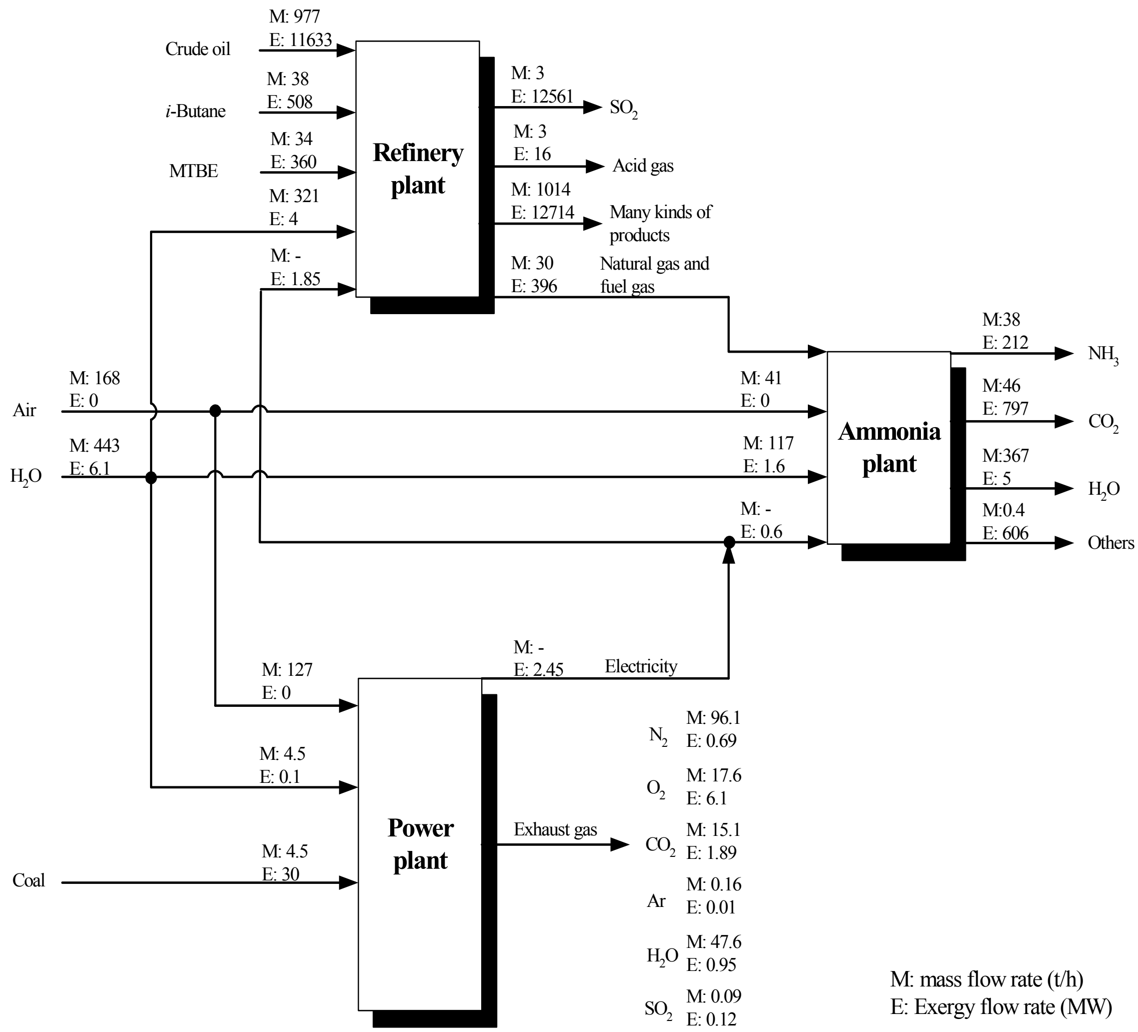


Figure 6.6: Mass and exergy flow for an ammonia plant and selected processes in its supply chain (Yi et al., 2004).

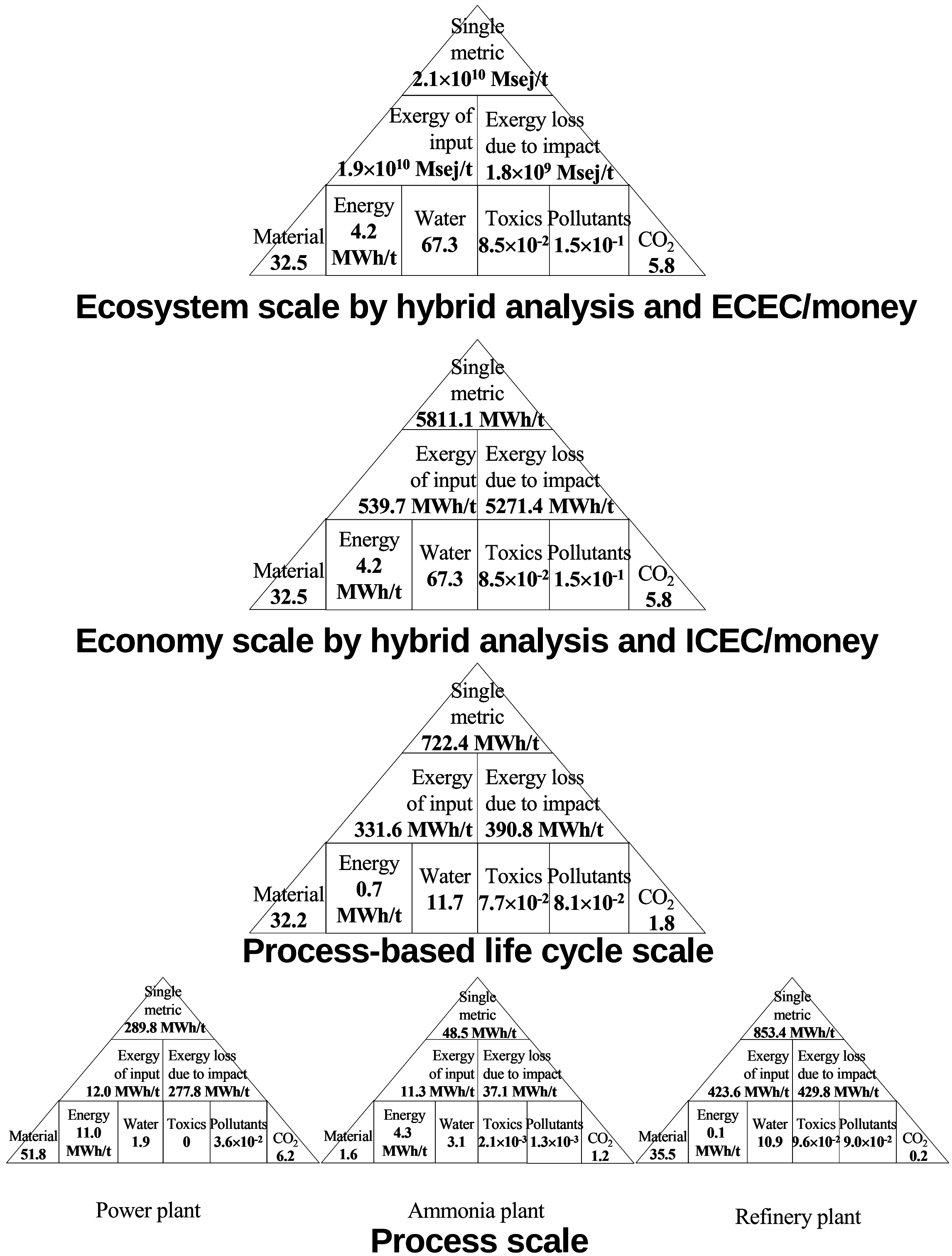


Figure 6.7: Multiscale hierarchy of sustainability metrics for ammonia process (Yi et al., 2004).

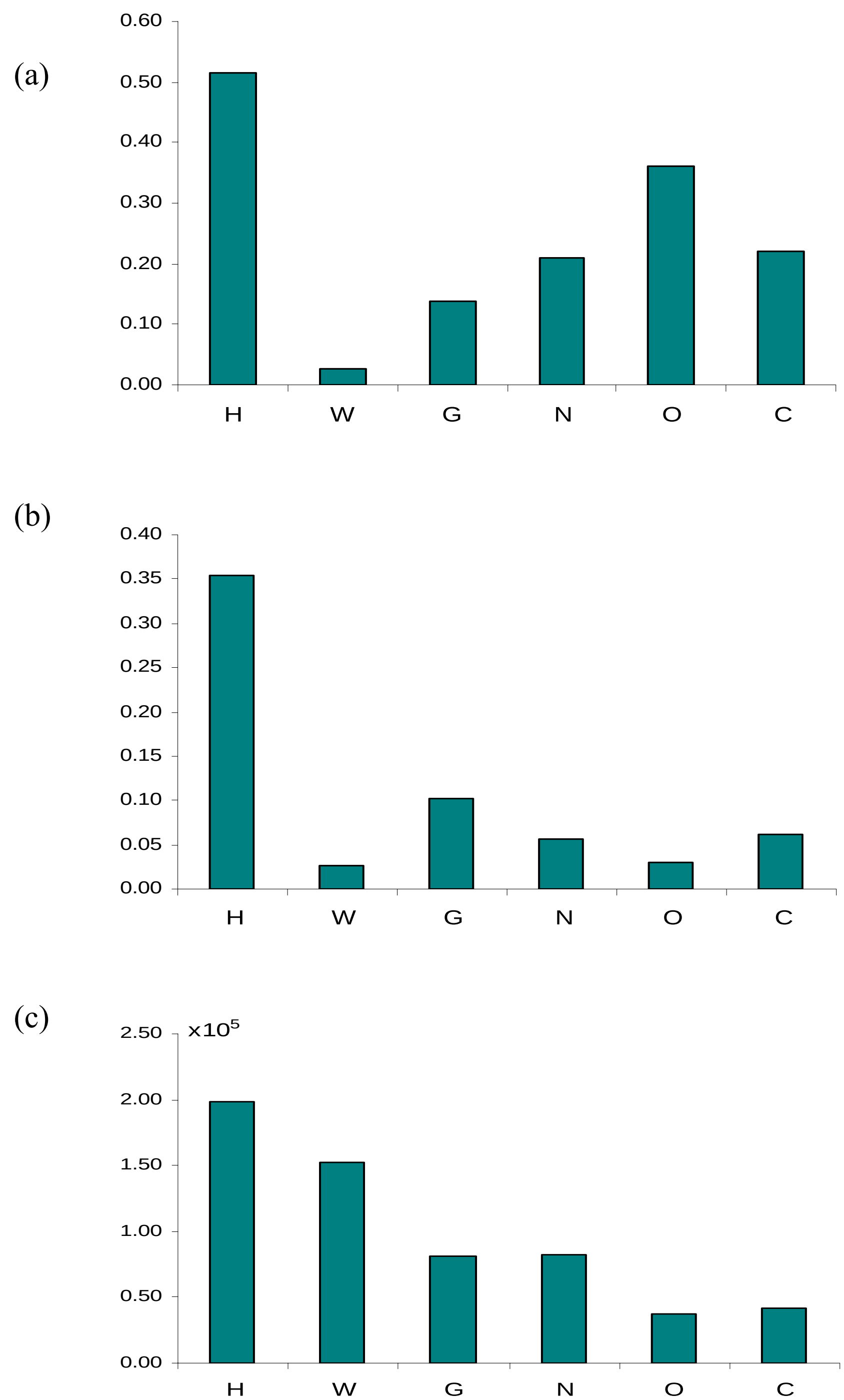


Figure 6.8: Efficiency Values for the Six Systems (a) exergetic efficiency (b) ICDP and (c) ECDP (H: Hydroelectricity, W: Wind electricity, G: Geothermal Electricity N: NG-based Thermoelectric, O: Oil-based Thermoelectric, C: Coal-based Thermoelectric)

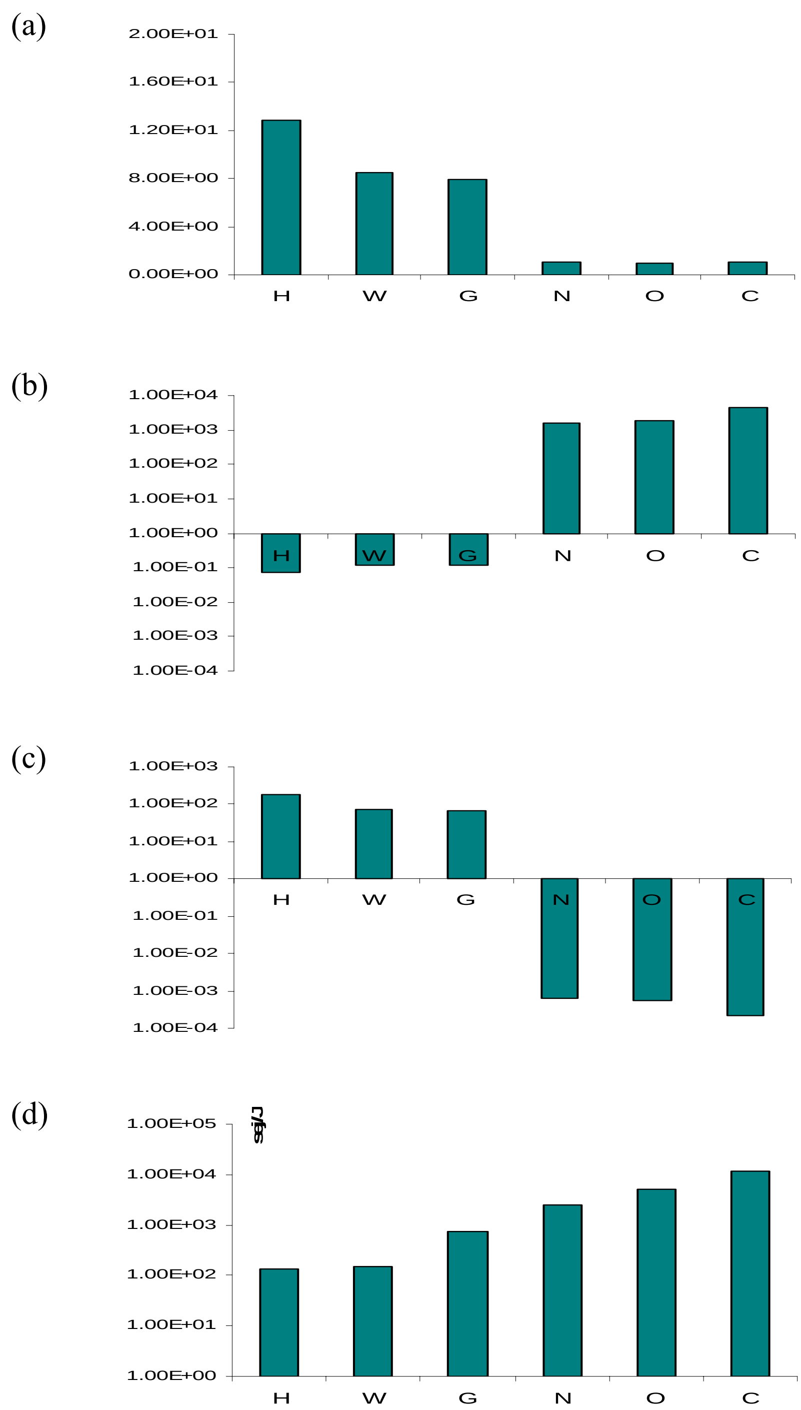


Figure 6.9: Performance Metrics for the Six Systems (a) Yield Ratio (b) Loading Ratio (c) Sustainability Index (Yield-to-loading ratio) and (d) Impact per value added (H: Hydroelectricity, W: Wind electricity, G: Geothermal Electricity N: NG-based Thermoelectric, O: Oil-based Thermoelectric, C: Coal-based Thermoelectric)

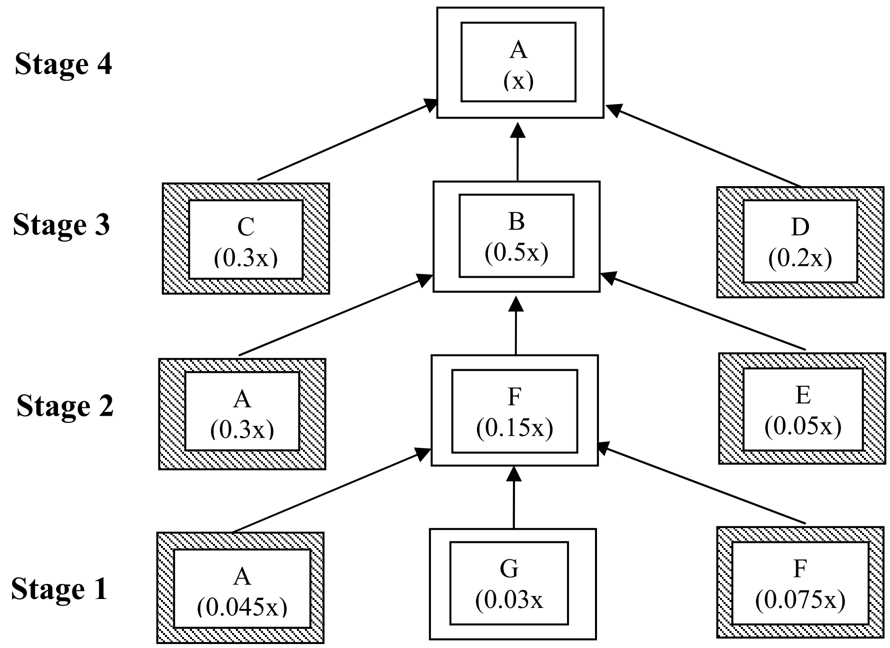


Figure 6.10: Selection of Supply Chain Components from Supply Network

	Economic Activity ($), α	Cumulative Economic Activity, *m* ($)	ECEC/money Ratio (sej/$), *r*	Ecosystem Contribution (sej), $\alpha \times r$	Cumulative Ecosystem Contribution, *e* (sej)
Stage 1	1.00E+01	1.10E+01	2.00E+15	2.00E+16	2.00E+16
Stage 2	1.00E+02	1.11E+02	5.00E+13	5.00E+15	2.50E+16
Stage 3	1.00E+03	1.11E+03	7.00E+12	7.00E+15	3.20E+16
Stage 4	1.00E+04	1.11E+04	8.00E+11	8.00E+15	4.00E+16

Table 6.2: ECEC/money ratios, Cumulative Economic Activity and Cumulative Ecosystem Contribution for supply chain shown in Figure 5.10.

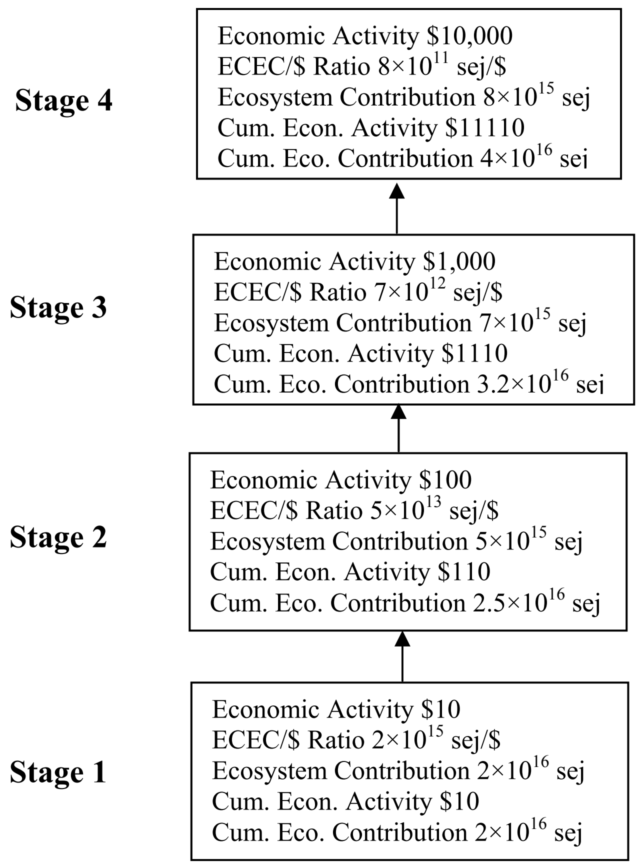
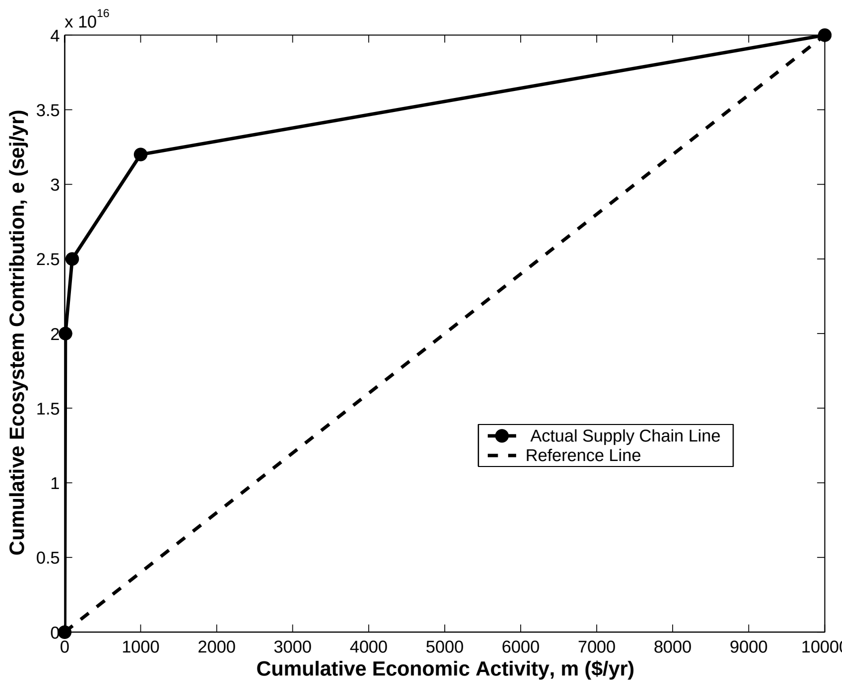
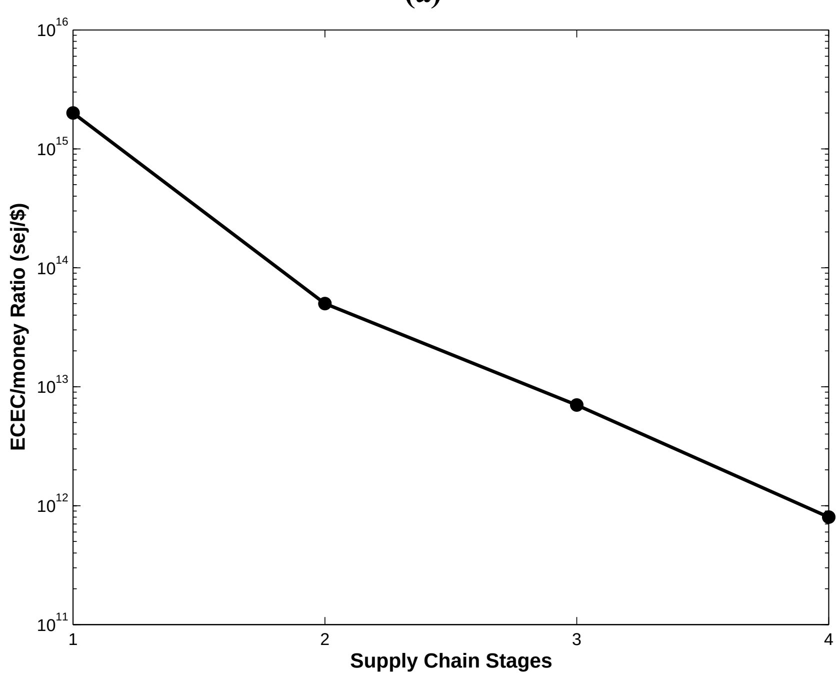


Figure 6.11: Supply Chain for the Illustrative Example presented in Table 6.2.



(a)



(b)

Figure 6.12: (a) Cumulative Ecosystem Contribution, (*e*), and Economic Throughput, (*m*), along supply chain of a hypothetical process (b) Corresponding variation in ECEC/money ratio along various stages of the supply chain

Position In Figure 4	Subdivisions of US Economy (1997 US Industry Benchmark Model Definitions)	Corresponding NAICS Codes
1	Mining and Utilities	21, 22
2	Government and special	S00101-S00500
3	Plastic, Rubber and Nonmetallic Mineral Products	326, 327
4	Petroleum, Coal and Basic Chemical	324, 3251
5	Ferrous and Non-ferrous metal production	331, 3321
6	Construction	23
7	Resin, Rubber, Artificial Fibers and Agricultural and Pharmaceutical Manufacturing	3252, 3253, 3254
8	Wood Paper and Printing	321, 322, 323
9	Cutlery, Handtools, Structural and Metal Containers	3322-3324
10	Ordnance and other metal products	3325-3329
11	Vehicles and other Transportation Equipments	336
12	Furniture, Medical Equipment and Supplies	337, 3391
13	Paint, Coating, Adhesives, Cleaning and Other Chemicals	3255-3259
14	Engines and machinery	333
15	Lighting, electric components, batteries and other	335
16	Misc. Manufacturing	3399
17	Textiles, Apparel and Leather	313, 314, 315, 316
18	Semiconductors, Electronic Equipment, Media Reproduction	3344, 3345, 3346
19	Agriculture, Forestry, Fishing and Hunting	11
20	Food, Beverage and Tobacco	311, 312
21	Management, administrative and waste services	55, 56
22	Computers, Audio, Video and Communication Equipment	3341, 3342, 3343
23	Trade, Transport and Information	42, 45, 45, 48, 49, 51
24	Education and Health Care Services	61,62
25	Arts, Entertainment, Recreation, Hotels and Food Services	71, 72
26	Professional and Technical Services	54
27	Other services except public administration	81
28	Finance, Insurance, Real Estate, Rental and Leasing	52,53

Table 6.3: 28 Major subdivisions of US Economy and their corresponding NAICS codes used for Figure 6.13.

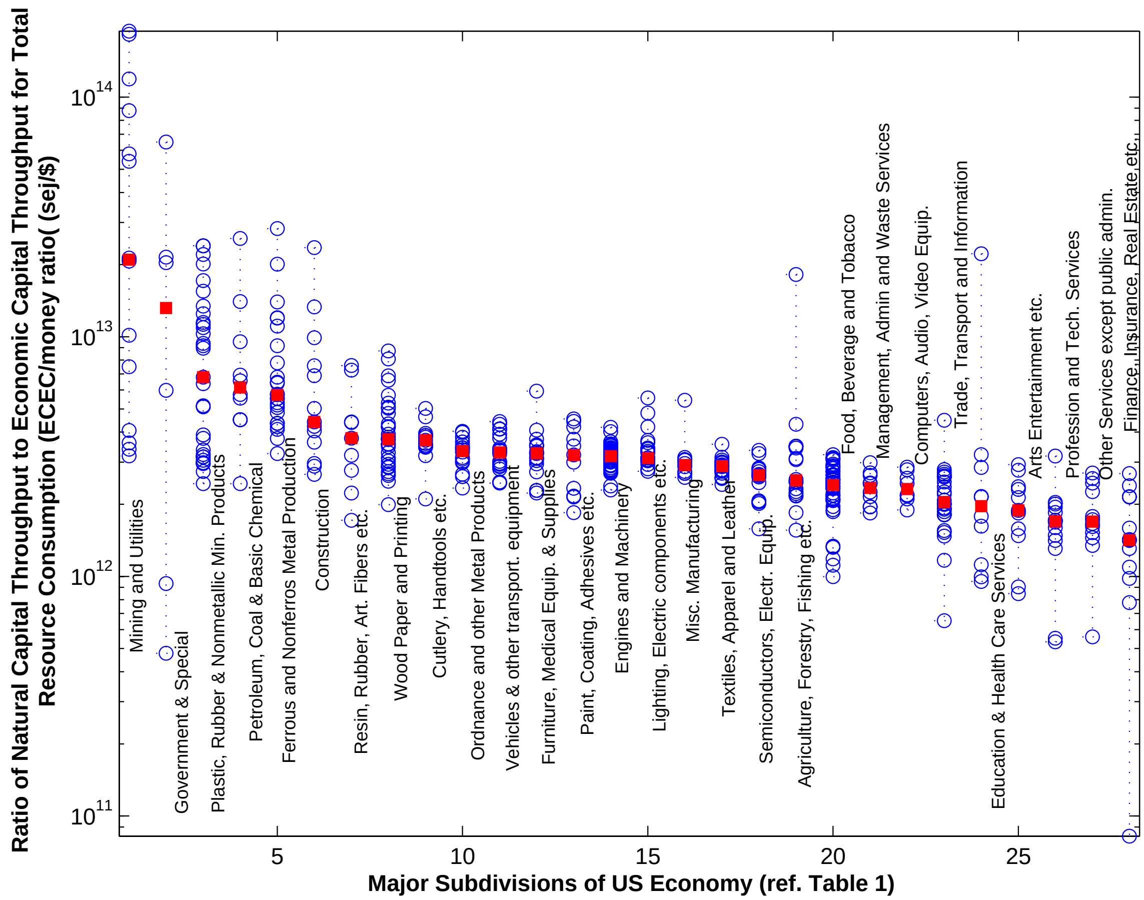


Figure 6.13: Subdivisions of US Economy organized in ascending order of median ECEC/$ ratios. Blue open circles represent ratio for individual sectors in each subdivision. Red filled squares represent median for each subdivision. Details about sectors are in Table 6.3.

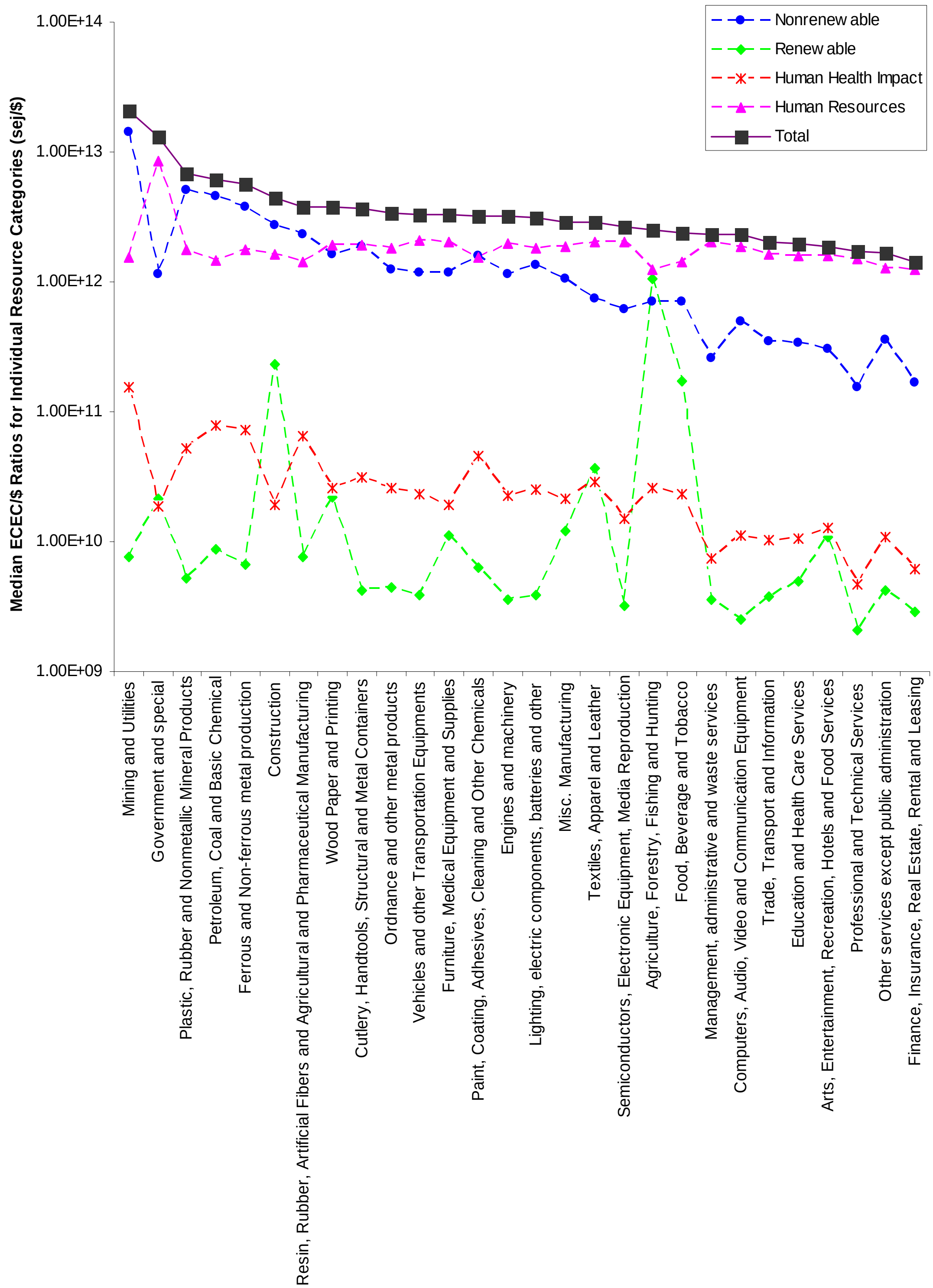


Figure 6.14: ECEC/money ratios for individual resources categories for Industrial Subdivisions listed in Table 6.3.

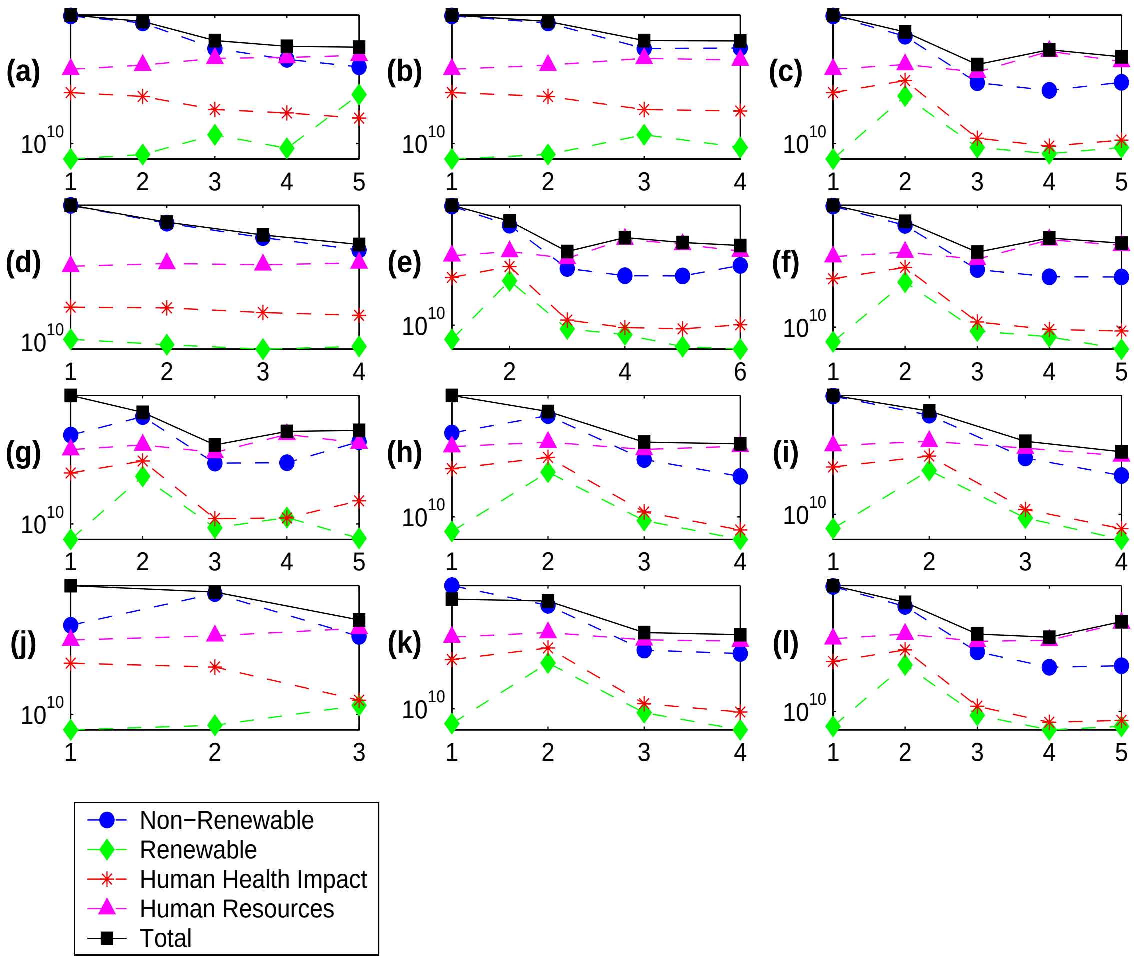
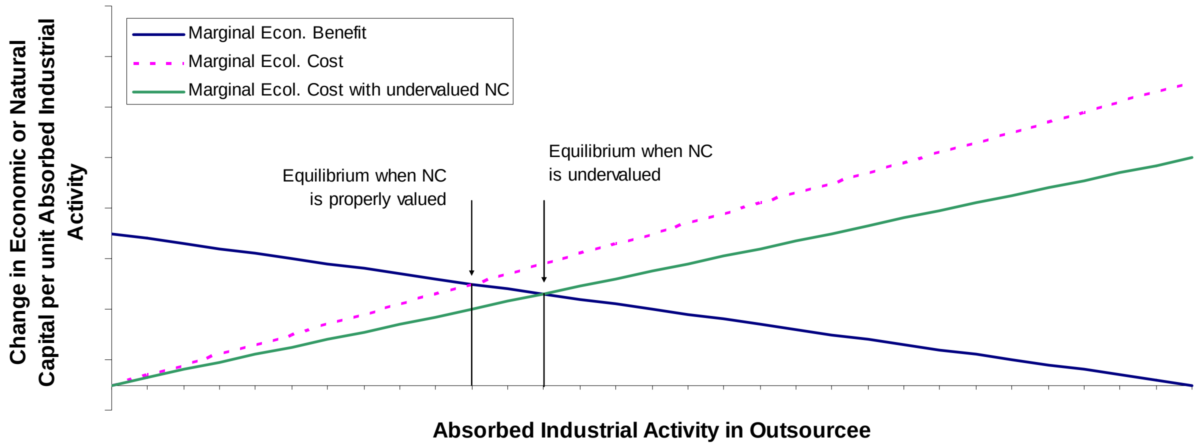
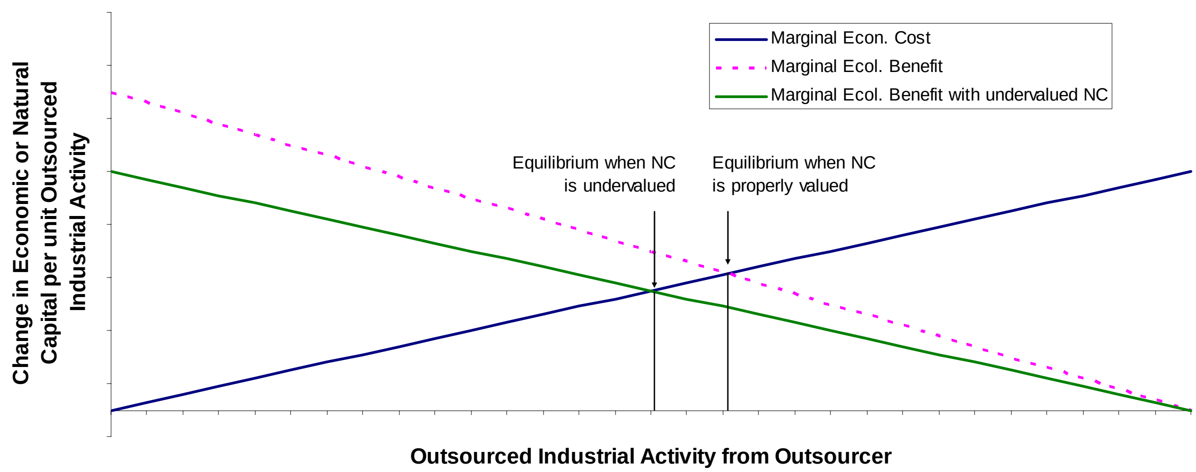


Figure 6.15: Variation in ECEC/money ratio along supply chain stages (*x*-axis: Supply Chain Stages; *y*-axis: ECEC/money ratio (sej/$)); (a) Fiber, yarn & thread mills (NAICS 313100) (b) Plastic Material and Resin Manufacturing (NAICS 325211) (c) Pharmaceutical and Medical Manufacturing (NAICS 325400) (d) Copper wire, except mechanical, drawing (NAICS 331422) (e) Semiconductor and related device manufacturing (NAICS 334413) (f) Wholesale trade (NAICS 420000) (g) Air transportation (NAICS 481000) (h) Machinery and equipment rental and leasing (NAICS 532400) (i) Legal Services (NAICS 541100) (j) Waste Management and remediation services (NAICS 562000) (k) Colleges, universities, and junior colleges (NAICS 611A00) (i) Spectator sports (NAICS 711200). Additional details are in the Supplementary Information.



(a)



(b)

Figure 6.16: (a) Marginal Changes in Economic and Natural Capital as a function of Absorbed Industrial Activity in Outsourcees (b) Marginal Changes in Economic and Natural Capital as a function of Outsourced Industrial Activity in Outsourcers

CHAPTER 7

MULTISCALE BAYESIAN FRAMEWORK FOR LIFE CYCLE INVENTORY ESTIMATION

7.1. Introduction

As businesses continue to realize the tangible and intangible benefits of sustainable development, there is a pressing need for systematic methods for environmentally conscious process engineering. Meeting this need requires expansion of the process engineering boundary beyond the process and its supply chain to consider the entire life cycle of product or process design (Bakshi and Fiksel, 2003). Environmental life cycle assessment (LCA) has become a popular technique for considering the "cradle-to-grave" resource consumption and emissions of a product or process and the corresponding impact on human health. It is a systematic way of collecting and analyzing information about various stages of the life cycle including, resource extraction, manufacturing, use, and final disposal or recycling. Besides assessment, LCA can also play a crucial role in environmentally conscious process design (ECPD) by quantifying the environmental objective (Burgess and Brennan, 2001). Consequently, better methods for obtaining and assessing life cycle inventory (LCI) are essential for improved LCA and ECPD.

Since life cycles are large and complex networks of interconnected systems, it is virtually impossible to capture them accurately. The most common type of LCA focuses on the most important processes, but the use of such an, often arbitrary, boundary can introduce significant errors in the LCA results (Lave et al., 1995). LCA based on economic data considers the entire economic network, but the data are highly aggregated. Detailed engineering knowledge is another source of data. However, this extremely detailed equipment scale data is usually computationally prohibitive for LCA.

Available LCI are typically at different levels of aggregation and represent multiple spatial scales. *Equipment scale* data are at the *finest* scale, and the most accurate. *Life cycle scale* data are at an *intermediate* scale and represent averages of equipment scale data. *Economy scale* data are at the *coarsest* scale, and represent averages over industries in a sector. Recent Hybrid LCA methods attempt to combine the comprehensiveness of EIO-LCA with the greater detail and accuracy of Process LCA (Joshi, 2000). However, such integration of data at widely different scales and with vastly different levels of uncertainty needs to be done carefully, if meaningful results are to be expected. Currently, no systematic framework exists for addressing the challenges of using multiscale data for obtaining the LCI for ECPD.

This dissertation develops such a framework by treating LCA as a *multiscale statistical data fusion problem*. It relies on the latest advances in deterministic and stochastic multiscale methods to develop a systematic framework for obtaining life cycle inventory of products and processes. This approach uses a tree representation to connect data and models at multiple scales. The proposed framework ensures satisfaction of intra-scale and inter-scale models and data consistency, and easily renders itself to both, deterministic and stochastic formulations. The rest of this chapter provides a brief background of LCI methods, and describes the MSLCI methodology.

7.2. Existing Methods for Life Cycle Inventory

7.2.1. Economy Scale

Data at this scale represent the entire economy or interaction between several economic sectors. Economic Input-Output data are compiled for many countries and contain information about monetary exchanges between multiple sectors. National statistics also provide information about resource use and emissions for these sectors. Such data form the basis of Economic Input-Output LCA (EIO-LCA) (Lave et al., 1995). An important advantage of this approach is that it considers the entire national economy and avoids defining an arbitrary boundary around selected processes. However, data representing each sector are significantly aggregated to maintain computational tractability. Thus, EIO-LCA uses a relatively complete network, but at a coarse scale.

7.2.2. Life Cycle Scale

This is the most popular scale for LCA, and focuses on the most important processes in a life cycle. The resulting Process LCA relies on detailed inventory about the inputs and emissions of the selected processes, and extensive databases of life cycle inventory continue to be compiled (Curran, 1996). These LCI usually represent average industry numbers for a selected geographical region and product or manufacturing process. Thus, data at the life cycle scale are more detailed than data at the economy scale, but fail to capture details about an individual process or equipment. Despite its popularity and standardization, the biggest shortcoming of Process LCA is that its results depend on the selected boundary. Consequently, it is not difficult for different users to obtain different LCI results for the same product.

7.2.3. Equipment Scale

Process engineering knowledge and tools enable the development of detailed and relatively accurate models of individual equipment and flowsheets at this fine scale. Public domain studies are also available for most processes and reasonably accurate simulation is possible via software packages such as HYSYS and ASPEN. The benefits of using such information for LCA has been identified and "gate to gate" inventory models for many chemical equipment and processes are being developed (Jiménez-González et al., 2001). Although performing LCA at this fine scale is practically infeasible, the available data could be utilized in LCA studies and for environmentally conscious design and manufacturing. Unfortunately, most LCA studies tend to ignore this trove of information.

7.2.4. Hybrid LCI

Having realized the shortcomings of existing methods, many researchers are combining the best features of LCA at different scales. Most efforts are hybridizing the comprehensiveness of the economy scale with the greater detail of the life cycle scale (Joshi, 2000). Many variations of hybrid LCA methods have been developed. Examples of such methods include the use of Process LCA to compensate for the absence of some sectors such as, the use phase in EIO-LCA; or the use of EIO-LCA at the boundary of Process LCA; or disaggregation of existing economic sectors to include more detailed information. Most hybrid LCA methods usually do not utilize equipment scale information. Moreover, integrated hybrid analysis is completely deterministic in nature, and cannot incorporate stochastic information and subjective and expert knowledge. The multiscale framework proposed in the next section can overcome many of these shortcomings.

7.3. Multiscale Statistical Framework for LCI

Since LCI information is available at multiple scales, a rigorous framework may be developed by treating it as a multiscale statistical data fusion problem (Bakshi and Ukidwe, 2004). The multiple scales may correspond to the finest equipment scale, coarser plant or life cycle scales and the coarsest economy scale. Such a framework is described in this section for deterministic and stochastic multiscale LCI (MSLCI).

7.3.1. Deterministic MSLCI

Deterministic multiscale LCI may be formulated as the following data fusion and inference task.

Given:

(1) Data at multiple scales represented by the set of life cycle state variables, $\mathbf{Y}_m$, m=0,…,L with m = 0 representing the finest scale (equipment), and m=L representing the coarsest scale (economy).

(2) Models relating the data at each scale (intra-scale models), $\Phi_m(\mathbf{Y}_m) = 0$

Determine:

Estimated values of life cycle state variables for system at selected scale, m, based on knowledge at all scales, $\mathbf{Y}_{m,0:L}$.

Ideally, the estimated state variables obtained by combining data at multiple scales should be consistent with physical laws and maximally utilize available data and models at all scales. Since the assessment of individual processes or life cycles at any scale involves analysis of networks, each intra-scale model is represented by network algebra equations of the same general form. Assuming static networks, the total output of the nodes of a network at scale m, $\mathbf{x}_m$, is related to the output leaving the network, $\mathbf{f}_m$, and the interactions between the nodes, $\mathbf{A}_m$ as,

$$\mathbf{x}_m = [\mathbf{I}_m - \mathbf{A}_m]^{-1}\mathbf{f}_m = \mathbf{T}_m\mathbf{f}_m \quad (7.1)$$

The emissions from this network may be determined as,

$$\mathbf{e}_m = \mathbf{R}_m\mathbf{T}_m\mathbf{f}_m \quad (7.2)$$

where $\mathbf{R}_m$ represents the emissions per unit of network output. For a network of n_m nodes, $\mathbf{x}_m$ and $\mathbf{f}_m$ are $n_m \times 1$ vectors, while $\mathbf{A}_m$, $\mathbf{T}_m$, and $\mathbf{R}_m$ are $n_m \times n_m$ matrices. Equation 7.1 is commonly encountered in network algebra, including economic input-output (EIO) analysis described in Chapter 2, and would be available at scales, m = 0, …, L. The set of

LCI state variables, $\mathbf{Y}_m$ used in the problem formulation and in Equation 7.1 represents all the variables in the previous two equations, that is,

$$\mathbf{Y}_m = \{\mathbf{x}_m, \mathbf{f}_m, \mathbf{e}_m, \mathbf{A}_m, \mathbf{R}_m, \mathbf{T}_m\} \tag{7.3}$$

The available data and MSLCI problem may be represented as grids at different resolutions, that are connected by edges, as shown in Figure 7.1. The approach for fusing the available data in a deterministic setting consists of two steps that go up and down the tree.

- **Fine-to-Coarse (FtC):** Identify coarser scale nodes that are relevant to the selected node by propagating information about inputs and outputs from finer to coarser scales.
- **Coarse-to-Fine (CtF):** Refine relevant coarse scale sectors identified in FtC to finer scale by using available finer scale data.

The FtC step is the information-gathering step, while CtF is the computation step. For example, consider the need for life cycle inventory relevant to equipment represented by unit, $S_{3(0)}$, shown lightly shaded in Figure 7.1. The FtC step would identify the coarser light shaded node, $S_{2(1)}$ as the parent, and obtain coarser scale information for all the inputs and outputs of the equipment, $S_{3(0)}$. This life cycle information would get propagated to the coarser scale of the economy to identify the relevant economic sector, shown as $S_{1(2)}$ in Figure 7.1.

$$Y_{1(2),1(2)} = Y_{1(1),1(1)} + Y_{1(1),2(1)} + Y_{2(1),(1)} + Y_{2(1),(1)} \tag{7.4}$$

$$Y_{1(2),(2)} = Y_{1(1),(2)} + Y_{2(1),(2)} \tag{7.5}$$

$$Y_{2(2),(2)} = Y_{2(2)1(1)} + Y_{2(2),(1)} \tag{7.6}$$

In the CtF step, the coarsest scale sector identified in the FtC step, $S_{1(2)}$, is refined by using finer scale data and ensuring satisfaction of the conservation equations 7.4-7.6. These three equalities relate eight variables, indicating the need for additional information about the interaction of the refined sector with other sectors at the coarser scale. Iterative calculations between the coarse and fine scales may be required to reconcile the data and models at all scales and to ensure consistency with physical principles such as those of conservation of mass and energy. These inter-scale models are represented by arrows connecting the scales in Figure 7.1. The grid at scale $m = 1$ is obtained by refining Sector $S_{1(2)}$ to $S_{1(1)}$ and $S_{2(1)}$ which requires satisfaction of the above balances along with the input-output models at each scale. Refining the shaded grids by combining data at multiple scales results in mixing of scales, as indicated by rectangles of different sizes at $m = 0$ and $m = 1$. The result of the MSLCI approach is represented by the grid at $m = 0$, which fuses the data at all scales.

7.3.2. Illustrative Example for deterministic MSLCI

This case study illustrates the application of deterministic MSLCI approach. The case study considers following two scales

- *Coarser Plant Scale* ($m = 1$) comprising two processes, namely a polymer manufacturing process $A_{(1)}$ and an on-site power plant, $B_{(1)}$
- *Finer Equipment Scale* ($m = 0$) comprising two unit operations, namely a reactor, $R_{(0)}$ and a distillation column, $DC_{(0)}$.

Data at individual scales is available in the form transaction matrices, $\mathbf{Y}_{(2)}$ and $\mathbf{Y}_{(1)}$, that could be in physical or monetary units depending on the scales considered. The flow sheet showing interactions between $B_{(1)}$, $R_{(0)}$ and $DC_{(0)}$ is shown in Figure 7.2, whereas Equations 7.7 and 7.8 show transaction matrices for the equipment- and plant-scales respectively.

$$\mathbf{Y}_{(1)} = \begin{array}{ccccc} & B_{(1)} & A_{(1)} & \text{Output} & \text{Total} \\ B_{(1)} & 400 & 400 & 100 & 900 \\ A_{(1)} & 200 & 1000 & 300 & 1500 \\ \text{Input} & 300 & 100 & & \\ \text{Total} & 900 & 1500 & & \end{array} \tag{7.7}$$

$$\mathbf{Y}_{(0)} = \begin{array}{ccccc} & R_{(0)} & DC_{(0)} & \text{Output} & \text{Total} \\ R_{(0)} & 100 & y & 0 & 100+y \\ DC_{(0)} & x & 400 & 500 & 900+x \\ \text{Input} & 300 & 200 & & \\ \text{Total} & 400+x & 600+y & & \end{array} \tag{7.8}$$

As seen from Equation 7.8 certain data points in $\mathbf{Y}_{(0)}$ are missing because of lack of measurement. These data points cannot be estimated by solving balance equations at m = 0 alone as there are more unknowns than equations. To estimate missing data points at m = 0, it is necessary to use inter-scale relations defined by Equations 7.4-7.6. Accordingly, the intra-scale and inter-scale balance constraints can be written as shown in Equations 7.9 and 7.10 respectively.

$$\begin{gathered} \mathbf{Y}_{(0)R_{(0)},R_{(0)}} + \mathbf{Y}_{(0)R_{(0)},DC_{(0)}} + \mathbf{Y}_{(0)R_{(0)},\text{output}} = \mathbf{Y}_{(0)R_{(0)},R_{(0)}} + \mathbf{Y}_{(0)DC_{(0)},R_{(0)}} + \mathbf{Y}_{(0)\text{input},R_{(0)}} \\ 100 + x + 300 = 100 + y \quad \text{(Intrascale)} \end{gathered} \tag{7.9}$$

$$\begin{gathered} \mathbf{Y}_{(0)R_{(0)},R_{(0)}} + \mathbf{Y}_{(0)R_{(0)},DC_{(0)}} + \mathbf{Y}_{(0)DC_{(0)},R_{(0)}} + \mathbf{Y}_{(0)DC_{(0)},DC_{(0)}} = \mathbf{Y}_{(1)A_{(1)},A_{(1)}} \\ 100 + y + x + 400 = 1000 \quad \text{(Interscale)} \end{gathered} \tag{7.10}$$

Solving Equations 7.9 and 7.10 simultaneously gives $x = 100$ and $y = 400$. When matrices $\mathbf{Y}_{(0)}$ and $\mathbf{Y}_{(1)}$ and balance constraints represented by Equation 7.9 and 7.10 are used together a hybrid transaction matrix can be obtained that fuses all available model and data information. Such hybrid transaction matrix for the system under consideration is shown by Equation 7.11.

$$\mathbf{Y}_{\text{hybrid}} = \begin{array}{cccccc} & B_{(1)} & R_{(0)} & DC_{(0)} & \text{Output} & \text{Total} \\ B_{(1)} & 400 & 200 & 200 & 100 & 900 \\ R_{(0)} & 0 & 100 & 400 & 0 & 500 \\ DC_{(0)} & 200 & 100 & 400 & 300 & 1000 \\ \text{Input} & 300 & 100 & 0 & & \\ \text{Total} & 900 & 500 & 1000 & & \end{array} \tag{7.11}$$

$\mathbf{Y}_{\text{hybrid}}$ combines all available information from the two scales and complies with inter- and intra-scale balance constraints. $\mathbf{Y}_{\text{hybrid}}$ represents deterministic MSLCI over Equipment- and Plant- scales. Similar matrices can be compiled at coarser life cycle- and economy-scales as well. These matrices have many potential applications for environmentally conscious process design, and can be easily extended to include stochastic information. Furthermore, hybrid transaction matrices can be used in Thermodynamic Input-Output Analysis proposed in this dissertation to obtain contribution of ecosystems to industrial systems at multiple scales. Following paragraph discusses theoretical aspects of stochastic MSLCI, and illustrates its utility by evaluating truncation errors in embodied CO_2 estimation at different scales.

7.3.3. Stochastic MSLCI

One of the shortcomings of conventional LCA is its inability to evaluate confidence bounds on LCA results. As a result, the practitioner of LCA can get very different results depending on how the LCA problem is set up. This, at the least, undermines the credibility of LCA and prevents its wide-spread use as a sound decision-support tool. An important and attractive feature of the deterministic MSLCI approach described above is that it can readily handle stochastic variables, and utilize the powerful approach of Bayesian hierarchical modeling (Lauritzen, 1996; Wikle, 2003). The stochastic problem formulation treats all variables to be random and all data to be contaminated by noise or errors. Each of the variables used in the deterministic formulation, $\mathbf{Y}_m$ are now considered to represent the noisy versions of the "true" or underlying but unknown values, $\tilde{\mathbf{Y}}_m$, which need to be estimated. Variables, $\tilde{\mathbf{Y}}_m$ are equivalent to the "state variables" in the jargon of stochastic systems, and $\mathbf{Y}_m$ represents the "measured variables". The deterministic input-output models at each scale and those relating different scales may be represented, in general, as the following multiscale stochastic formulation. These models capture all the available inter- and intra-scale information along with various kinds of uncertainty.

$$\tilde{\mathbf{Y}}_m = h_m\left(\tilde{\mathbf{Y}}_{m+1}, \omega_m\right) \tag{7.12}$$

$$\mathbf{Y}_m = g_m\left(\tilde{\mathbf{Y}}_m, \nu_m\right) \tag{7.13}$$

The function, $h_m(.)$ represents the inter-scale model, while $g_m(.)$ represents the intra-scale relationship between the measured and underlying variables and the model at each scale. Thus, Equation 7.12 is the stochastic counterpart of Equations 7.1, and is expected to be linear, while Equation 7.13 is the stochastic counterpart of Equation 7.4-7.6, and may be nonlinear because of the product term. The variables, ω_m and ν_m represent the uncertainty in the data and models, respectively. Equations 7.12 and 7.13 are in the standard form commonly encountered in nonlinear estimation problems (Chen et al., 2004). Due to recent advances in statistics such as Markov Chain Monte Carlo methods and particle filtering, it is becoming possible to find the Bayesian solution to these equations in an efficient manner. The proposed approach for solving the Bayesian MSLCI problem will aim to obtain properties of the posterior distribution which may be written in a scale recursive form via Bayes rule as,

$$P\left(\widetilde{\mathbf{Y}}_0 \mid \mathbf{Y}_{0:L}\right) = \frac{P\left(\mathbf{Y}_0 \mid \widetilde{\mathbf{Y}}_0\right) P\left(\widetilde{\mathbf{Y}}_0 \mid \mathbf{Y}_{1:L}\right)}{P\left(\mathbf{Y}_0 \mid \mathbf{Y}_{1:L}\right)} \tag{7.14}$$

The left-hand side of Equation 7.14 is the posterior probability of the unknown quantities at the finest scale, given information at all scales. Equation 7.14 shows that this posterior probability may be determined from information of the data at scale $m = 0$, represented by the likelihood, $P\left(\mathbf{Y}_0 \mid \widetilde{\mathbf{Y}}_0\right)$, and the information about the unknown quantity available from data and models at other scales, as represented by the prior, $P\left(\widetilde{\mathbf{Y}}_0 \mid \mathbf{Y}_{1:L}\right)$. The posterior represents the distribution of the unknown quantities based on capturing all the data and models at all scales. Equation 7.14 represents recursion from the parent node to the children or the coarse-to-fine (CtF) change of the posterior. A similar equation may be written for the opposite direction or fine-to-coarse (FtC) change. These steps may be combined in different ways depending on the nature of the problem to result in a stochastic multiscale algorithm for life cycle inventory.

If Equations 7.12 and 7.13 are both linear with additive noise and Gaussian distributions, the posterior will also be Gaussian, and the above algorithm will become multiscale Kalman filtering (Chou et al., 1994). However, in general, due to the product terms in Equation 7.1, the state equation is not likely to be linear. In this case, the distributions will be determined via hierarchical methods based on MCMC methods. The multiscale approach described in this section can primarily fuse life cycle inventory information at multiple scales.

7.3.4. Illustrative Example for stochastic MSLCI

Figure 7.3 shows the hypothetical system considered in this analysis. The system comprises of a polymer manufacturer at process scale (m = 0), an organic chemical manufacturer in its supply chain at the life cycle scale (m = 1), and the rest of supply network at the economy scale (m = 2). Data are available about transactions between the polymer manufacturer, the organic chemical manufacturer and the rest of the economy as well as CO_2 emissions from them. The data is in the form of normal distributions that incorporate the underlying variability as well as uncertainty in each of the variables considered. The resulting stochastic transaction matrix and CO_2 emission vector are depicted in Figure 7.4. These data were used to estimate embodied CO_2 content of the output from the polymer manufacturer. The analysis was performed at three levels, a a process-specific analysis focusing only on process-scale information, a semi-hybridized analysis using information at the process- and life cycle- scales, and a fully hybridized analysis using all available information at process-, life cycle- and economy- scales. The results at the three analyses are depicted in Table 7.1. The intrinsic variability in the results is measured in terms of coefficient of variation which is defined as the ratio of standard deviation to the mean of the distribution. Furthermore, truncation error is estimated as the degree of deviation from the embodied CO_2 estimate obtained for the fully hybridized analysis.

The results indicate that reliance on process scale alone introduces a large truncation error. This is so because indirect CO_2 emissions resulting from the polymer process are completely ignored in process scale analysis. The indirect CO_2 emissions occur at various stages in the production chain of polymer manufacturer such as the electricity generation and extraction of coal and petroleum feed stocks. However, the results at the process scale have the lowest coefficient of variation because process scale information is quite specific and accurate. Expansion of the system boundary to include life cycle stages of the polymer manufacturer reduces the truncation error but increases the coefficient of variation. Further expansion of the system boundary to include the entire economic supply network eliminates the truncation error completely but increases coefficient of variation 10 folds. This is so because expansion of system boundary makes the analysis progressively more comprehensive, but susceptible to increasingly aggregate and uncertain information. A 0% truncation error suggests that all the available information up to the economy scale has been utilized fully. If there are CO_2 emissions outside the boundary of the national or regional economy, such as the ones embodied in imports, they will result into a finite non-zero truncation error in the fully hybridized analysis as well.

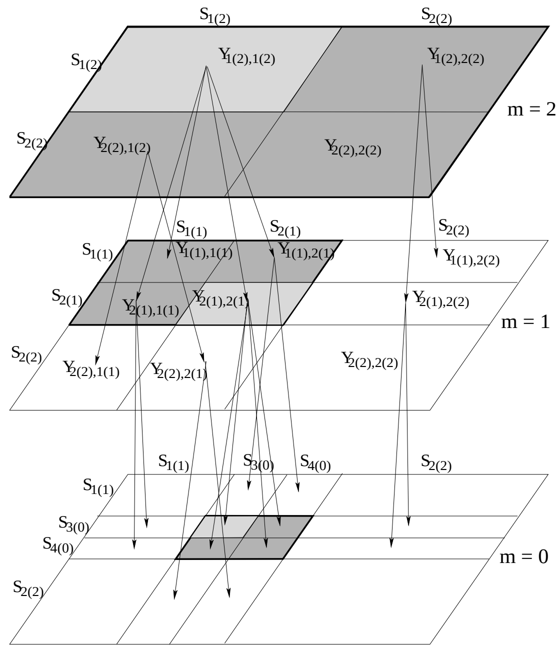


Figure 7.1: Tree representation of MSLCI.

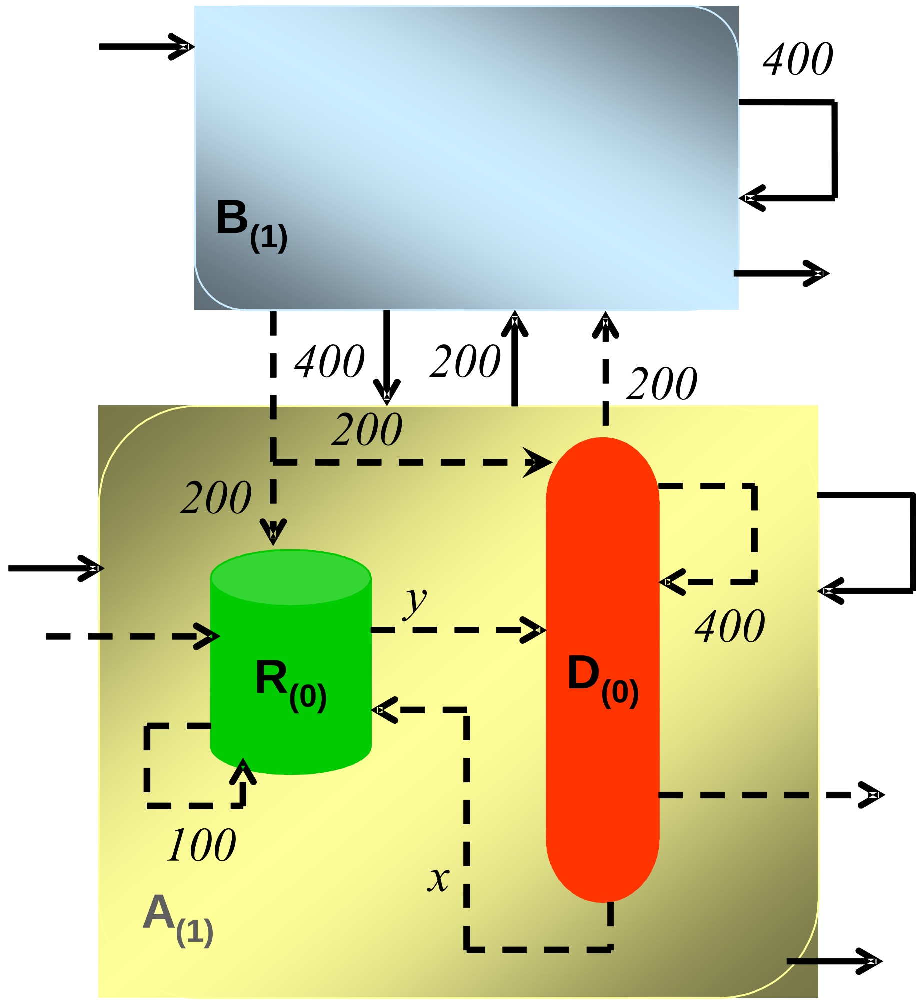


Figure 7.2: Flow diagram at scales $m = 0$ and $m = 1$

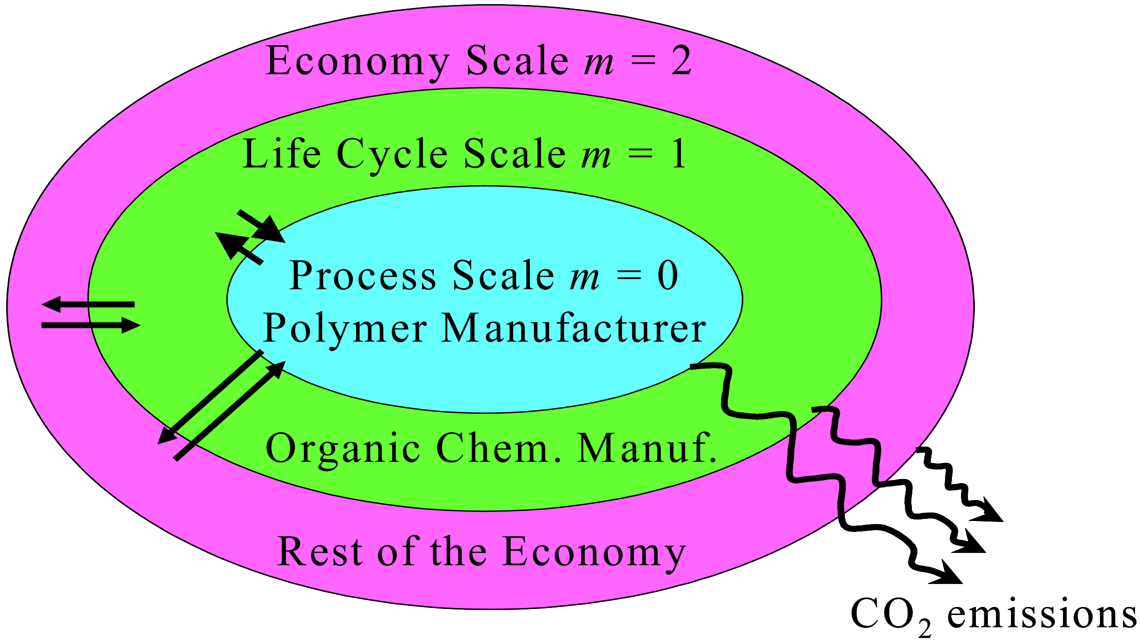


Figure 7.3: Illustrative Example for stochastic MSLCI

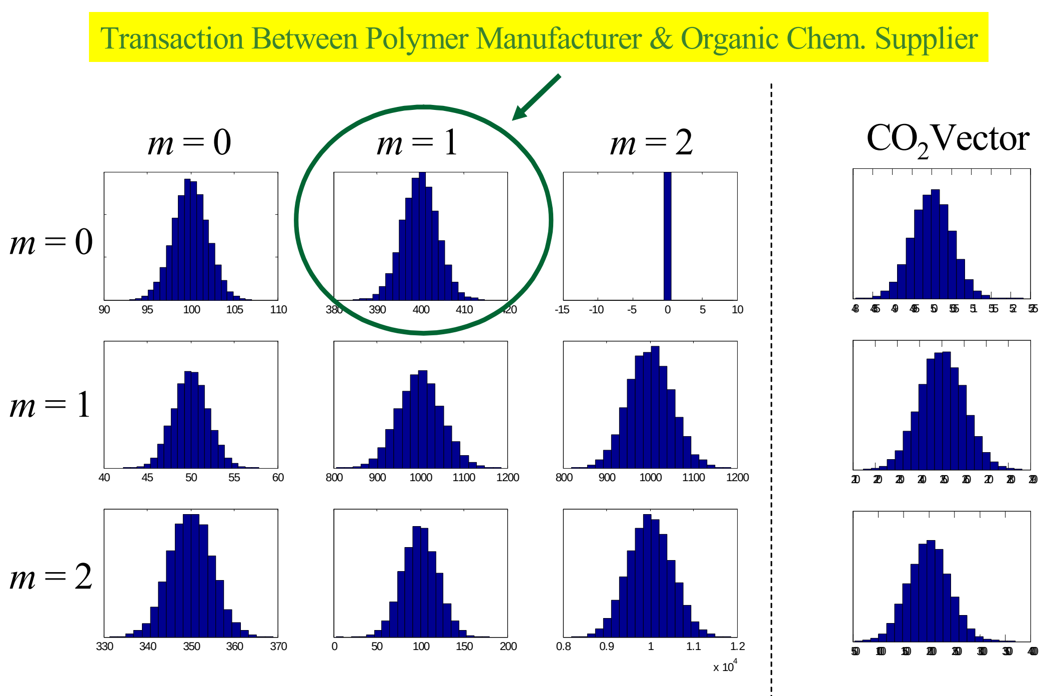


Figure 7.4: Stochastic Transaction Matrix and CO2 emissions vector for the illustrative example of Figure 7.3

	Embodied CO_2 in output from Polymer Manufacturer			
	Mean	Std. Dev.	Coeff. Of Variation	Truncation Error
Process Scale	50	0.5	1%	98%
Process + Life Cycle Scale	81	1.6	2%	96%
Process + Life Cycle + Economy Scale	2044	407	20%	0%*

* other types of errors such as aggregation error, sampling error etc. may be present and can be estimated independently

Table 7.1: Variability and Truncation errors in estimates of embodied CO_2 in the output from polymer manufacturer.

CHAPTER 8

CONCLUSION AND FUTURE WORK

8.1. Conclusion

Ecological resources are imperative to any activity on earth. However, these resources, being mostly outside the realm of conventional economics, are often consumed in an unsustainable fashion. Existing methods for engineering design also concentrate on economic objectives while turning a blind's eye on ecosystem contribution. The result is a business enterprise that is likely to be viable in the short-term but potentially unsustainable in the long-term. This dissertation presents a novel approach for including the contribution of ecosystems into cumulative exergy-based methods, and applies it to study the US macroeconomic system. The new technique, called Thermodynamic Input-Output Analysis, synthesizes available resource consumption and emission data from various public-domain databases and transformity values from systems ecology to determine direct inputs to the economic system. Furthermore, it uses the 91-sector 1992 and 488-sector 1997 US industry-by-industry input-output models to allocate exergy flows in the economic network. Such industry-specific ECEC analysis offers an insight into addressing several policy- and design- related issues at the micro- as well as the macro-scales.

The results obtained in this analysis have several unique features in comparison with the traditional thermodynamic methods for environmental decision-making, some of which are summarized here.

- TIOA considers exergy lost in the ecological stages during the production of ecological resources. Since such exergy losses are higher for non-renewable resources and vice versa, TIOA can successfully acknowledge quality differences between ecological resources. Traditional exergy and ICEC analyses fail in this regard, as they ignore exergy losses in ecosystems. As a result ECEC analysis is a more powerful technique for environmental decision-making as illustrated by the electricity generation case studies in Chapter 6.
- Unlike exergy or emergy analyses for the entire national or global economy, TIOA considers the network structure of the economic system via input-output models. Consequently, TIOA provides industry-specific results that are more disaggregate and accurate than similar, but aggregate metrics for the entire economy. The industry-specific ECEC/money ratios, for instance, can be readily used to replace the single emergy/$ ratio for the entire economy in emergy analysis. ECEC/money ratios also provide an insight into the discrepancy between thermodynamic work required to produce a product or service and the willingness of people to pay for them. Such insight is potentially useful in rationalizing the macro-economic policies-such as through introduction of pro-ecological taxes-to better internalize the contribution of ecosystems.
- TIOA offers a systematic way of combining diverse flows including those of materials, energy, ecological products and services, emissions and their impact on

human and ecosystem health and human resources that are typically measured in disparate units. TIOA does this by expressing all the flows in terms of single thermodynamic unit, namely solar equivalent joules (sej). This facilitates construction of hierarchical thermodynamic metrics of sustainability that are stackable, robust and protective of proprietary information (Yi et al., 2004).

Thermodynamic Input-Output Analysis has some common features with Full Fuel Cycle Analysis (FFCA) and Net Energy Analysis (NEA). FFCA and NEA were initially promoted during the energy crisis of early 1970s. Starting mid-1980s, there has been a renewed interest in these techniques, this time prompted and driven by concerns over environmental emissions rather than by the quantity of the energy supply. However, FFCA has faced technical and philosophical criticisms (Chwalowski, 1996; Herendeen, 1998) that have hindered its wide-spread application. TIOA addresses some these criticisms. For instance, unlike process-based FFCA, TIOA enjoys a consistent system boundary through the use of national input-output models. Secondly, TIOA overcomes the problem of comparing different kinds of energy through the application of exergy analysis. Thirdly, FFCA and NEA ignore energy embodied in labor inputs. From a larger perspective, since energy expenditure is a part of gross national product, labor should be included in FFCA. Otherwise, labor would remain a hidden subsidy to the energy system, and can unfairly represent a labor-intensive system when it is compared to another. TIOA overcomes this shortcoming by considering ECEC content of human resources.

8.2. Future Work

In the future the techniques presented in this dissertation can be made more comprehensive by including more ecosystem products and services. Besides human health, other impact categories such as ecosystem health and land use can also be included. Results presented in this work are based on a purely deterministic analysis. Considering the fact that all data are susceptible to uncertainties of various types, a stochastic analysis needs to be done to determine confidence bounds on the presented results. Different allocation approaches, along with ways to avoid allocation must be tried. Applications to various products and processes are essential to validate the expected benefits of the proposed method. Finally, the analysis presented in this dissertation is not meant to compete with valuation-based techniques, but rather, the prospects of using TIOA to provide a sound biophysical basis to valuation-based methods must be explored.

APPENDIX A

LIST OF STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODES FOR 91-SECTOR 1992 AND NORTH AMERICAN INDUSTRIAL CLASSIFICATION SYSTEM (NAICS) CODES FOR 488-SECTOR 1997 US ECONOMIC MODELS

This appendix lists Industry Sector definitions and their identification codes for 91-sector 1992 and 488-sector 1997 US economic models. Table A.1 lists the industry sectors in 91-sector 1992 model along with their Standard Industrial Classification (SIC) codes. Table A.2 lists industry sectors in 488-sector 1997 US economic model along with their North American Industrial Classification System (NAICS) Codes.

SR	SIC	Sector	SR	SIC	Sector	SR	SIC	Sector
1	1	Livestock and livestock products	32	33+34	Footwear, leather, leather prod.	61	63	Ophthalmic and photographic equipment
2	2	Other agricultural products	33	35	Glass and glass products	62	64	Miscellaneous manufacturing
3	3	Forestry and fishery products	34	36	Stone and clay products	63	65A	Railroads and related services; passenger ground transport.
4	4	Agricultural, forestry, and fishery services	35	37	Primary iron and steel manufacturing	64	65B	Motor freight transportation and warehousing
5	5+6	Metallic ores mining	36	38	Primary nonferrous metals manufacturing	65	65C	Water transportation
6	7	Coal mining	37	39	Metal containers	66	65D	Air transportation
7	8	Crude petroleum and natural gas	38	40	Heating, plumbing, fabricated structural metal products	67	65E	Pipelines, freight forwarders, and related services
8	9+10	Nonmetallic minerals mining	39	41	Screw machine products and stampings	68	66	Communications, except radio and TV
9	11	New construction	40	42	Other fab. metal products	69	67	Radio and TV broadcasting
10	12	Maint. & repair construction	41	43	Engines and turbines	70	68A	Electric services (utilities)
11	13	Ordnance and accessories	42	44+45	Farm, construction, and mining machinery	71	68B	Gas production and distribution (utilities)
12	14	Food and kindred products	43	46	Materials handling machinery	72	68C	Water and sanitary services
13	15	Tobacco products	44	47	Metalworking machinery and equipment	73	69A	Wholesale trade
14	16	Broad and narrow fabrics, yarn and thread mills	45	48	Special industry machinery and equipment	74	69B	Retail trade
15	17	Miscellaneous textile goods and floor coverings	46	49	General industrial machinery and equipment	75	70A	Finance
16	18	Apparel	47	50	Miscellaneous machinery, except electrical	76	70B	Insurance
17	19	Miscellaneous fabricated textile products	48	51	Computer and office equipment	77	71A	Owner-occupied dwellings
18	20+21	Lumber and wood products	49	52	Service industry machinery	78	71B	Real estate and royalties
19	22+23	Furniture and fixtures	50	53	Electrical industrial equipment and apparatus	79	72A	Hotels and lodging places
20	24	Paper and allied products, except containers	51	54	Household appliances	80	72B	Personal and repair services (except auto)
21	25	Paperboard containers and boxes	52	55	Electric lighting and wiring equipment	81	73A	Computer and data processing services
22	26A	Newspapers and periodicals	53	56	Audio, video, and communication equipment	82	73B	Legal, engineering, accounting, and related services
23	26B	Other printing and publishing	54	57	Electronic components and accessories	83	73C	Other business & professional services, except medical
24	27A	Industrial and other chemicals	55	58	Miscellaneous electrical machinery and supplies	84	73D	Advertising
25	27B	Agricultural fertilizers and chemicals	56	59A	Motor vehicles (passenger cars and trucks)	85	74	Eating and drinking places
26	28	Plastics and synthetic materials	57	59B	Truck and bus bodies, trailers, and motor vehicles parts	86	75	Automotive repair and services
27	29A	Drugs	58	60	Aircraft and parts	87	76	Amusements
28	29B	Cleaning and toilet preparations	59	61	Other transportation equipment	88	77A	Health services
29	30	Paints and allied products	60	62	Scientific and controlling instruments	89	77B	Educational & social services, and membership organizations
30	31	Petroleum refining and related products				90	78	Federal Government enterprises
31	32	Rubber and miscellaneous plastics products				91	79	State and local government enterprises

Table A.1: List of industry sectors, Standard Industrial Classification (SIC) codes and Serial Rank (SR) for 91-sector 1992 model

SR	NAICS	Description	SR	NAICS	Description
1	1111A0	Oilseed farming	37	230210	Manufacturing and industrial buildings
2	1111B0	Grain farming	38	230220	Commercial and institutional buildings
3	111200	Vegetable and melon farming	39	230230	Highway, street, bridge, and tunnel construction
4	111335	Tree nut farming	40	230240	Water, sewer, and pipeline construction
5	1113A0	Fruit farming	41	230250	Other new construction
6	111400	Greenhouse and nursery production	42	230310	Maintenance & repair farm & nonfarm res. structures
7	111910	Tobacco farming	43	230320	Maintenance and repair of nonresidential buildings
8	111920	Cotton farming	44	230330	Maint. & repair highways, streets, bridges, & tunnels
9	1119A0	Sugarcane and sugar beet farming	45	230340	Other maintenance and repair construction
10	1119B0	All other crop farming	46	311111	Dog and cat food manufacturing
11	112100	Cattle ranching and farming	47	311119	Other animal food manufacturing
12	112300	Poultry and egg production	48	311211	Flour milling
13	112A00	Animal production, except cattle and poultry and eggs	49	311212	Rice milling
14	113300	Logging	50	311213	Malt manufacturing
15	113A00	Forest nurseries, forest products, and timber tracts	51	311221	Wet corn milling
16	114100	Fishing	52	311222	Soybean processing
17	114200	Hunting and trapping	53	311223	Other oilseed processing
18	115000	Agriculture and forestry support activities	54	311225	Fats and oils refining and blending
19	211000	Oil and gas extraction	55	311230	Breakfast cereal manufacturing
20	212100	Coal mining	56	311310	Sugar manufacturing
21	212210	Iron ore mining	57	311320	Confectionery manuf. cacao beans
22	212230	Copper, nickel, lead, and zinc mining	58	311330	Confectionery manuf. purchased chocolate
23	2122A0	Gold, silver, and other metal ore mining	59	311340	Nonchocolate confectionery manufacturing
24	212310	Stone mining and quarrying	60	311410	Frozen food manufacturing
25	212320	Sand, gravel, clay, and refractory mining	61	311420	Fruit and vegetable canning and drying
26	212390	Other nonmetallic mineral mining	62	311511	Fluid milk manufacturing
27	213111	Drilling oil and gas wells	63	311512	Creamery butter manufacturing
28	213112	Support activities for oil and gas operations	64	311513	Cheese manufacturing
29	21311A	Support activities for other mining	65	311514	Dry, condensed, and evaporated dairy products
30	221100	Power generation and supply	66	311520	Ice cream and frozen dessert manufacturing
31	221200	Natural gas distribution	67	311611	Animal, except poultry, slaughtering
32	221300	Water, sewage and other systems	68	311612	Meat processed from carcasses
33	230110	New residential 1-unit structures, nonfarm	69	311613	Rendering and meat byproduct processing
34	230120	New multifamily housing structures, nonfarm	70	311615	Poultry processing
35	230130	New residential additions and alterations, nonfarm	71	311700	Seafood product preparation and packaging
36	230140	New farm housing units and additions and alterations	72	311813	Frozen cakes and other pastries manufacturing

Continued

Table A.2: List of industry sectors, North American Industrial Classification System (NAICS) Codes and Sector Serial Rank (SR) for 488-sector 1997 model

Table A.2 continued

SR	NAICS	Description
73	31181A	Bread and bakery product, except frozen, manufacturing
74	311821	Cookie and cracker manufacturing
75	311822	Mixes and dough made from purchased flour
76	311823	Dry pasta manufacturing
77	311830	Tortilla manufacturing
78	311911	Roasted nuts and peanut butter manufacturing
79	311919	Other snack food manufacturing
80	311920	Coffee and tea manufacturing
81	311930	Flavoring syrup and concentrate manufacturing
82	311941	Mayonnaise, dressing, and sauce manufacturing
83	311942	Spice and extract manufacturing
84	311990	All other food manufacturing
85	312110	Soft drink and ice manufacturing
86	312120	Breweries
87	312130	Wineries
88	312140	Distilleries
89	312210	Tobacco stemming and redrying
90	312221	Cigarette manufacturing
91	312229	Other tobacco product manufacturing
92	313100	Fiber, yarn, and thread mills
93	313210	Broadwoven fabric mills
94	313220	Narrow fabric mills and schiffli embroidery
95	313230	Nonwoven fabric mills
96	313240	Knit fabric mills
97	313310	Textile and fabric finishing mills
98	313320	Fabric coating mills
99	314110	Carpet and rug mills
100	314120	Curtain and linen mills
101	314910	Textile bag and canvas mills
102	314992	Tire cord and tire fabric mills
103	31499A	Other miscellaneous textile product mills
104	315111	Sheer hosiery mills
105	315119	Other hosiery and sock mills
106	315190	Other apparel knitting mills
107	315200	Cut and sew apparel manufacturing
108	315900	Accessories and other apparel manufacturing
109	316100	Leather and hide tanning and finishing
110	316200	Footwear manufacturing
111	316900	Other leather product manufacturing
112	321113	Sawmills
113	321114	Wood preservation
114	321219	Reconstituted wood product manufacturing
115	32121A	Veneer and plywood manufacturing
116	32121B	Engineered wood member and truss manufacturing
117	321911	Wood windows and door manufacturing
118	321912	Cut stock, resawing lumber, and planing
119	321918	Other millwork, including flooring
120	321920	Wood container and pallet manufacturing
121	321991	Manufactured home, mobile home, manufacturing
122	321992	Prefabricated wood building manufacturing
123	321999	Miscellaneous wood product manufacturing
124	322110	Pulp mills
125	3221A0	Paper and paperboard mills
126	322210	Paperboard container manufacturing
127	322225	Flexible packaging foil manufacturing
128	322226	Surface-coated paperboard manufactuing
129	32222A	Coated and laminated paper and packaging materials
130	32222B	Coated and uncoated paper bag manufacturing
131	322231	Die-cut paper office supplies manufacturing
132	322232	Envelope manufacturing
133	322233	Stationery and related product manufacturing
134	322291	Sanitary paper product manufacturing
135	322299	All other converted paper product manufacturing
136	323116	Manifold business forms printing
137	323117	Books printing
138	323118	Blankbook and looseleaf binder manufacturing
139	32311A	Commercial printing
140	323121	Tradebinding and related work
141	323122	Prepress services
142	324110	Petroleum refineries
143	324121	Asphalt paving mixture and block manufacturing
144	324122	Asphalt shingle and coating materials manufacturing

Continued

Table A.2 continued

SR	NAICS	Description	SR	NAICS	Description
145	324191	Petroleum lubricating oil and grease manufacturing	181	326290	Other rubber product manufacturing
146	324199	All other petroleum and coal products manufacturing	182	327111	Vitreous china plumbing fixture manufacturing
147	325110	Petrochemical manufacturing	183	327112	Vitreous china and earthenware articles manufacturing
148	325120	Industrial gas manufacturing	184	327113	Porcelain electrical supply manufacturing
149	325130	Synthetic dye and pigment manufacturing	185	327121	Brick and structural clay tile manufacturing
150	325180	Other basic inorganic chemical manufacturing	186	327122	Ceramic wall and floor tile manufacturing
151	325190	Other basic organic chemical manufacturing	187	327125	Nonclay refractory manufacturing
152	325211	Plastics material and resin manufacturing	188	32712A	Clay refractory and other structural clay products
153	325212	Synthetic rubber manufacturing	189	327213	Glass container manufacturing
154	325221	Cellulosic organic fiber manufacturing	190	32721A	Glass and glass products, except glass containers
155	325222	Noncellulosic organic fiber manufacturing	191	327310	Cement manufacturing
156	325311	Nitrogenous fertilizer manufacturing	192	327320	Ready-mix concrete manufacturing
157	325312	Phosphatic fertilizer manufacturing	193	327331	Concrete block and brick manufacturing
158	325314	Fertilizer, mixing only, manufacturing	194	327332	Concrete pipe manufacturing
159	325320	Pesticide and other agricultural chemical manufacturing	195	327390	Other concrete product manufacturing
160	325400	Pharmaceutical and medicine manufacturing	196	327410	Lime manufacturing
161	325510	Paint and coating manufacturing	197	327420	Gypsum product manufacturing
162	325520	Adhesive manufacturing	198	327910	Abrasive product manufacturing
163	325611	Soap and other detergent manufacturing	199	327991	Cut stone and stone product manufacturing
164	325612	Polish and other sanitation good manufacturing	200	327992	Ground or treated minerals and earths manufacturing
165	325613	Surface active agent manufacturing	201	327993	Mineral wool manufacturing
166	325620	Toilet preparation manufacturing	202	327999	Miscellaneous nonmetallic mineral products
167	325910	Printing ink manufacturing	203	331111	Iron and steel mills
168	325920	Explosives manufacturing	204	331112	Ferroalloy and related product manufacturing
169	325991	Custom compounding of purchased resins	205	331210	Iron, steel pipe and tube from purchased steel
170	325992	Photographic film and chemical manufacturing	206	331221	Rolled steel shape manufacturing
171	325998	Other miscellaneous chemical product manufacturing	207	331222	Steel wire drawing
172	326110	Plastics packaging materials, film and sheet	208	331311	Alumina refining
173	326120	Plastics pipe, fittings, and profile shapes	209	331312	Primary aluminum production
174	326130	Laminated plastics plate, sheet, and shapes	210	331314	Secondary smelting and alloying of aluminum
175	326160	Plastics bottle manufacturing	211	331315	Aluminum sheet, plate, and foil manufacturing
176	326192	Resilient floor covering manufacturing	212	331316	Aluminum extruded product manufacturing
177	32619A	Plastics plumbing fixtures and all other plastics products	213	331319	Other aluminum rolling and drawing
178	3261A0	Foam product manufacturing	214	331411	Primary smelting and refining of copper
179	326210	Tire manufacturing	215	331419	Primary nonferrous metal, except copper and aluminum
180	326220	Rubber and plastics hose and belting manufacturing	216	331421	Copper rolling, drawing, and extruding

Continued

Table A.2 continued

SR	NAICS	Description	SR	NAICS	Description
217	331422	Copper wire, except mechanical, drawing	253	332997	Industrial pattern manufacturing
218	331423	Secondary processing of copper	254	332998	Enameled iron and metal sanitary ware manufacturing
219	331491	Nonferrous metal, except copper and aluminum, shaping	255	332999	Miscellaneous fabricated metal product manufacturing
220	331492	Secondary processing of other nonferrous	256	33299A	Ammunition manufacturing
221	331510	Ferrous metal foundaries	257	333111	Farm machinery and equipment manufacturing
222	33152A	Aluminum foundries	258	333112	Lawn and garden equipment manufacturing
223	33152B	Nonferrous foundries, except aluminum	259	333120	Construction machinery manufacturing
224	332111	Iron and steel forging	260	333131	Mining machinery and equipment manufacturing
225	332112	Nonferrous forging	261	333132	Oil and gas field machinery and equipment
226	332114	Custom roll forming	262	333210	Sawmill and woodworking machinery
227	33211A	All other forging and stamping	263	333220	Plastics and rubber industry machinery
228	332211	Cutlery and flatware, except precious, manufacturing	264	333291	Paper industry machinery manufacturing
229	332212	Hand and edge tool manufacturing	265	333292	Textile machinery manufacturing
230	332213	Saw blade and handsaw manufacturing	266	333293	Printing machinery and equipment manufacturing
231	332214	Kitchen utensil, pot, and pan manufacturing	267	333294	Food product machinery manufacturing
232	332311	Prefabricated metal buildings and components	268	333295	Semiconductor machinery manufacturing
233	332312	Fabricated structural metal manufacturing	269	333298	All other industrial machinery manufacturing
234	332313	Plate work manufacturing	270	333313	Office machinery manufacturing
235	332321	Metal window and door manufacturing	271	333314	Optical instrument and lens manufacturing
236	332322	Sheet metal work manufacturing	272	333315	Photographic and photocopying equipment manufacturing
237	332323	Ornamental and architectural metal work manufacturing	273	333319	Other commercial and service industry machinery manufacturing
238	332410	Power boiler and heat exchanger manufacturing	274	33331A	Automatic vending, commercial laundry & drycleaning machinery
239	332420	Metal tank, heavy gauge, manufacturing	275	333411	Air purification equipment manufacturing
240	332430	Metal can, box, and other container manufacturing	276	333412	Industrial and commercial fan and blower manufacturing
241	332500	Hardware manufacturing	277	333414	Heating equipment, except warm air furnaces
242	332600	Spring and wire product manufacturing	278	333415	AC, refrigeration, and forced air heating
243	332710	Machine shops	279	333511	Industrial mold manufacturing
244	332720	Turned product and screw, nut, and bolt manufacturing	280	333512	Metal cutting machine tool manufacturing
245	332811	Metal heat treating	281	333513	Metal forming machine tool manufacturing
246	332812	Metal coating and nonprecious engraving	282	333514	Special tool, die, jig, and fixture manufacturing
247	332813	Electroplating, anodizing, and coloring metal	283	333515	Cutting tool and machine tool accessory manufacturing
248	332910	Metal valve manufacturing	284	33351A	Rolling mill and other metalworking machinery
249	332991	Ball and roller bearing manufacturing	285	333611	Turbine and turbine generator set units manufacturing
250	332994	Small arms manufacturing	286	333618	Other engine equipment manufacturing
251	332995	Other ordnance and accessories manufacturing	287	33361A	Speed changers and mechanical power transmission equipment
252	332996	Fabricated pipe and pipe fitting manufacturing	288	333911	Pump and pumping equipment manufacturing

Continued

Table A.2 continued

SR	NAICS	Description	SR	NAICS	Description
289	333912	Air and gas compressor manufacturing	325	335110	Electric lamp bulb and part manufacturing
290	333913	Measuring and dispensing pump manufacturing	326	335120	Lighting fixture manufacturing
291	333921	Elevator and moving stairway manufacturing	327	335211	Electric housewares and household fan manufacturing
292	333922	Conveyor and conveying equipment manufacturing	328	335212	Household vacuum cleaner manufacturing
293	333923	Overhead cranes, hoists, and monorail systems	329	335221	Household cooking appliance manufacturing
294	333924	Industrial truck, trailer, and stacker manufacturing	330	335222	Household refrigerator and home freezer manufacturing
295	333991	Power-driven handtool manufacturing	331	335224	Household laundry equipment manufacturing
296	333992	Welding and soldering equipment manufacturing	332	335228	Other major household appliance manufacturing
297	333993	Packaging machinery manufacturing	333	335311	Electric power and specialty transformer manufacturing
298	333994	Industrial process furnace and oven manufacturing	334	335312	Motor and generator manufacturing
299	333995	Fluid power cylinder and actuator manufacturing	335	335313	Switchgear and switchboard apparatus manufacturing
300	333996	Fluid power pump and motor manufacturing	336	335314	Relay and industrial control manufacturing
301	33399A	Scales, balances, and miscellaneous general purpose machinery	337	335911	Storage battery manufacturing
302	334111	Electronic computer manufacturing	338	335912	Primary battery manufacturing
303	334112	Computer storage device manufacturing	339	335921	Fiber optic cable manufacturing
304	334113	Computer terminal manufacturing	340	335929	Other communication and energy wire manufacturing
305	334119	Other computer peripheral equipment manufacturing	341	335930	Wiring device manufacturing
306	334210	Telephone apparatus manufacturing	342	335991	Carbon and graphite product manufacturing
307	334220	Broadcast and wireless communications equipment	343	335999	Miscellaneous electrical equipment manufacturing
308	334290	Other communications equipment manufacturing	344	336110	Automobile and light truck manufacturing
309	334300	Audio and video equipment manufacturing	345	336120	Heavy duty truck manufacturing
310	334411	Electron tube manufacturing	346	336211	Motor vehicle body manufacturing
311	334413	Semiconductors and related device manufacturing	347	336212	Truck trailer manufacturing
312	33441A	All other electronic component manufacturing	348	336213	Motor home manufacturing
313	334510	Electromedical apparatus manufacturing	349	336214	Travel trailer and camper manufacturing
314	334511	Search, detection, and navigation instruments	350	336300	Motor vehicle parts manufacturing
315	334512	Automatic environmental control manufacturing	351	336411	Aircraft manufacturing
316	334513	Industrial process variable instruments	352	336412	Aircraft engine and engine parts manufacturing
317	334514	Totalizing fluid meters and counting devices	353	336413	Other aircraft parts and equipment
318	334515	Electricity and signal testing instruments	354	336414	Guided missile and space vehicle manufacturing
319	334516	Analytical laboratory instrument manufacturing	355	33641A	Propulsion units and parts for space vehicles and guided missiles
320	334517	Irradiation apparatus manufacturing	356	336500	Railroad rolling stock manufacturing
321	33451A	Watch, clock & other measuring and controlling device manufacturing	357	336611	Ship building and repairing
322	334611	Software reproducing	358	336612	Boat building
323	334612	Audio and video media reproduction	359	336991	Motorcycle, bicycle, and parts manufacturing
324	334613	Magnetic and optical recording media manufacturing	360	336992	Military armored vehicles and tank parts manufacturing

Continued

Table A.2 continued

SR	NAICS	Description	SR	NAICS	Description
361	336999	All other transportation equipment manufacturing	397	48A000	Scenic & sightseeing transport & support activities for transport
362	337110	Wood kitchen cabinet and countertop manufacturing	398	491000	Postal service
363	337121	Upholstered household furniture manufacturing	399	492000	Couriers and messengers
364	337122	Nonupholstered wood household furniture manufacturing	400	493000	Warehousing and storage
365	337124	Metal household furniture manufacturing	401	4A0000	Retail trade
366	337127	Institutional furniture manufacturing	402	511110	Newpaper publishers
367	33712A	Other household and institutional furniture	403	511120	Periodical publishers
368	337211	Wood office furniture manufacturing	404	511130	Book publishers
369	337212	Custom architectural woodwork and millwork	405	5111A0	Database, directory, and other publishers
370	337214	Office furniture, except wood, manufacturing	406	511200	Software publishers
371	337215	Showcases, partitions, shelving, and lockers	407	512100	Motion picture and video industries
372	337910	Mattress manufacturing	408	512200	Sound recording industries
373	337920	Blind and shade manufacturing	409	513100	Radio and television broadcasting
374	339111	Laboratory apparatus and furniture manufacturing	410	513200	Cable networks and program distribution
375	339112	Surgical and medical instrument manufacturing	411	513300	Telecommunications
376	339113	Surgical appliance and supplies manufacturing	412	514100	Information services
377	339114	Dental equipment and supplies manufacturing	413	514200	Data processing services
378	339115	Ophthalmic goods manufacturing	414	522A00	Nondepository credit intermediation and related activities
379	339116	Dental laboratories	415	523000	Securities, commodity contracts, investments
380	339910	Jewelry and silverware manufacturing	416	524100	Insurance carriers
381	339920	Sporting and athletic goods manufacturing	417	524200	Insurance agencies, brokerages, and related
382	339930	Doll, toy, and game manufacturing	418	525000	Funds, trusts, and other financial vehicles
383	339940	Office supplies, except paper, manufacturing	419	52A000	Monetary authorities and depository credit intermediation
384	339950	Sign manufacturing	420	531000	Real estate
385	339991	Gasket, packing, and sealing device manufacturing	421	532100	Automotive equipment rental and leasing
386	339992	Musical instrument manufacturing	422	532230	Video tape and disc rental
387	339994	Broom, brush, and mop manufacturing	423	532400	Machinery and equipment rental and leasing
388	339995	Burial casket manufacturing	424	532A00	General & consumer goods rental except video tapes and discs
389	33999A	Buttons, pins, and all other miscellaneous manufacturing	425	533000	Lessors of nonfinancial intangible assets
390	420000	Wholesale trade	426	541100	Legal services
391	481000	Air transportation	427	541200	Accounting and bookkeeping services
392	482000	Rail transportation	428	541300	Architectural and engineering services
393	483000	Water transportation	429	541400	Specialized design services
394	484000	Truck transportation	430	541511	Custom computer programming services
395	485000	Transit and ground passenger transportation	431	541512	Computer systems design services
396	486000	Pipeline transportation	432	54151A	Other computer related services, including facilities management

Continued

Table A.2 continued

SR	NAICS	Description
433	541610	Management consulting services
434	5416A0	Environmental and other technical consulting services
435	541700	Scientific research and development services
436	541800	Advertising and related services
437	541920	Photographic services
438	541940	Veterinary services
439	5419A0	All other miscellaneous professional and technical services
440	550000	Management of companies and enterprises
441	561100	Office administrative services
442	561200	Facilities support services
443	561300	Employment services
444	561400	Business support services
445	561500	Travel arrangement and reservation services
446	561600	Investigation and security services
447	561700	Services to buildings and dwellings
448	561900	Other support services
449	562000	Waste management and remediation services
450	611100	Elementary and secondary schools
451	611A00	Colleges, universities, and junior colleges
452	611B00	Other educational services
453	621600	Home health care services
454	621A00	Offices of physicians, dentists, and other health practioners
455	621B00	Other ambulatory health care services
456	622000	Hospitals
457	623000	Nursing and residential care facilities
458	624400	Child day care services
459	624A00	Social assistance, except child day care services
460	711100	Performing arts companies
461	711200	Spectator sports
462	711500	Independent artists, writers, and performers
463	711A00	Promoters of performing arts and sports and agents for public figures
464	712000	Museums, historical sites, zoos, and parks
465	713940	Fitness and recreational sports centers
466	713950	Bowling centers
467	713A00	Other amusement, gambling, and recreation industries
468	7211A0	Hotels and motels, including casino hotels
469	721A00	Other accommodations
470	722000	Food services and drinking places
471	811192	Car washes
472	8111A0	Automotive repair and maintenance, except car washes
473	811200	Electronic equipment repair and maintenance
474	811300	Commercial machinery repair and maintenance
475	811400	Household goods repair and maintenance
476	812100	Personal care services
477	812200	Death care services
478	812300	Drycleaning and laundry services
479	812900	Other personal services
480	813100	Religious organizations
481	813A00	Grantmaking and giving and social advocacy organizations
482	813B00	Civic, social, professional and similar organizations
483	S00101	Federal electric utilities
484	S00102	Other Federal Government enterprises
485	S00201	State and local government passenger transit
486	S00202	State and local government electric utilities
487	S00203	Other State and local government enterprises
488	S00800	Owner-occupied dwellings

APPENDIX B

ECEC/$ AND ICEC/$ RATIOS FOR 91-SECTOR 1992 AND 488-SECTOR 1997 US ECONOMIC MODELS

Table B.2 presents ECEC/$ and ICEC/$ ratios for 91 sectors from the 1992 US economic model. ECEC/$ ratios include those for individual resource categories as well as aggregate ratios. These ratios have been discussed and applied in Chapter 4 of this dissertation. Table B.3 presents similar ratios for 488 industry sectors form the 1997 US economic model. Table B.1 defines the terminology used in Tables B.2 and B.3.

SIC	Standard Industrial Classification System codes defined in Table A.1	**NAICS**	North American Industrial Classification System codes defined in Table A.2
Econ.	Economic size in million dollars	**LS/$**	ECEC/$ Ratio for Lithosphere
BSNR/$	ECEC/$ Ratio for Biosphere	**HS/$**	ECEC/$ Ratio for hydrosphere
AS/$	ECEC/$ Ratio for Atmosphere	**sltot/$**	ECEC/$ Ratio for sunlight
hydrotot/$	ECEC/$ Ratio for hydropotential	**geotot/$**	ECEC/$ Ratio for geopotenitial
windtot/$	ECEC/$ Ratio for wind	**erotot/$**	ECEC/$ Ratio for fertile soil
HR/$	ECEC/$ Ratio for Human Resources	**ESO2/$**	ECEC/$ Ratio for impact of SO_2 emission
ENO2/$	ECEC/$ Ratio for impact of NO_2 emission	**EPM10/$**	ECEC/$ Ratio for impact of PM10 emission
ECO2/$	ECEC/$ Ratio for impact of CO_2 emission	**EMETH/$**	ECEC/$ Ratio for impact of Methanol emission
EAMM/$	ECEC/$ Ratio for impact of Ammonia emission	**ETOL/$**	ECEC/$ Ratio for impact of Toluene emission
ETCE/$	ECEC/$ Ratio for impact of 1,1,1-TCE emission	**ESTY-A/$**	ECEC/$ Ratio for impact of Styrene emission to Air
ESTY-W/$	ECEC/$ Ratio for impact of Styrene emission to water	**ESTY-S/$**	ECEC/$ Ratio for impact of styrene emission to soil
NR/$	ECEC/$ Ratio for total Non-Renewable resources	**REN/$**	ECEC/$ Ratio for total renewable resources
Impact/$	ECEC/$ Ratio for total impact of emission	**Total/$**	Total ECEC/$ Ratio

Table B.1: Key to Tables B.2 and B.3.

SIC	1	2	3	4	5+6	7	8	9+10	11	12	13	14	15	16	17
Econ.	89375	104546	11865	29805	10739	26917	97623	12283	456949	222381	22217	408757	40147	37528	17983
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	8.74E+11	1.19E+12	5.74E+11	1.15E+12	8.90E+13	3.74E+13	9.74E+12	1.72E+14	2.49E+12	2.60E+12	6.34E+11	7.10E+11	2.34E+11	1.08E+12	9.92E+11
BSNR/$	2.32E+11	3.00E+10	2.49E+13	4.95E+10	2.90E+10	1.76E+10	1.37E+10	1.32E+10	1.62E+11	2.00E+11	2.12E+10	2.85E+11	9.78E+09	2.29E+10	2.13E+10
HS/$	1.53E+10	1.88E+10	6.39E+09	6.11E+09	6.79E+09	4.52E+09	8.78E+09	6.84E+09	8.95E+09	9.05E+09	7.82E+09	1.27E+10	3.75E+09	1.55E+10	1.66E+10
AS/$	1.77E+11	5.42E+11	1.45E+10	6.25E+10	7.56E+08	5.54E+08	4.65E+08	4.56E+08	2.11E+09	2.32E+09	5.46E+08	8.73E+10	4.58E+10	5.41E+10	1.21E+10
sltot/$	7.65E+10	2.26E+11	1.03E+12	2.78E+10	1.50E+09	9.51E+08	7.56E+08	7.31E+08	7.55E+09	9.18E+09	1.09E+09	4.66E+10	1.94E+10	2.33E+10	5.84E+09
hydrotot/$	4.89E+09	2.34E+09	8.71E+08	1.29E+09	1.34E+10	4.08E+09	3.77E+09	8.67E+09	2.04E+09	1.91E+09	2.82E+09	3.49E+09	8.90E+08	7.46E+09	5.07E+09
geotot/$	1.03E+08	4.95E+07	1.84E+07	2.74E+07	2.83E+08	8.64E+07	7.99E+07	1.83E+08	4.33E+07	4.04E+07	5.97E+07	7.39E+07	1.88E+07	1.58E+08	1.07E+08
windtot/$	1.55E+07	7.42E+06	2.76E+06	4.11E+06	4.24E+07	1.30E+07	1.20E+07	2.75E+07	6.49E+06	6.06E+06	8.95E+06	1.11E+07	2.82E+06	2.36E+07	1.61E+07
erotot/$	4.83E+11	1.48E+12	3.96E+10	1.70E+11	2.06E+09	1.51E+09	1.26E+09	1.24E+09	3.27E+11	6.31E+09	1.49E+09	2.38E+11	1.25E+11	1.47E+11	3.28E+10
HR/$	1.09E+12	7.29E+11	2.30E+12	7.92E+11	1.20E+12	8.95E+11	7.17E+11	1.31E+12	1.05E+12	1.05E+12	1.22E+13	1.12E+12	3.70E+11	1.28E+12	1.76E+12
ESO2/$	1.38E+10	9.91E+09	4.86E+09	6.33E+09	7.81E+10	1.20E+10	3.13E+10	2.50E+10	9.16E+09	8.09E+09	1.01E+10	1.22E+10	3.47E+09	2.54E+10	1.93E+10
ENO2/$	1.79E+08	2.05E+08	2.55E+07	4.68E+07	2.39E+08	4.91E+07	2.00E+08	8.68E+07	5.56E+07	6.51E+07	2.85E+07	9.00E+07	2.73E+07	9.42E+07	8.05E+07
EPM10/$	3.47E+07	3.54E+07	2.34E+07	2.52E+07	3.49E+08	1.01E+08	3.82E+07	1.67E+09	2.77E+08	4.47E+08	1.94E+07	2.81E+07	8.09E+06	3.53E+07	3.04E+07
ECO2/$	2.24E+10	2.30E+10	1.33E+10	1.36E+10	5.41E+10	2.73E+11	2.40E+11	5.75E+10	1.36E+10	1.37E+10	1.13E+10	1.75E+10	5.60E+09	2.83E+10	2.39E+10
EMETH/$	1.25E+05	8.68E+04	5.23E+04	5.50E+04	8.50E+04	4.27E+04	3.24E+04	5.90E+04	1.61E+05	1.56E+05	6.53E+04	2.57E+05	9.58E+04	6.49E+05	3.05E+05
EAMM/$	1.19E+07	8.90E+06	6.67E+06	5.79E+06	2.33E+07	1.02E+07	8.68E+06	1.58E+07	2.08E+07	1.85E+07	1.78E+07	2.31E+07	4.53E+06	8.74E+07	3.32E+07
ETOL/$	1.62E+05	1.37E+05	9.69E+04	7.84E+04	2.17E+05	1.51E+05	6.41E+04	2.39E+05	3.49E+05	3.19E+05	1.53E+05	2.15E+05	6.29E+04	2.89E+06	7.81E+05
ETCE/$	3.19E+06	2.05E+06	1.13E+06	1.22E+06	4.59E+06	2.99E+06	1.21E+06	3.93E+06	8.45E+06	7.55E+06	4.34E+06	5.55E+06	1.42E+06	3.01E+07	1.16E+07
ESTY-A/$	1.41E+03	8.78E+02	4.17E+02	5.01E+02	1.45E+03	1.15E+03	3.24E+02	1.44E+03	2.02E+03	2.03E+03	1.86E+03	2.47E+03	6.76E+02	3.65E+03	2.68E+03
ESTY-W/$	6.18E+00	5.37E+00	3.12E+00	3.30E+00	1.04E+01	4.75E+00	3.05E+00	6.70E+00	1.08E+01	1.19E+01	6.11E+00	9.42E+00	3.50E+00	3.39E+01	3.82E+01
ESTY-S/$	1.33E+01	1.43E+01	5.74E+00	1.17E+01	5.29E+01	1.31E+01	1.44E+01	2.33E+01	1.50E+01	1.42E+01	1.68E+01	1.77E+01	6.39E+00	9.57E+01	1.04E+02
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.11E+12	1.22E+12	2.55E+13	1.20E+12	8.90E+13	3.74E+13	9.76E+12	1.72E+14	2.66E+12	2.80E+12	6.56E+11	9.96E+11	2.44E+11	1.11E+12	1.01E+12
REN/$	4.81E+11	1.47E+12	1.03E+12	1.70E+11	1.33E+10	4.57E+09	8.86E+09	8.64E+09	3.28E+11	9.20E+09	7.90E+09	2.37E+11	1.24E+11	1.47E+11	3.27E+10
Impact/$	3.64E+10	3.31E+10	1.82E+10	2.00E+10	1.33E+11	2.86E+11	2.71E+11	8.43E+10	2.31E+10	2.24E+10	2.15E+10	2.99E+10	9.12E+09	5.39E+10	4.33E+10
HR/$	1.09E+12	7.29E+11	2.30E+12	7.92E+11	1.20E+12	8.95E+11	7.17E+11	1.31E+12	1.05E+12	1.05E+12	1.22E+13	1.12E+12	3.70E+11	1.28E+12	1.76E+12
Total/$	2.71E+12	3.46E+12	2.89E+13	2.18E+12	9.04E+13	3.86E+13	1.08E+13	1.73E+14	4.06E+12	3.89E+12	1.29E+13	2.38E+12	7.48E+11	2.59E+12	2.85E+12
ICEC to money ratio (J/$)															
ICEC/$	7.66E+10	2.26E+11	1.03E+12	2.78E+10	1.53E+09	2.03E+09	9.35E+08	7.75E+08	7.58E+09	9.21E+09	1.10E+09	4.66E+10	1.94E+10	2.33E+10	5.85E+09

Continued

Table B.2: ECEC to Money and ICEC to money ratios for 91-sector 1992 model

Table B.2 continued

SIC	18	19	20+21	22+23	24	25	26A	26B	27A	27B	28	29A	29B	30	31
Econ.	68637	21021	87127	42849	98497	31743	19895	81202	113359	17850	50944	62321	40557	14379	149831
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	5.57E+11	5.60E+11	5.88E+11	7.98E+11	1.62E+12	1.08E+12	1.03E+12	7.49E+11	4.27E+12	1.15E+13	1.88E+12	3.45E+11	8.43E+11	1.76E+12	6.45E+12
BSNR/$	1.05E+11	2.42E+10	2.90E+12	2.52E+11	2.49E+11	1.16E+11	9.96E+10	7.40E+10	2.67E+10	3.76E+10	2.96E+10	2.64E+10	3.09E+10	2.96E+10	1.69E+10
HS/$	9.26E+09	1.09E+10	1.05E+10	9.88E+09	2.29E+10	1.62E+10	1.83E+10	1.29E+10	2.86E+10	2.47E+10	2.52E+10	8.80E+09	1.11E+10	2.04E+10	1.45E+10
AS/$	1.63E+10	1.51E+10	2.14E+09	3.50E+09	1.76E+09	1.08E+09	1.44E+09	9.76E+08	4.44E+09	2.52E+09	1.92E+09	2.20E+09	1.94E+09	2.18E+09	6.18E+08
sltot/$	1.10E+10	7.24E+09	1.20E+11	1.18E+10	1.10E+10	5.23E+09	4.68E+09	3.44E+09	2.93E+09	2.56E+09	2.01E+09	1.99E+09	2.05E+09	2.10E+09	9.45E+08
hydrotot/$	4.41E+09	3.87E+09	3.32E+09	3.34E+09	5.68E+09	4.43E+09	5.56E+09	3.89E+09	5.64E+09	4.61E+09	5.44E+09	1.89E+09	2.31E+09	3.30E+09	4.22E+09
geotot/$	9.33E+07	8.19E+07	7.03E+07	7.07E+07	1.20E+08	9.38E+07	1.18E+08	8.23E+07	1.19E+08	9.75E+07	1.15E+08	4.00E+07	4.90E+07	6.99E+07	8.93E+07
windtot/$	1.40E+07	1.23E+07	1.05E+07	1.06E+07	1.80E+07	1.41E+07	1.76E+07	1.23E+07	1.79E+07	1.46E+07	1.73E+07	5.99E+06	7.34E+06	1.05E+07	1.34E+07
erotot/$	4.43E+10	4.12E+10	5.82E+09	9.54E+09	4.80E+09	2.94E+09	3.93E+09	2.66E+09	1.21E+10	6.86E+09	5.23E+09	5.98E+09	5.27E+09	5.93E+09	1.68E+09
HR/$	1.14E+12	1.71E+12	1.55E+12	1.57E+12	1.00E+12	1.58E+12	4.86E+12	1.64E+12	8.23E+11	1.73E+12	1.01E+12	7.40E+11	9.89E+11	1.79E+12	8.27E+11
ESO2/$	1.30E+10	1.29E+10	1.07E+10	1.18E+10	4.41E+10	2.49E+10	2.39E+10	1.74E+10	3.83E+10	3.95E+10	2.75E+10	6.65E+09	1.02E+10	1.67E+10	3.88E+10
ENO2/$	4.70E+07	4.67E+07	7.74E+07	4.49E+07	1.51E+08	9.46E+07	8.91E+07	6.51E+07	1.41E+08	1.50E+08	1.03E+08	2.47E+07	4.07E+07	7.04E+07	1.87E+08
EPM10/$	2.03E+07	1.95E+07	5.66E+07	2.86E+07	7.74E+07	4.49E+07	5.08E+07	3.31E+07	7.34E+07	1.60E+08	4.59E+07	1.40E+07	2.07E+07	3.67E+07	5.72E+07
ECO2/$	1.61E+10	1.54E+10	1.67E+10	1.72E+10	3.46E+10	2.68E+10	2.44E+10	1.77E+10	4.55E+10	7.08E+10	3.35E+10	7.66E+09	1.37E+10	2.21E+10	1.64E+11
EMETH/$	2.35E+05	2.38E+05	1.08E+06	1.06E+06	6.99E+06	3.01E+06	2.40E+06	1.72E+06	6.21E+05	1.63E+05	5.69E+05	4.08E+05	2.72E+05	2.22E+05	8.39E+04
EAMM/$	2.86E+07	2.86E+07	3.76E+07	3.06E+07	2.05E+08	9.51E+07	7.72E+07	5.59E+07	1.14E+08	2.24E+07	5.01E+07	3.95E+07	2.59E+07	3.67E+07	8.66E+07
ETOL/$	8.87E+05	8.96E+05	6.51E+05	6.26E+06	6.46E+05	3.71E+05	3.04E+07	3.59E+05	6.93E+05	2.07E+05	8.22E+05	5.86E+05	3.74E+05	2.92E+05	1.53E+06
ETCE/$	1.03E+07	1.14E+07	4.05E+06	2.61E+07	7.41E+06	4.71E+06	4.60E+07	5.33E+06	9.77E+06	3.71E+06	1.84E+07	9.02E+06	1.03E+07	5.02E+06	3.49E+06
ESTY-A/$	1.84E+03	2.55E+03	1.92E+03	4.49E+03	4.10E+03	2.37E+03	2.22E+03	2.70E+03	3.94E+03	1.64E+03	4.44E+03	2.13E+03	5.19E+03	1.59E+03	9.16E+02
ESTY-W/$	1.37E+01	1.69E+01	9.41E+01	1.90E+01	8.78E+01	4.19E+01	3.40E+01	2.75E+01	1.00E+02	1.66E+01	1.14E+02	8.00E+00	2.14E+01	3.62E+01	3.29E+01
ESTY-S/$	3.57E+01	4.52E+01	1.45E+01	2.48E+01	6.46E+01	4.83E+01	4.76E+01	4.39E+01	7.85E+02	1.04E+02	2.71E+02	2.94E+01	9.45E+01	1.98E+02	2.28E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	6.63E+11	5.85E+11	3.49E+12	1.05E+12	1.87E+12	1.20E+12	1.14E+12	8.23E+11	4.30E+12	1.16E+13	1.92E+12	3.72E+11	8.74E+11	1.79E+12	6.47E+12
REN/$	4.42E+10	4.11E+10	1.20E+11	1.18E+10	2.31E+10	1.63E+10	1.85E+10	1.30E+10	2.88E+10	2.49E+10	2.54E+10	8.88E+09	1.12E+10	2.06E+10	1.46E+10
Impact/$	2.92E+10	2.84E+10	2.76E+10	2.92E+10	7.92E+10	5.19E+10	4.86E+10	3.53E+10	8.41E+10	1.11E+11	6.13E+10	1.44E+10	2.40E+10	3.89E+10	2.03E+11
HR/$	1.14E+12	1.71E+12	1.55E+12	1.57E+12	1.00E+12	1.58E+12	4.86E+12	1.64E+12	8.23E+11	1.73E+12	1.01E+12	7.40E+11	9.89E+11	1.79E+12	8.27E+11
Total/$	1.88E+12	2.37E+12	5.19E+12	2.66E+12	2.98E+12	2.84E+12	6.06E+12	2.51E+12	5.23E+12	1.34E+13	3.01E+12	1.14E+12	1.90E+12	3.64E+12	7.52E+12
ICEC to money ratio (J/$)															
ICEC/$	1.10E+10	7.24E+09	1.20E+11	1.18E+10	1.10E+10	5.25E+09	4.71E+09	3.46E+09	2.95E+09	2.59E+09	2.02E+09	2.00E+09	2.06E+09	2.12E+09	1.05E+09

Continued

Table B.2 continued

SIC	32	33+34	35	36	37	38	39	40	41	42	43	44+45	46	47	48
Econ.	111813	9538	17981	42291	73922	64813	13238	49050	34564	56518	17895	30946	8290	27046	20218
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	9.48E+11	6.23E+11	3.16E+12	1.41E+13	5.78E+12	5.68E+12	3.32E+12	1.95E+12	1.86E+12	1.40E+12	1.42E+12	1.28E+12	1.24E+12	1.16E+12	1.07E+12
BSNR/$	2.18E+11	5.29E+10	5.02E+10	2.98E+10	2.15E+10	3.54E+10	2.37E+10	1.89E+10	1.72E+10	2.30E+10	1.57E+10	2.71E+10	2.02E+10	2.12E+10	2.58E+10
HS/$	1.38E+10	3.50E+10	1.10E+10	1.39E+10	2.67E+10	1.62E+10	1.72E+10	1.26E+10	3.66E+10	1.31E+10	1.23E+10	1.11E+10	9.57E+09	7.62E+09	8.51E+09
AS/$	1.66E+09	1.26E+10	5.98E+08	8.08E+08	5.01E+08	5.44E+08	5.95E+08	4.83E+08	4.33E+08	4.73E+08	4.27E+08	4.91E+08	4.12E+08	3.82E+08	4.28E+08
sltot/$	9.67E+09	7.26E+09	2.31E+09	1.56E+09	1.09E+09	1.68E+09	1.22E+09	9.75E+08	8.83E+08	1.14E+09	8.19E+08	1.32E+09	9.97E+08	1.03E+09	1.24E+09
hydrotot/$	4.85E+09	3.03E+09	5.44E+09	5.89E+09	7.99E+09	8.80E+09	6.90E+09	4.24E+09	4.56E+09	4.19E+09	3.56E+09	3.58E+09	3.15E+09	3.07E+09	3.14E+09
geotot/$	1.03E+08	6.41E+07	1.15E+08	1.25E+08	1.69E+08	1.86E+08	1.46E+08	8.97E+07	9.65E+07	8.86E+07	7.54E+07	7.58E+07	6.66E+07	6.50E+07	6.65E+07
windtot/$	1.54E+07	9.60E+06	1.73E+07	1.87E+07	2.53E+07	2.79E+07	2.19E+07	1.34E+07	1.45E+07	1.33E+07	1.13E+07	1.14E+07	9.98E+06	9.75E+06	9.97E+06
erotot/$	4.52E+09	3.44E+10	1.63E+09	2.20E+09	1.37E+09	1.48E+09	1.62E+09	1.32E+09	1.18E+09	1.29E+09	1.16E+09	1.34E+09	1.12E+09	1.04E+09	1.16E+09
HR/$	1.35E+12	1.42E+12	1.75E+12	1.21E+12	1.26E+12	1.47E+12	3.72E+12	1.45E+12	1.68E+12	1.24E+12	2.39E+12	1.81E+12	4.12E+12	1.60E+12	2.09E+12
ESO2/$	1.69E+10	1.04E+10	2.23E+10	4.48E+10	4.80E+10	6.10E+10	3.61E+10	2.01E+10	1.99E+10	1.68E+10	1.51E+10	1.53E+10	1.33E+10	1.16E+10	1.28E+10
ENO2/$	6.23E+07	4.45E+07	1.45E+08	1.99E+08	1.47E+08	9.83E+07	8.67E+07	5.94E+07	6.10E+07	5.01E+07	5.08E+07	4.93E+07	4.20E+07	3.55E+07	3.75E+07
EPM10/$	2.93E+07	2.22E+07	7.82E+07	2.58E+08	1.47E+08	8.87E+07	6.88E+07	4.70E+07	5.03E+07	3.75E+07	3.99E+07	3.56E+07	3.34E+07	2.88E+07	2.87E+07
ECO2/$	2.03E+10	1.51E+10	3.53E+10	4.65E+10	1.05E+11	2.74E+10	3.78E+10	3.07E+10	3.29E+10	2.44E+10	2.47E+10	2.40E+10	2.25E+10	1.71E+10	1.74E+10
EMETH/$	6.40E+05	1.94E+05	5.48E+05	1.64E+05	9.77E+04	1.01E+05	1.03E+05	3.53E+05	8.40E+04	1.16E+05	6.51E+04	9.61E+04	6.93E+04	6.33E+04	1.14E+05
EAMM/$	3.72E+07	1.76E+07	6.33E+08	1.72E+07	2.32E+08	2.07E+08	1.20E+08	9.51E+07	6.76E+07	4.79E+07	4.83E+07	4.45E+07	4.30E+07	2.96E+07	3.61E+07
ETOL/$	3.64E+06	3.62E+05	2.69E+06	1.77E+05	3.07E+05	2.11E+05	1.79E+05	2.94E+06	1.40E+05	2.09E+05	1.90E+05	4.05E+05	2.20E+05	1.43E+05	2.09E+05
ETCE/$	1.27E+08	8.09E+06	9.00E+07	3.41E+06	1.63E+07	8.16E+06	6.76E+06	8.60E+07	5.45E+06	7.03E+06	6.68E+06	1.34E+07	7.44E+06	4.50E+06	6.70E+06
ESTY-A/$	6.90E+04	3.65E+03	2.35E+04	1.37E+03	7.94E+02	1.68E+03	1.11E+03	4.76E+03	8.67E+02	2.47E+03	1.57E+03	3.95E+03	2.08E+03	1.11E+03	2.09E+03
ESTY-W/$	1.21E+02	1.46E+01	7.97E+01	9.16E+00	4.87E+00	8.07E+00	6.79E+00	6.35E+00	4.47E+00	8.31E+00	4.42E+00	8.61E+00	5.36E+00	4.14E+00	5.98E+00
ESTY-S/$	1.77E+02	5.31E+01	4.31E+01	3.27E+01	1.92E+01	1.94E+01	2.39E+01	2.20E+01	1.37E+01	2.29E+01	9.86E+00	1.63E+01	1.07E+01	1.18E+01	1.09E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.17E+12	6.76E+11	3.21E+12	1.41E+13	5.81E+12	5.71E+12	3.35E+12	1.97E+12	1.88E+12	1.42E+12	1.44E+12	1.31E+12	1.26E+12	1.18E+12	1.09E+12
REN/$	1.40E+10	3.53E+10	1.11E+10	1.41E+10	2.70E+10	1.64E+10	1.73E+10	1.27E+10	3.69E+10	1.32E+10	1.24E+10	1.12E+10	9.66E+09	7.69E+09	8.59E+09
Impact/$	3.75E+10	2.56E+10	5.85E+10	9.18E+10	1.54E+11	8.88E+10	7.42E+10	5.10E+10	5.30E+10	4.13E+10	4.00E+10	3.95E+10	3.59E+10	2.88E+10	3.03E+10
HR/$	1.35E+12	1.42E+12	1.75E+12	1.21E+12	1.26E+12	1.47E+12	3.72E+12	1.45E+12	1.68E+12	1.24E+12	2.39E+12	1.81E+12	4.12E+12	1.60E+12	2.09E+12
Total/$	2.57E+12	2.16E+12	5.03E+12	1.55E+13	7.25E+12	7.29E+12	7.16E+12	3.48E+12	3.65E+12	2.72E+12	3.89E+12	3.17E+12	5.42E+12	2.82E+12	3.22E+12
ICEC to money ratio (J/$)															
ICEC/$	9.70E+09	7.27E+09	2.33E+09	1.58E+09	1.13E+09	1.70E+09	1.23E+09	9.88E+08	8.98E+08	1.15E+09	8.29E+08	1.33E+09	1.01E+09	1.04E+09	1.25E+09

Continued

Table B.2 continued

SIC	49	50	51	52	53	54	55	56	57	58	59A	59B	60	61	62
Econ.	29678	24946	62088	25801	28574	16833	19055	50981	73298	21103	149684	81258	102154	29907	107915
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.06E+12	1.14E+12	4.48E+11	1.26E+12	1.47E+12	1.57E+12	1.16E+12	5.01E+11	5.94E+11	9.03E+11	1.09E+12	1.85E+12	6.36E+11	9.27E+11	4.80E+11
BSNR/$	2.12E+10	1.27E+10	1.61E+10	2.90E+10	2.13E+10	3.83E+10	2.24E+10	1.89E+10	1.55E+10	2.81E+10	3.59E+10	2.71E+10	1.61E+10	5.65E+10	1.67E+10
HS/$	9.55E+09	8.25E+09	6.93E+09	1.52E+10	8.79E+09	1.07E+10	1.01E+10	5.96E+09	7.33E+09	1.32E+10	1.48E+10	1.73E+10	9.09E+09	1.06E+10	5.97E+09
AS/$	5.17E+08	3.70E+08	4.48E+08	4.83E+08	4.44E+08	6.61E+08	4.92E+08	4.36E+08	4.52E+08	5.82E+08	1.23E+09	5.38E+08	5.62E+08	5.70E+08	6.43E+08
sltot/$	1.08E+09	6.72E+08	8.44E+08	1.39E+09	1.06E+09	1.85E+09	1.12E+09	9.57E+08	8.21E+08	1.39E+09	1.98E+09	1.33E+09	8.91E+08	2.56E+09	9.48E+08
hydrotot/$	3.50E+09	3.56E+09	2.58E+09	3.47E+09	3.31E+09	3.72E+09	3.49E+09	2.33E+09	3.21E+09	3.55E+09	3.43E+09	4.24E+09	2.51E+09	2.87E+09	2.29E+09
geotot/$	7.40E+07	7.53E+07	5.46E+07	7.34E+07	7.00E+07	7.86E+07	7.38E+07	4.92E+07	6.78E+07	7.52E+07	7.26E+07	8.97E+07	5.30E+07	6.07E+07	4.84E+07
windtot/$	1.11E+07	1.13E+07	8.18E+06	1.10E+07	1.05E+07	1.18E+07	1.11E+07	7.38E+06	1.02E+07	1.13E+07	1.09E+07	1.35E+07	7.95E+06	9.10E+06	7.25E+06
erotot/$	1.41E+09	1.01E+09	1.22E+09	1.31E+09	1.21E+09	1.80E+09	1.34E+09	1.19E+09	1.23E+09	1.58E+09	3.36E+09	1.46E+09	1.53E+09	1.55E+09	1.75E+09
HR/$	1.66E+12	1.72E+12	1.06E+12	1.56E+12	1.30E+12	1.93E+12	1.68E+12	9.45E+11	8.09E+11	1.59E+12	1.49E+12	1.46E+12	1.12E+12	2.25E+12	9.43E+11
ESO2/$	1.33E+10	1.37E+10	7.72E+09	1.46E+10	1.39E+10	1.56E+10	1.37E+10	7.34E+09	9.91E+09	1.29E+10	1.29E+10	1.82E+10	8.53E+09	1.18E+10	8.21E+09
ENO2/$	3.96E+07	3.85E+07	2.41E+07	4.60E+07	4.24E+07	4.93E+07	4.31E+07	2.28E+07	2.89E+07	3.83E+07	4.72E+07	5.47E+07	2.55E+07	3.87E+07	2.25E+07
EPM10/$	2.98E+07	2.98E+07	1.74E+07	3.36E+07	3.45E+07	3.65E+07	2.93E+07	1.65E+07	2.13E+07	2.42E+07	2.93E+07	4.03E+07	1.94E+07	2.76E+07	1.57E+07
ECO2/$	1.96E+10	1.83E+10	8.76E+09	1.85E+10	1.75E+10	2.08E+10	1.70E+10	8.35E+09	1.06E+10	1.41E+10	1.83E+10	2.40E+10	1.01E+10	1.72E+10	8.89E+09
EMETH/$	1.07E+05	5.01E+04	1.08E+05	1.24E+05	1.10E+05	2.52E+05	1.73E+05	1.06E+05	7.95E+04	1.47E+05	2.45E+05	1.06E+05	5.64E+04	9.06E+04	9.44E+04
EAMM/$	3.52E+07	3.70E+07	3.24E+07	4.09E+07	3.16E+07	4.40E+07	4.79E+07	1.52E+07	2.24E+07	2.88E+07	4.03E+07	5.20E+07	1.70E+07	3.37E+07	1.65E+07
ETOL/$	2.26E+05	1.09E+05	3.63E+05	2.39E+05	2.07E+05	4.52E+05	2.80E+05	2.51E+05	1.74E+05	3.57E+05	1.36E+06	2.96E+05	1.63E+05	2.99E+05	1.87E+05
ETCE/$	7.38E+06	3.56E+06	8.45E+06	7.77E+06	6.45E+06	1.48E+07	8.77E+06	5.53E+06	5.04E+06	1.14E+07	3.51E+07	9.51E+06	4.72E+06	8.80E+06	5.26E+06
ESTY-A/$	2.50E+03	8.02E+02	1.93E+03	2.82E+03	2.53E+03	6.88E+03	3.32E+03	2.24E+03	1.92E+03	5.37E+03	1.22E+04	2.88E+03	2.04E+03	2.67E+03	2.03E+03
ESTY-W/$	6.56E+00	2.96E+00	5.20E+00	8.14E+00	7.11E+00	1.89E+01	1.19E+01	6.20E+00	6.55E+00	1.36E+01	1.54E+01	8.46E+00	5.43E+00	8.08E+00	6.06E+00
ESTY-S/$	1.17E+01	6.64E+00	1.05E+01	1.61E+01	1.38E+01	3.66E+01	2.10E+01	1.20E+01	1.84E+01	2.91E+01	1.47E+02	2.05E+01	1.06E+01	1.63E+01	1.17E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.09E+12	1.15E+12	4.64E+11	1.29E+12	1.49E+12	1.61E+12	1.18E+12	5.20E+11	6.10E+11	9.32E+11	1.12E+12	1.87E+12	6.52E+11	9.84E+11	4.97E+11
REN/$	9.63E+09	8.33E+09	6.99E+09	1.54E+10	8.87E+09	1.08E+10	1.02E+10	6.02E+09	7.40E+09	1.33E+10	1.50E+10	1.74E+10	9.17E+09	1.07E+10	6.03E+09
Impact/$	3.30E+10	3.21E+10	1.66E+10	3.32E+10	3.15E+10	3.66E+10	3.08E+10	1.57E+10	2.06E+10	2.71E+10	3.14E+10	4.24E+10	1.87E+10	2.91E+10	1.72E+10
HR/$	1.66E+12	1.72E+12	1.06E+12	1.56E+12	1.30E+12	1.93E+12	1.68E+12	9.45E+11	8.09E+11	1.59E+12	1.49E+12	1.46E+12	1.12E+12	2.25E+12	9.43E+11
Total/$	2.79E+12	2.92E+12	1.55E+12	2.89E+12	2.83E+12	3.59E+12	2.90E+12	1.49E+12	1.45E+12	2.56E+12	2.66E+12	3.40E+12	1.80E+12	3.28E+12	1.46E+12
ICEC to money ratio (J/$)															
ICEC/$	1.09E+09	6.81E+08	8.50E+08	1.40E+09	1.06E+09	1.86E+09	1.13E+09	9.63E+08	8.27E+08	1.40E+09	1.99E+09	1.35E+09	8.97E+08	2.57E+09	9.54E+08

Continued

Table B.2 continued

SIC	63	64	65A	65B	65C	65D	65E	66	67	68A	68B	68C	69A	69B	70A
Econ.	22745	39450	62058	157110	34347	98819	28966	205941	2674	195695	96155	50265	568970	526178	390774
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	5.11E+11	9.94E+11	6.37E+11	6.07E+11	3.37E+11	7.71E+11	3.04E+11	2.37E+11	2.71E+12	3.43E+12	5.10E+12	3.63E+11	2.14E+11	2.39E+11	1.50E+11
BSNR/$	2.52E+10	7.53E+10	1.55E+10	1.37E+10	1.21E+10	1.26E+10	2.92E+10	1.48E+10	1.45E+11	1.84E+10	2.59E+10	1.93E+10	1.86E+10	9.88E+09	7.63E+09
HS/$	7.77E+09	9.53E+09	7.86E+09	4.27E+10	6.24E+09	7.14E+09	6.42E+09	5.68E+09	1.27E+11	4.86E+09	6.63E+09	2.29E+12	6.62E+09	1.05E+10	1.05E+10
AS/$	5.29E+08	2.14E+09	3.46E+08	3.79E+08	6.28E+08	8.76E+08	3.97E+08	3.75E+08	1.31E+10	3.50E+08	5.23E+08	2.27E+08	4.96E+08	3.57E+08	2.92E+08
sltot/$	1.25E+09	3.97E+09	7.78E+08	7.19E+08	7.52E+08	8.70E+08	1.36E+09	7.62E+08	1.13E+10	9.00E+08	1.28E+09	8.86E+08	9.67E+08	5.52E+08	4.33E+08
hydrotot/$	2.17E+09	3.26E+09	1.08E+09	2.21E+09	1.36E+09	1.49E+09	2.77E+09	1.19E+09	3.15E+10	1.30E+11	2.52E+09	7.07E+08	1.67E+09	3.46E+09	1.28E+09
geotot/$	4.59E+07	6.90E+07	2.28E+07	4.67E+07	2.88E+07	3.15E+07	5.86E+07	2.52E+07	6.66E+08	2.75E+09	5.32E+07	1.50E+07	3.54E+07	7.33E+07	2.71E+07
windtot/$	6.88E+06	1.03E+07	3.42E+06	7.01E+06	4.31E+06	4.72E+06	8.78E+06	3.78E+06	9.98E+07	4.12E+08	7.98E+06	2.24E+06	5.31E+06	1.10E+07	4.07E+06
erotot/$	1.44E+09	5.82E+09	9.42E+08	1.03E+09	1.71E+09	2.39E+09	1.08E+09	1.02E+09	3.56E+10	9.54E+08	1.42E+09	6.17E+08	1.35E+09	9.73E+08	7.96E+08
HR/$	2.61E+12	1.48E+12	1.31E+12	1.59E+12	1.02E+12	7.51E+11	8.50E+11	8.78E+11	4.78E+13	5.55E+11	1.05E+12	9.47E+11	1.41E+12	1.70E+12	1.84E+12
ESO2/$	8.37E+09	1.34E+10	1.39E+10	9.83E+09	3.21E+10	7.01E+09	6.90E+09	3.18E+09	7.21E+10	2.55E+11	2.79E+10	1.36E+10	4.46E+09	7.73E+09	3.38E+09
ENO2/$	3.76E+07	4.30E+07	3.49E+08	2.24E+08	1.27E+08	4.76E+07	2.60E+07	1.18E+07	2.15E+08	5.40E+08	2.66E+08	9.00E+07	2.71E+07	2.84E+07	1.32E+07
EPM10/$	1.76E+07	2.67E+07	9.74E+07	1.53E+07	7.35E+07	4.11E+07	1.87E+07	2.53E+07	1.82E+08	1.43E+08	6.14E+07	4.37E+07	9.77E+06	1.32E+07	7.71E+06
ECO2/$	1.10E+10	1.54E+10	2.88E+10	3.42E+10	1.69E+10	4.18E+10	1.01E+10	4.13E+09	7.89E+10	1.89E+11	1.96E+11	1.74E+10	7.06E+09	8.48E+09	4.50E+09
EMETH/$	3.90E+05	2.32E+05	4.02E+04	4.94E+04	3.75E+04	3.48E+04	6.90E+04	4.30E+04	5.08E+05	2.81E+04	3.85E+04	2.94E+04	8.72E+04	7.83E+04	6.43E+04
EAMM/$	2.35E+07	3.11E+07	1.11E+07	9.52E+06	6.68E+06	1.11E+07	5.18E+06	3.88E+06	4.05E+07	4.76E+06	6.90E+06	5.65E+06	5.13E+06	4.06E+06	3.27E+06
ETOL/$	2.23E+05	3.34E+05	1.55E+05	2.02E+05	1.34E+05	1.93E+05	1.02E+05	6.80E+04	7.31E+05	7.17E+04	7.50E+04	7.40E+04	7.78E+04	5.50E+04	6.31E+04
ETCE/$	5.60E+06	8.65E+06	1.92E+06	3.07E+06	1.53E+06	9.99E+05	1.76E+06	1.26E+06	9.96E+06	1.18E+06	1.41E+06	1.28E+06	1.29E+06	9.56E+05	6.05E+05
ESTY-A/$	2.57E+03	3.69E+03	7.07E+02	1.47E+03	5.85E+02	3.65E+02	7.80E+02	4.88E+02	3.83E+03	3.97E+02	3.99E+02	5.04E+02	5.81E+02	4.30E+02	2.38E+02
ESTY-W/$	1.28E+01	1.50E+01	4.08E+00	5.44E+00	2.71E+00	4.43E+00	3.30E+00	1.94E+00	2.01E+01	2.30E+00	2.97E+00	3.16E+00	2.84E+00	2.12E+00	1.54E+00
ESTY-S/$	3.25E+01	3.26E+01	5.91E+00	7.39E+00	4.43E+00	4.23E+00	4.39E+00	3.15E+00	4.12E+01	4.49E+00	8.91E+00	1.06E+01	4.16E+00	2.79E+00	2.42E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	5.36E+11	1.07E+12	6.53E+11	6.21E+11	3.49E+11	7.84E+11	3.34E+11	2.52E+11	2.85E+12	3.45E+12	5.13E+12	3.83E+11	2.32E+11	2.49E+11	1.57E+11
REN/$	7.84E+09	9.62E+09	7.94E+09	4.31E+10	6.30E+09	7.21E+09	6.47E+09	5.73E+09	1.28E+11	1.30E+11	6.69E+09	2.32E+12	6.68E+09	1.06E+10	1.06E+10
Impact/$	1.95E+10	2.89E+10	4.32E+10	4.43E+10	4.93E+10	4.89E+10	1.71E+10	7.35E+09	1.52E+11	4.45E+11	2.24E+11	3.12E+10	1.16E+10	1.63E+10	7.91E+09
HR/$	2.61E+12	1.48E+12	1.31E+12	1.59E+12	1.02E+12	7.51E+11	8.50E+11	8.78E+11	4.78E+13	5.55E+11	1.05E+12	9.47E+11	1.41E+12	1.70E+12	1.84E+12
Total/$	3.17E+12	2.59E+12	2.01E+12	2.30E+12	1.43E+12	1.59E+12	1.21E+12	1.14E+12	5.10E+13	4.58E+12	6.40E+12	3.68E+12	1.66E+12	1.97E+12	2.01E+12
ICEC to money ratio (J/$)															
ICEC/$	1.26E+09	3.99E+09	7.87E+08	7.31E+08	7.58E+08	8.84E+08	1.37E+09	7.65E+08	1.14E+10	9.98E+08	1.37E+09	9.47E+08	9.72E+08	5.57E+08	4.36E+08

Continued

Table B.2 continued

SIC	70B	71A	71B	72A	72B	73A	73B	73C	73D	74	75	76	77A	77B	78	79
Econ.	231654	457250	559738	58936	92016	118038	252597	332385	138530	282017	164408	122937	564607	227631	50200	30162
ECEC to money ratios for individual resource categories (sej/$)																
LS/$	1.31E+11	1.57E+11	2.64E+11	4.16E+11	2.97E+11	1.50E+11	1.19E+11	1.84E+11	3.56E+10	4.14E+11	4.69E+11	2.36E+11	2.52E+11	3.44E+11	8.71E+11	6.43E+12
BSNR/$	8.91E+09	1.07E+10	1.47E+10	1.73E+10	1.29E+10	8.03E+09	7.12E+09	8.91E+09	2.53E+09	2.29E+11	1.32E+10	1.41E+10	1.63E+10	2.59E+10	1.38E+10	1.60E+11
HS/$	5.43E+09	1.39E+09	1.69E+10	3.61E+10	1.62E+10	3.76E+09	4.13E+09	4.80E+09	9.24E+08	1.91E+10	1.08E+10	1.03E+10	1.04E+10	1.19E+10	1.83E+10	1.05E+11
AS/$	3.85E+08	6.43E+08	6.32E+08	1.06E+09	6.22E+08	3.04E+08	2.81E+08	3.81E+08	8.47E+07	2.35E+10	3.62E+08	1.94E+09	1.49E+09	1.95E+09	6.52E+08	3.07E+09
sltot/$	5.23E+08	7.07E+08	8.64E+08	1.14E+09	7.84E+08	4.54E+08	4.07E+08	5.20E+08	1.38E+08	1.88E+10	6.89E+08	1.37E+09	1.27E+09	1.85E+09	8.30E+08	7.84E+09
hydrotot/$	9.12E+08	2.19E+08	1.96E+09	5.57E+09	2.70E+09	1.17E+09	9.81E+08	1.11E+09	3.08E+08	4.24E+09	2.20E+09	2.84E+09	1.71E+09	2.14E+09	1.41E+09	2.12E+10
geotot/$	1.93E+07	4.64E+06	4.14E+07	1.18E+08	5.71E+07	2.47E+07	2.08E+07	2.35E+07	6.52E+06	8.96E+07	4.66E+07	6.01E+07	3.62E+07	4.53E+07	2.99E+07	4.48E+08
windtot/$	2.89E+06	6.95E+05	6.21E+06	1.77E+07	8.56E+06	3.70E+06	3.11E+06	3.53E+06	9.78E+05	1.34E+07	6.99E+06	9.00E+06	5.42E+06	6.78E+06	4.48E+06	6.71E+07
erotot/$	1.05E+09	1.75E+09	1.72E+09	2.87E+09	1.69E+09	8.27E+08	7.65E+08	1.04E+09	2.31E+08	6.39E+10	9.86E+08	5.30E+09	4.05E+09	5.30E+09	1.77E+09	8.37E+09
HR/$	1.91E+12	2.25E+11	3.33E+11	1.64E+12	1.00E+12	3.30E+12	2.25E+12	7.17E+11	4.13E+11	1.79E+12	8.67E+11	1.08E+12	1.98E+12	9.72E+11	6.24E+12	2.36E+13
ESO2/$	2.52E+09	7.50E+08	4.52E+09	1.33E+10	6.90E+09	3.15E+09	2.63E+09	3.35E+09	8.79E+08	1.07E+10	7.06E+09	6.55E+09	4.82E+09	6.20E+09	4.76E+09	5.61E+10
ENO2/$	1.01E+07	4.60E+06	1.49E+07	3.69E+07	2.16E+07	1.05E+07	9.18E+06	1.26E+07	2.94E+06	4.47E+07	2.30E+07	1.93E+07	1.69E+07	2.25E+07	2.62E+07	2.10E+08
EPM10/$	7.94E+06	2.29E+07	2.96E+07	2.62E+07	1.28E+07	7.80E+06	6.46E+06	7.58E+06	1.92E+06	1.89E+07	1.39E+07	1.32E+07	1.10E+07	2.91E+07	1.86E+07	3.74E+08
ECO2/$	3.53E+09	1.17E+09	5.10E+09	1.32E+10	8.72E+09	3.83E+09	3.33E+09	5.59E+09	1.01E+09	1.24E+10	1.19E+10	7.39E+09	5.82E+09	7.66E+09	1.33E+10	1.03E+11
EMETH/$	5.66E+04	1.14E+04	2.82E+04	7.22E+04	8.10E+04	6.07E+04	5.74E+04	7.22E+04	3.64E+04	1.17E+05	5.69E+04	4.79E+04	8.91E+04	1.58E+05	6.34E+04	2.19E+05
EAMM/$	3.21E+06	1.20E+06	2.31E+06	7.16E+06	6.31E+06	5.35E+06	3.27E+06	5.21E+06	1.41E+06	9.45E+06	1.35E+07	3.49E+06	7.36E+06	8.27E+06	6.06E+06	3.88E+07
ETOL/$	4.85E+04	2.08E+04	3.67E+04	1.10E+05	9.70E+04	6.95E+04	5.05E+04	6.88E+04	1.36E+04	1.16E+05	1.68E+05	6.40E+04	1.24E+05	2.08E+05	8.44E+04	5.59E+05
ETCE/$	8.42E+05	4.70E+05	7.48E+05	1.84E+06	1.83E+06	1.34E+06	6.76E+05	1.14E+06	2.08E+05	2.86E+06	4.33E+06	8.72E+05	2.60E+06	1.84E+06	9.50E+05	8.67E+06
ESTY-A/$	3.76E+02	1.33E+02	2.54E+02	7.01E+02	7.89E+02	4.81E+02	2.79E+02	4.95E+02	9.48E+01	1.32E+03	1.86E+03	3.50E+02	1.20E+03	6.95E+02	3.36E+02	2.70E+03
ESTY-W/$	1.68E+00	7.32E-01	1.33E+00	2.98E+00	3.37E+00	1.92E+00	1.50E+00	2.50E+00	6.94E-01	4.65E+00	5.03E+00	1.83E+00	4.82E+00	4.07E+00	2.50E+00	2.04E+01
ESTY-S/$	2.70E+00	1.05E+00	1.99E+00	4.68E+00	7.66E+00	3.40E+00	2.42E+00	6.10E+00	1.12E+00	8.23E+00	9.14E+00	3.69E+00	1.68E+01	6.41E+00	4.91E+00	5.37E+01
Aggregate ECEC to money ratios (sej/$)																
NR/$	1.40E+11	1.68E+11	2.78E+11	4.33E+11	3.10E+11	1.58E+11	1.26E+11	1.93E+11	3.82E+10	6.44E+11	4.83E+11	2.50E+11	2.69E+11	3.71E+11	8.85E+11	6.60E+12
REN/$	5.48E+09	1.75E+09	1.70E+10	3.65E+10	1.64E+10	3.80E+09	4.17E+09	4.85E+09	9.33E+08	6.38E+10	1.09E+10	1.04E+10	1.05E+10	1.20E+10	1.85E+10	1.06E+11
Impact/$	6.07E+09	1.95E+09	9.66E+09	2.66E+10	1.57E+10	7.01E+09	5.98E+09	8.96E+09	1.89E+09	2.31E+10	1.90E+10	1.40E+10	1.07E+10	1.39E+10	1.81E+10	1.60E+11
HR/$	1.91E+12	2.25E+11	3.33E+11	1.64E+12	1.00E+12	3.30E+12	2.25E+12	7.17E+11	4.13E+11	1.79E+12	8.67E+11	1.08E+12	1.98E+12	9.72E+11	6.24E+12	2.36E+13
Total/$	2.06E+12	3.96E+11	6.38E+11	2.14E+12	1.34E+12	3.47E+12	2.38E+12	9.24E+11	4.54E+11	2.52E+12	1.38E+12	1.35E+12	2.27E+12	1.37E+12	7.16E+12	3.04E+13
ICEC to money ratio (J/$)																
ICEC/$	5.25E+08	7.09E+08	8.68E+08	1.15E+09	7.89E+08	4.56E+08	4.10E+08	5.24E+08	1.39E+08	1.89E+10	6.95E+08	1.38E+09	1.28E+09	1.86E+09	8.51E+08	7.96E+09

NAICS	1111A0	1111B0	111200	111335	1113A0	111400	111910	111920	1119A0	1119B0	112100	112300	112A00	113300	113A00
Econ.	20249.8	38516.5	14469.1	2200.2	11250.9	13415.1	3270.5	7180.6	2230.2	22127.8	60552.2	24576.8	19943.8	22706	4946
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	3.66E+11	1.26E+12	1.88E+11	1.90E+11	3.43E+11	-5.62E+10	6.82E+11	6.87E+11	1.07E+12	1.33E+12	1.24E+12	8.20E+11	1.14E+12	3.62E+11	3.71E+11
BS/$	1.56E+10	1.74E+10	6.54E+10	6.71E+10	6.99E+10	1.20E+10	1.43E+10	2.31E+10	2.17E+10	1.80E+10	2.75E+11	2.27E+10	2.64E+10	1.60E+13	5.98E+10
HS/$	2.62E+10	2.35E+10	2.13E+10	2.21E+10	2.04E+10	3.86E+09	4.89E+09	4.65E+10	5.14E+10	2.56E+10	2.11E+10	1.30E+10	1.83E+10	1.83E+09	5.61E+09
AS/$	4.32E+11	4.40E+11	4.18E+11	4.13E+11	4.18E+11	4.20E+11	4.03E+11	4.31E+11	4.20E+11	4.22E+11	1.91E+11	9.63E+10	1.90E+11	1.25E+10	4.15E+10
sltot/$	1.81E+11	1.85E+11	1.77E+11	1.76E+11	1.78E+11	1.76E+11	1.69E+11	1.81E+11	1.76E+11	1.77E+11	8.14E+10	4.14E+10	8.10E+10	4.34E+11	2.44E+12
hydrotot/$	3.40E+09	3.45E+09	2.73E+09	2.82E+09	2.97E+09	3.30E+09	2.45E+09	4.47E+09	4.80E+09	3.47E+09	5.99E+09	4.90E+09	6.01E+09	1.11E+09	1.53E+09
geotot/$	3.07E+07	3.12E+07	2.47E+07	2.55E+07	2.69E+07	2.98E+07	2.22E+07	4.04E+07	4.34E+07	3.14E+07	5.41E+07	4.43E+07	5.43E+07	1.00E+07	1.39E+07
windtot/$	1.69E+06	1.72E+06	1.36E+06	1.41E+06	1.48E+06	1.64E+06	1.22E+06	2.23E+06	2.40E+06	1.73E+06	2.98E+06	2.44E+06	2.99E+06	5.54E+05	7.65E+05
erotot/$	1.11E+12	1.13E+12	1.07E+12	1.06E+12	1.07E+12	1.08E+12	1.04E+12	1.11E+12	1.08E+12	1.08E+12	4.91E+11	2.48E+11	4.88E+11	3.22E+10	1.07E+11
HR/$	9.71E+11	1.05E+12	8.15E+11	8.74E+11	9.58E+11	5.06E+11	7.79E+11	1.26E+12	1.27E+12	1.03E+12	1.38E+12	1.20E+12	1.38E+12	1.35E+12	1.43E+12
ESO2/$	8.79E+09	1.05E+10	6.92E+09	7.20E+09	8.73E+09	6.33E+09	7.26E+09	1.17E+10	1.24E+10	1.03E+10	1.27E+10	1.05E+10	1.28E+10	2.98E+09	4.33E+09
ENO2/$	1.66E+08	1.77E+08	1.56E+08	1.55E+08	1.63E+08	1.50E+08	1.53E+08	1.76E+08	1.76E+08	1.70E+08	1.70E+08	1.28E+08	1.62E+08	1.61E+07	3.20E+07
EPM10/$	1.93E+07	3.09E+07	1.46E+07	1.49E+07	2.00E+07	8.97E+06	1.86E+07	2.44E+07	2.86E+07	2.71E+07	2.79E+07	2.15E+07	2.81E+07	5.41E+06	1.07E+07
ECO2/$	1.88E+10	2.25E+10	1.49E+10	1.57E+10	1.81E+10	1.26E+10	1.78E+10	2.38E+10	2.48E+10	2.28E+10	2.34E+10	1.72E+10	2.24E+10	7.61E+09	9.79E+09
EMETH/$	4.24E+04	5.39E+04	1.06E+05	1.07E+05	1.20E+05	2.60E+04	4.84E+04	5.27E+04	5.91E+04	5.21E+04	6.49E+04	1.20E+05	7.50E+04	2.12E+04	2.86E+04
EAMM/$	7.27E+06	9.56E+06	6.72E+06	7.15E+06	8.71E+06	3.48E+06	8.92E+06	8.50E+06	9.58E+06	9.90E+06	1.00E+07	8.99E+06	1.01E+07	2.94E+06	3.71E+06
ETOL/$	1.14E+05	1.23E+05	1.35E+05	1.40E+05	1.57E+05	1.00E+05	1.67E+05	1.26E+05	1.50E+05	1.26E+05	1.55E+05	1.16E+05	1.58E+05	5.06E+04	5.66E+04
ETCE/$	1.44E+06	1.61E+06	1.27E+06	1.30E+06	1.52E+06	2.42E+06	2.05E+06	1.51E+06	1.96E+06	1.69E+06	2.07E+06	1.68E+06	2.44E+06	7.08E+05	8.44E+05
ESTY-A/$	5.60E+02	5.89E+02	4.55E+02	4.58E+02	5.47E+02	1.18E+03	7.29E+02	5.66E+02	7.79E+02	6.25E+02	7.68E+02	6.29E+02	9.72E+02	2.92E+02	3.23E+02
ESTY-W/$	4.18E+00	4.97E+00	4.17E+00	4.23E+00	5.46E+00	3.14E+00	4.53E+00	5.00E+00	5.52E+00	5.09E+00	4.98E+00	4.52E+00	5.31E+00	1.94E+00	2.00E+00
ESTY-S/$	1.61E+01	2.17E+01	1.01E+01	9.94E+00	1.70E+01	6.30E+00	1.61E+01	2.13E+01	2.10E+01	2.22E+01	1.65E+01	1.49E+01	1.76E+01	5.40E+00	7.74E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	3.81E+11	1.28E+12	2.53E+11	2.57E+11	4.13E+11	-4.41E+10	6.97E+11	7.10E+11	1.09E+12	1.35E+12	1.52E+12	8.43E+11	1.17E+12	1.64E+13	4.31E+11
REN/$	1.11E+12	1.13E+12	1.07E+12	1.06E+12	1.07E+12	1.08E+12	1.04E+12	1.11E+12	1.08E+12	1.08E+12	4.91E+11	2.48E+11	4.88E+11	4.34E+11	2.44E+12
Impact/$	2.78E+10	3.32E+10	2.20E+10	2.31E+10	2.70E+10	1.91E+10	2.52E+10	3.57E+10	3.75E+10	3.33E+10	3.63E+10	2.79E+10	3.55E+10	1.06E+10	1.42E+10
HR/$	9.71E+11	1.05E+12	8.15E+11	8.74E+11	9.58E+11	5.06E+11	7.79E+11	1.26E+12	1.27E+12	1.03E+12	1.38E+12	1.20E+12	1.38E+12	1.35E+12	1.43E+12
Total/$	2.49E+12	3.50E+12	2.16E+12	2.21E+12	2.47E+12	1.56E+12	2.54E+12	3.11E+12	3.48E+12	3.49E+12	3.43E+12	2.32E+12	3.07E+12	1.82E+13	4.31E+12
ICEC to money ratio (J/$)															
ICEC/$	1.81E+11	1.85E+11	1.78E+11	1.75E+11	1.78E+11	1.76E+11	1.69E+11	1.81E+11	1.76E+11	1.77E+11	8.14E+10	4.14E+10	8.09E+10	4.35E+11	2.44E+12

Continued

Table B.3: ECEC to Money and ICEC to money ratios for 488-sector 1997 model

Table B.3 continued

NAICS	114100	114200	115000	211000	212100	212210	212230	2122A0	212310	212320	212390	213111	213112	21311A	221100
Econ.	3582	2466	12596	91333.1	23316	1919	4532	4776	7819	5590	3752	9494.6	13484.8	1974.7	212960.7
Individual ECEC to money ratios (sej/$)															
LS/$	8.46E+11	3.31E+11	6.08E+11	1.96E+13	5.61E+13	1.17E+14	8.62E+13	5.07E+13	1.87E+14	1.81E+14	2.49E+12	1.31E+12	9.42E+11	1.63E+12	5.80E+12
BS/$	3.06E+10	2.05E+10	2.85E+10	7.86E+09	3.22E+10	1.50E+10	2.63E+10	3.61E+10	1.29E+10	9.80E+09	1.21E+10	2.11E+10	1.46E+10	1.27E+10	1.91E+10
HS/$	1.73E+09	6.57E+09	2.93E+09	4.05E+09	2.27E+09	2.87E+09	2.27E+09	2.25E+09	3.43E+09	3.59E+09	2.15E+09	7.66E+09	3.14E+09	2.33E+09	3.21E+09
AS/$	1.21E+09	3.29E+10	3.92E+10	3.08E+08	4.07E+08	3.63E+08	5.07E+08	6.75E+08	3.07E+08	3.80E+08	4.46E+08	6.59E+08	4.23E+08	1.41E+09	3.85E+08
sltot/$	2.21E+09	1.55E+10	2.09E+10	5.68E+08	2.11E+09	1.62E+09	3.19E+09	3.56E+09	1.49E+09	8.19E+08	9.43E+08	1.51E+09	1.00E+09	1.36E+09	1.20E+09
hydrotot/$	1.08E+09	1.41E+09	2.29E+09	3.91E+09	4.35E+09	2.01E+10	1.17E+10	8.56E+09	6.09E+09	7.39E+09	9.18E+09	2.15E+09	2.52E+09	2.39E+09	1.68E+11
geotot/$	9.74E+06	1.27E+07	2.07E+07	3.53E+07	3.93E+07	1.82E+08	1.06E+08	7.74E+07	5.51E+07	6.68E+07	8.30E+07	1.95E+07	2.28E+07	2.16E+07	1.52E+09
windtot/$	5.37E+05	7.03E+05	1.14E+06	1.95E+06	2.17E+06	1.00E+07	5.85E+06	4.27E+06	3.04E+06	3.68E+06	4.58E+06	1.07E+06	1.26E+06	1.19E+06	8.37E+07
erotot/$	3.11E+09	8.45E+10	1.01E+11	7.91E+08	1.05E+09	9.33E+08	1.30E+09	1.74E+09	7.90E+08	9.76E+08	1.15E+09	1.69E+09	1.09E+09	3.62E+09	9.89E+08
HR/$	1.36E+12	1.40E+12	1.41E+12	8.23E+11	1.55E+12	1.78E+12	1.51E+12	3.12E+12	1.56E+12	1.55E+12	1.49E+12	1.87E+12	2.04E+12	1.92E+12	1.09E+12
ESO2/$	4.82E+09	3.86E+09	7.02E+09	2.39E+10	1.01E+10	7.08E+10	6.01E+10	5.42E+10	1.35E+10	1.52E+10	1.82E+10	2.08E+10	2.04E+10	9.66E+09	2.35E+11
ENO2/$	3.31E+07	2.62E+07	4.22E+07	1.49E+08	4.15E+07	2.09E+08	1.85E+08	1.73E+08	4.85E+07	5.11E+07	6.62E+07	1.37E+08	1.34E+08	4.17E+07	4.98E+08
EPM10/$	8.16E+07	9.76E+06	1.81E+07	1.44E+07	1.79E+08	3.07E+08	2.98E+08	2.84E+08	1.08E+09	1.09E+09	1.13E+09	1.98E+07	1.90E+07	1.09E+09	1.22E+08
ECO2/$	1.15E+10	8.82E+09	1.60E+10	1.84E+11	3.02E+11	5.50E+10	3.88E+10	3.64E+10	3.29E+10	3.63E+10	4.22E+10	1.63E+11	1.61E+11	3.12E+10	1.84E+11
EMETH/$	5.77E+04	2.20E+04	4.11E+04	3.69E+04	5.28E+04	5.39E+04	6.11E+04	7.21E+04	5.05E+04	4.09E+04	5.05E+04	6.84E+04	5.01E+04	5.78E+04	3.92E+04
EAMM/$	9.91E+06	3.05E+06	5.44E+06	7.82E+06	1.02E+07	1.96E+07	1.31E+07	1.47E+07	9.95E+06	8.27E+06	9.18E+06	1.45E+07	9.82E+06	1.49E+07	5.40E+06
ETOL/$	1.88E+05	4.70E+04	8.25E+04	8.84E+04	1.54E+05	1.48E+05	1.87E+05	1.93E+05	1.62E+05	1.42E+05	1.25E+05	1.93E+05	1.53E+05	1.43E+05	8.44E+04
ETCE/$	1.67E+06	6.64E+05	1.17E+06	1.49E+06	3.06E+06	3.20E+06	4.16E+06	3.53E+06	2.96E+06	1.99E+06	1.84E+06	2.65E+06	2.58E+06	2.51E+06	1.15E+06
ESTY-A/$	6.04E+02	2.49E+02	4.26E+02	5.15E+02	1.20E+03	1.03E+03	1.63E+03	1.48E+03	1.09E+03	6.26E+02	6.77E+02	7.61E+02	5.91E+02	7.00E+02	3.83E+02
ESTY-W/$	4.96E+00	1.62E+00	3.21E+00	2.97E+00	4.88E+00	4.54E+00	5.77E+00	8.03E+00	4.80E+00	3.37E+00	4.15E+00	5.73E+00	3.44E+00	4.43E+00	2.41E+00
ESTY-S/$	7.53E+00	6.27E+00	1.46E+01	1.03E+01	1.35E+01	1.50E+01	1.70E+01	3.04E+01	1.64E+01	8.82E+00	1.59E+01	2.14E+01	1.06E+01	1.68E+01	4.57E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	8.76E+11	3.51E+11	6.37E+11	1.96E+13	5.61E+13	1.17E+14	8.62E+13	5.07E+13	1.87E+14	1.81E+14	2.50E+12	1.34E+12	9.56E+11	1.64E+12	5.82E+12
REN/$	3.11E+09	8.45E+10	1.01E+11	4.05E+09	4.35E+09	2.01E+10	1.17E+10	8.56E+09	6.09E+09	7.39E+09	9.18E+09	7.66E+09	3.14E+09	3.62E+09	1.68E+11
Impact/$	1.64E+10	1.27E+10	2.31E+10	2.08E+11	3.13E+11	1.26E+11	9.94E+10	9.11E+10	4.75E+10	5.27E+10	6.16E+10	1.84E+11	1.82E+11	4.20E+10	4.20E+11
HR/$	1.36E+12	1.40E+12	1.41E+12	8.23E+11	1.55E+12	1.78E+12	1.51E+12	3.12E+12	1.56E+12	1.55E+12	1.49E+12	1.87E+12	2.04E+12	1.92E+12	1.09E+12
Total/$	2.26E+12	1.85E+12	2.17E+12	2.07E+13	5.80E+13	1.19E+14	8.78E+13	5.39E+13	1.89E+14	1.83E+14	4.07E+12	3.40E+12	3.18E+12	3.60E+12	7.50E+12
ICEC to money ratio (J/$)															
ICEC/$	2.24E+09	1.55E+10	2.09E+10	1.35E+09	2.13E+09	1.70E+09	3.23E+09	3.61E+09	1.57E+09	9.02E+08	9.80E+08	1.54E+09	1.02E+09	1.38E+09	1.28E+09

Continued

Table B.3 continued

NAICS	221200	221300	230110	230120	230130	230140	230210	230220	230230	230240	230250	230310	230320	230330	230340
Econ.	53413.3	5903.7	172439	26234.4	57679	5429	27486.9	190817.6	43401	17207	90757	36383.7	56012.2	12411.2	17832.7
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	8.82E+12	6.96E+11	3.00E+12	2.29E+12	4.08E+12	4.05E+12	1.68E+12	1.14E+12	7.68E+12	1.79E+12	1.16E+12	4.31E+12	1.15E+12	1.16E+13	2.63E+12
BS/$	1.10E+10	1.51E+10	2.52E+11	1.82E+11	2.58E+11	2.64E+11	5.68E+10	1.23E+11	2.27E+10	2.66E+10	4.64E+10	4.40E+11	2.12E+11	4.98E+10	6.19E+10
HS/$	3.24E+09	1.91E+13	3.85E+09	2.40E+09	3.40E+09	3.33E+09	2.64E+09	2.99E+09	2.78E+09	3.06E+09	2.70E+09	5.62E+09	3.94E+09	3.24E+09	4.25E+09
AS/$	3.23E+08	3.92E+08	2.27E+09	1.17E+09	2.71E+09	1.58E+09	9.49E+08	1.02E+09	5.63E+08	7.87E+08	9.53E+08	3.95E+09	1.37E+09	1.70E+09	1.31E+09
sltot/$	7.42E+08	1.00E+09	1.46E+10	1.09E+10	1.52E+10	1.51E+10	3.56E+09	7.32E+09	1.56E+09	1.89E+09	3.13E+09	2.58E+10	1.26E+10	3.54E+09	4.23E+09
hydrotot/$	2.55E+09	3.59E+09	2.52E+09	2.35E+09	2.86E+09	2.71E+09	1.86E+09	2.04E+09	2.34E+09	2.11E+09	1.74E+09	3.07E+09	2.13E+09	2.69E+09	2.02E+09
geotot/$	2.31E+07	3.24E+07	2.28E+07	2.13E+07	2.59E+07	2.45E+07	1.68E+07	1.84E+07	2.12E+07	1.90E+07	1.57E+07	2.77E+07	1.93E+07	2.44E+07	1.83E+07
windtot/$	1.27E+06	1.79E+06	1.25E+06	1.17E+06	1.43E+06	1.35E+06	9.27E+05	1.01E+06	1.17E+06	1.05E+06	8.66E+05	1.53E+06	1.06E+06	1.34E+06	1.01E+06
erotot/$	8.29E+08	1.01E+09	2.32E+11	2.29E+11	2.33E+11	2.31E+11	2.29E+11	2.29E+11	2.28E+11	2.28E+11	2.29E+11	1.02E+10	3.52E+09	4.38E+09	3.36E+09
HR/$	1.09E+12	1.24E+12	1.53E+12	1.33E+12	2.97E+12	1.90E+13	1.65E+12	1.38E+12	1.95E+12	2.34E+12	1.22E+12	2.08E+12	1.57E+12	1.69E+12	1.51E+12
ESO2/$	2.78E+10	9.47E+10	7.39E+09	7.43E+09	9.43E+09	8.61E+09	5.63E+09	5.55E+09	7.79E+09	7.86E+09	5.05E+09	9.78E+09	5.85E+09	8.67E+09	6.20E+09
ENO2/$	3.05E+08	6.51E+08	4.53E+07	4.40E+07	5.49E+07	5.12E+07	3.49E+07	3.45E+07	4.70E+07	4.46E+07	3.15E+07	1.00E+08	7.79E+07	9.31E+07	7.82E+07
EPM10/$	1.71E+07	2.84E+08	2.05E+08	2.01E+08	2.17E+08	2.14E+08	1.91E+08	1.88E+08	2.29E+08	1.98E+08	1.86E+08	7.87E+08	7.58E+08	8.16E+08	7.66E+08
ECO2/$	1.93E+11	9.39E+10	1.02E+10	1.01E+10	1.31E+10	1.24E+10	8.24E+09	8.28E+09	1.45E+10	1.28E+10	8.21E+09	1.54E+10	9.58E+09	1.88E+10	1.22E+10
EMETH/$	3.65E+04	4.93E+04	2.14E+05	1.36E+05	2.07E+05	2.05E+05	7.97E+04	1.15E+05	6.98E+04	6.52E+04	7.63E+04	3.09E+05	1.42E+05	1.01E+05	8.42E+04
EAMM/$	6.82E+06	6.93E+06	1.52E+07	1.38E+07	1.75E+07	1.78E+07	1.07E+07	1.36E+07	1.32E+07	1.62E+07	1.17E+07	2.19E+07	1.29E+07	1.82E+07	1.52E+07
ETOL/$	9.90E+04	1.02E+05	4.05E+05	3.10E+05	4.78E+05	4.70E+05	2.17E+05	3.24E+05	2.75E+05	1.89E+05	2.62E+05	7.15E+05	3.31E+05	3.84E+05	2.25E+05
ETCE/$	1.30E+06	2.27E+06	6.56E+06	5.77E+06	7.13E+06	7.18E+06	5.08E+06	6.32E+06	4.92E+06	4.36E+06	6.19E+06	9.30E+06	5.88E+06	5.84E+06	4.97E+06
ESTY-A/$	3.78E+02	9.42E+02	2.13E+03	1.41E+03	2.11E+03	2.12E+03	1.17E+03	1.57E+03	1.34E+03	1.13E+03	1.47E+03	2.79E+03	1.65E+03	2.07E+03	1.50E+03
ESTY-W/$	2.68E+00	3.75E+00	1.35E+01	9.19E+00	1.40E+01	1.43E+01	4.81E+00	7.52E+00	6.03E+00	4.25E+00	5.18E+00	2.10E+01	9.80E+00	9.98E+00	6.12E+00
ESTY-S/$	6.02E+00	9.43E+00	1.21E+01	9.23E+00	1.38E+01	1.34E+01	6.76E+00	8.30E+00	9.70E+00	7.28E+00	7.81E+00	1.80E+01	9.20E+00	1.45E+01	8.92E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	8.83E+12	7.11E+11	3.25E+12	2.47E+12	4.34E+12	4.31E+12	1.74E+12	1.26E+12	7.71E+12	1.82E+12	1.20E+12	4.75E+12	1.36E+12	1.16E+13	2.70E+12
REN/$	3.24E+09	1.91E+13	2.32E+11	2.29E+11	2.33E+11	2.31E+11	2.29E+11	2.29E+11	2.28E+11	2.28E+11	2.29E+11	2.58E+10	1.26E+10	4.38E+09	4.25E+09
Impact/$	2.22E+11	1.90E+11	1.79E+10	1.78E+10	2.28E+10	2.13E+10	1.41E+10	1.41E+10	2.26E+10	2.10E+10	1.35E+10	2.61E+10	1.63E+10	2.84E+10	1.93E+10
HR/$	1.09E+12	1.24E+12	1.53E+12	1.33E+12	2.97E+12	1.90E+13	1.65E+12	1.38E+12	1.95E+12	2.34E+12	1.22E+12	2.08E+12	1.57E+12	1.69E+12	1.51E+12
Total/$	1.02E+13	2.13E+13	5.03E+12	4.05E+12	7.57E+12	2.36E+13	3.63E+12	2.89E+12	9.91E+12	4.41E+12	2.67E+12	6.88E+12	2.96E+12	1.33E+13	4.23E+12
ICEC to money ratio (J/$)															
ICEC/$	1.09E+09	1.48E+09	1.47E+10	1.09E+10	1.53E+10	1.51E+10	3.58E+09	7.34E+09	1.60E+09	1.91E+09	3.15E+09	2.59E+10	1.26E+10	3.58E+09	4.25E+09

Continued

Table B.3 continued

NAICS	311111	311119	311211	311212	311213	311221	311222	311223	311225	311230	311310	311320	311330	311340	311410
Econ.	8181.4	20129.4	7864.8	2312.1	768.4	8201.6	13538.9	1625.5	6852.2	8677	7394.3	3847.3	7797.7	5166.8	19205.8
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	7.31E+11	7.95E+11	8.47E+11	8.81E+11	1.19E+12	1.25E+12	4.96E+11	6.98E+11	6.16E+11	6.50E+11	9.68E+11	4.51E+11	4.20E+11	5.00E+11	5.07E+11
BS/$	4.24E+10	2.77E+10	2.41E+10	2.25E+10	2.75E+10	2.50E+10	2.14E+10	2.74E+10	3.50E+10	7.91E+10	2.49E+10	4.59E+10	6.90E+10	6.53E+10	6.89E+10
HS/$	9.34E+09	1.21E+10	1.24E+10	1.35E+10	1.34E+10	1.30E+10	2.06E+10	2.46E+10	1.45E+10	7.62E+09	2.20E+10	5.81E+09	4.44E+09	3.71E+09	5.69E+09
AS/$	1.20E+11	1.67E+11	2.07E+11	2.00E+11	2.04E+11	1.83E+11	3.22E+11	2.83E+11	1.91E+11	9.35E+10	1.50E+11	6.46E+10	3.44E+10	1.97E+10	5.94E+10
sltot/$	5.19E+10	7.10E+10	8.78E+10	8.48E+10	8.65E+10	7.78E+10	1.35E+11	1.20E+11	8.12E+10	4.21E+10	6.38E+10	2.88E+10	1.90E+10	1.30E+10	2.72E+10
hydrotot/$	4.23E+09	4.05E+09	4.25E+09	3.90E+09	6.31E+09	7.94E+09	4.08E+09	5.92E+09	4.42E+09	3.24E+09	4.79E+09	3.12E+09	2.90E+09	3.00E+09	3.95E+09
geotot/$	3.82E+07	3.66E+07	3.84E+07	3.53E+07	5.71E+07	7.18E+07	3.69E+07	5.35E+07	4.00E+07	2.93E+07	4.33E+07	2.82E+07	2.62E+07	2.71E+07	3.57E+07
windtot/$	2.11E+06	2.02E+06	2.12E+06	1.95E+06	3.15E+06	3.96E+06	2.04E+06	2.95E+06	2.20E+06	1.61E+06	2.39E+06	1.56E+06	1.45E+06	1.49E+06	1.97E+06
erotot/$	3.10E+11	4.30E+11	5.34E+11	5.16E+11	5.25E+11	4.71E+11	8.28E+11	7.27E+11	4.91E+11	2.41E+11	3.85E+11	1.66E+11	8.83E+10	5.07E+10	1.53E+11
HR/$	1.41E+12	1.45E+12	1.32E+12	1.41E+12	1.44E+12	1.31E+12	1.16E+12	1.33E+12	1.40E+12	1.64E+12	1.67E+12	1.40E+12	1.36E+12	1.43E+12	1.48E+12
ESO2/$	1.16E+10	1.09E+10	1.07E+10	1.05E+10	1.44E+10	1.63E+10	1.04E+10	1.29E+10	1.13E+10	9.51E+09	1.19E+10	8.17E+09	8.35E+09	8.98E+09	9.57E+09
ENO2/$	8.68E+07	1.04E+08	1.13E+08	1.11E+08	1.29E+08	1.22E+08	1.41E+08	1.35E+08	1.09E+08	7.11E+07	1.06E+08	5.50E+07	4.49E+07	4.05E+07	5.98E+07
EPM10/$	2.35E+07	2.70E+07	2.55E+07	2.63E+07	2.79E+07	3.02E+07	2.22E+07	2.96E+07	2.30E+07	2.15E+07	2.26E+07	1.77E+07	1.63E+07	1.67E+07	1.69E+07
ECO2/$	1.69E+10	1.76E+10	1.72E+10	1.71E+10	2.42E+10	2.57E+10	1.95E+10	2.17E+10	1.86E+10	1.36E+10	2.20E+10	1.15E+10	1.04E+10	1.08E+10	1.27E+10
EMETH/$	2.90E+05	1.39E+05	1.23E+05	9.78E+04	2.05E+05	1.08E+05	8.47E+04	5.53E+04	1.72E+05	4.24E+05	1.46E+05	2.22E+05	4.45E+05	4.79E+05	3.18E+05
EAMM/$	1.75E+07	1.21E+07	8.69E+06	9.71E+06	1.13E+07	9.18E+06	7.94E+06	6.95E+06	1.14E+07	1.64E+07	9.29E+06	1.20E+07	1.61E+07	1.97E+07	1.32E+07
ETOL/$	1.96E+05	1.61E+05	1.10E+05	1.46E+05	1.12E+05	1.21E+05	1.17E+05	1.16E+05	2.39E+05	3.73E+05	1.61E+05	2.21E+05	1.66E+05	1.79E+05	1.63E+05
ETCE/$	4.20E+06	2.46E+06	1.52E+06	2.11E+06	1.45E+06	1.79E+06	1.58E+06	1.47E+06	5.88E+06	3.11E+06	3.07E+06	4.75E+06	2.93E+06	3.46E+06	3.25E+06
ESTY-A/$	1.94E+03	9.49E+02	6.11E+02	8.45E+02	5.74E+02	7.23E+02	6.42E+02	5.51E+02	2.91E+03	1.35E+03	1.46E+03	2.31E+03	1.43E+03	1.67E+03	1.58E+03
ESTY-W/$	8.68E+00	6.63E+00	4.44E+00	5.96E+00	5.25E+00	5.21E+00	4.40E+00	4.07E+00	9.05E+00	8.58E+00	6.09E+00	8.24E+00	8.47E+00	1.09E+01	7.74E+00
ESTY-S/$	1.83E+01	2.68E+01	1.28E+01	2.50E+01	1.29E+01	1.77E+01	1.40E+01	1.39E+01	1.70E+01	1.36E+01	1.32E+01	1.49E+01	1.20E+01	2.59E+01	1.28E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	7.74E+11	8.23E+11	8.71E+11	9.04E+11	1.22E+12	1.27E+12	5.17E+11	7.26E+11	6.51E+11	7.29E+11	9.93E+11	4.97E+11	4.89E+11	5.66E+11	5.76E+11
REN/$	3.10E+11	4.30E+11	5.34E+11	5.16E+11	5.25E+11	4.71E+11	8.28E+11	7.27E+11	4.91E+11	2.41E+11	3.85E+11	1.66E+11	8.83E+10	5.07E+10	1.53E+11
Impact/$	2.86E+10	2.87E+10	2.81E+10	2.78E+10	3.88E+10	4.21E+10	3.00E+10	3.48E+10	3.00E+10	2.32E+10	3.41E+10	1.97E+10	1.88E+10	1.99E+10	2.24E+10
HR/$	1.41E+12	1.45E+12	1.32E+12	1.41E+12	1.44E+12	1.31E+12	1.16E+12	1.33E+12	1.40E+12	1.64E+12	1.67E+12	1.40E+12	1.36E+12	1.43E+12	1.48E+12
Total/$	2.53E+12	2.73E+12	2.75E+12	2.86E+12	3.22E+12	3.10E+12	2.54E+12	2.82E+12	2.57E+12	2.63E+12	3.08E+12	2.08E+12	1.96E+12	2.07E+12	2.23E+12
ICEC to money ratio (J/$)															
ICEC/$	5.19E+10	7.09E+10	8.77E+10	8.47E+10	8.65E+10	7.77E+10	1.35E+11	1.19E+11	8.11E+10	4.21E+10	6.38E+10	2.88E+10	1.90E+10	1.30E+10	2.72E+10

Continued

Table B.3 continued

NAICS	311420	311511	311512	311513	311514	311520	311611	311612	311613	311615	311700	311813	31181A	311821	311822
Econ.	26519.4	20155	1339.8	19660.8	8976	5434.7	52915.3	24046.2	2482.9	33132.4	6587.4	2486.4	28112.5	8689.5	4884.4
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	7.34E+11	9.50E+11	8.67E+11	9.26E+11	6.73E+11	5.96E+11	1.03E+12	7.77E+11	9.32E+11	6.60E+11	7.19E+11	5.05E+11	4.08E+11	4.48E+11	5.15E+11
BS/$	6.63E+10	1.76E+11	1.45E+11	1.72E+11	9.71E+10	1.10E+11	1.52E+11	1.09E+11	4.19E+10	3.18E+10	3.89E+10	6.31E+10	2.93E+10	5.81E+10	4.89E+10
HS/$	5.45E+09	1.26E+10	1.05E+10	1.28E+10	7.90E+09	5.59E+09	1.56E+10	1.03E+10	4.65E+09	8.58E+09	3.32E+09	4.33E+09	3.73E+09	3.82E+09	7.39E+09
AS/$	5.32E+10	1.04E+11	8.09E+10	1.06E+11	6.12E+10	3.41E+10	1.42E+11	7.86E+10	2.53E+10	5.61E+10	1.30E+10	2.72E+10	3.32E+10	2.51E+10	6.90E+10
sltot/$	2.51E+10	4.54E+10	3.58E+10	4.62E+10	2.69E+10	1.79E+10	6.10E+10	3.53E+10	1.19E+10	2.49E+10	7.31E+09	1.37E+10	1.51E+10	1.27E+10	3.07E+10
hydrotot/$	3.56E+09	5.33E+09	4.91E+09	5.13E+09	3.81E+09	4.32E+09	5.48E+09	4.74E+09	6.09E+09	4.69E+09	3.23E+09	3.88E+09	2.85E+09	2.73E+09	3.15E+09
geotot/$	3.21E+07	4.82E+07	4.44E+07	4.64E+07	3.44E+07	3.91E+07	4.95E+07	4.28E+07	5.51E+07	4.24E+07	2.92E+07	3.50E+07	2.58E+07	2.47E+07	2.85E+07
windtot/$	1.77E+06	2.66E+06	2.45E+06	2.56E+06	1.90E+06	2.15E+06	2.73E+06	2.36E+06	3.04E+06	2.34E+06	1.61E+06	1.93E+06	1.42E+06	1.36E+06	1.57E+06
erotot/$	1.37E+11	2.66E+11	2.08E+11	2.73E+11	1.57E+11	8.78E+10	3.66E+11	2.02E+11	6.50E+10	1.44E+11	3.33E+10	6.99E+10	8.53E+10	6.46E+10	1.78E+11
HR/$	1.48E+12	1.64E+12	1.65E+12	1.54E+12	1.22E+12	1.56E+12	1.55E+12	1.75E+12	1.45E+12	1.68E+12	1.85E+12	1.73E+12	7.82E+11	1.53E+12	1.42E+12
ESO2/$	9.65E+09	1.25E+10	1.19E+10	1.19E+10	9.16E+09	1.03E+10	1.25E+10	1.13E+10	1.24E+10	1.05E+10	8.15E+09	9.59E+09	7.00E+09	7.63E+09	8.41E+09
ENO2/$	5.66E+07	1.11E+08	9.78E+07	1.12E+08	7.07E+07	5.60E+07	1.37E+08	9.45E+07	6.13E+07	8.89E+07	4.35E+07	4.60E+07	3.81E+07	3.74E+07	5.76E+07
EPM10/$	1.94E+07	2.54E+07	2.45E+07	2.52E+07	1.85E+07	1.88E+07	2.65E+07	2.36E+07	2.54E+07	2.13E+07	4.64E+07	1.82E+07	1.48E+07	1.53E+07	1.77E+07
ECO2/$	1.33E+10	1.90E+10	1.82E+10	1.89E+10	1.36E+10	1.32E+10	2.08E+10	1.69E+10	1.94E+10	1.50E+10	1.31E+10	1.17E+10	9.38E+09	9.72E+09	1.17E+10
EMETH/$	2.52E+05	2.52E+05	2.18E+05	1.60E+05	1.49E+05	3.35E+05	1.18E+05	2.11E+05	1.03E+05	1.76E+05	1.23E+05	3.54E+05	1.80E+05	3.22E+05	2.62E+05
EAMM/$	2.72E+07	1.44E+07	1.29E+07	1.17E+07	1.11E+07	1.42E+07	1.05E+07	1.17E+07	7.69E+06	9.44E+06	9.62E+06	1.48E+07	7.97E+06	1.36E+07	1.11E+07
ETOL/$	2.02E+05	2.07E+05	2.11E+05	1.97E+05	1.54E+05	2.45E+05	1.84E+05	2.07E+05	1.37E+05	1.30E+05	1.61E+05	1.95E+05	1.30E+05	1.67E+05	1.59E+05
ETCE/$	4.62E+06	4.04E+06	4.51E+06	4.01E+06	3.21E+06	5.11E+06	3.50E+06	4.09E+06	2.66E+06	2.23E+06	2.27E+06	4.25E+06	2.82E+06	3.84E+06	3.49E+06
ESTY-A/$	1.73E+03	1.85E+03	2.13E+03	1.74E+03	1.45E+03	2.51E+03	1.59E+03	1.94E+03	1.24E+03	9.74E+02	9.66E+02	2.08E+03	1.39E+03	1.88E+03	1.64E+03
ESTY-W/$	7.95E+00	8.84E+00	8.40E+00	6.90E+00	5.80E+00	1.02E+01	6.62E+00	7.85E+00	5.66E+00	5.20E+00	5.05E+00	9.27E+00	5.32E+00	7.90E+00	6.97E+00
ESTY-S/$	1.32E+01	1.67E+01	1.56E+01	1.49E+01	1.14E+01	1.54E+01	1.71E+01	1.60E+01	1.49E+01	1.20E+01	7.93E+00	1.62E+01	8.45E+00	1.14E+01	1.13E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	8.00E+11	1.13E+12	1.01E+12	1.10E+12	7.70E+11	7.06E+11	1.18E+12	8.86E+11	9.74E+11	6.92E+11	7.58E+11	5.68E+11	4.38E+11	5.07E+11	5.64E+11
REN/$	1.37E+11	2.66E+11	2.08E+11	2.73E+11	1.57E+11	8.78E+10	3.66E+11	2.02E+11	6.50E+10	1.44E+11	3.33E+10	6.99E+10	8.53E+10	6.46E+10	1.78E+11
Impact/$	2.30E+10	3.17E+10	3.02E+10	3.09E+10	2.29E+10	2.36E+10	3.35E+10	2.83E+10	3.19E+10	2.56E+10	2.13E+10	2.14E+10	1.64E+10	1.74E+10	2.02E+10
HR/$	1.48E+12	1.64E+12	1.65E+12	1.54E+12	1.22E+12	1.56E+12	1.55E+12	1.75E+12	1.45E+12	1.68E+12	1.85E+12	1.73E+12	7.82E+11	1.53E+12	1.42E+12
Total/$	2.44E+12	3.07E+12	2.90E+12	2.94E+12	2.17E+12	2.38E+12	3.13E+12	2.86E+12	2.52E+12	2.54E+12	2.66E+12	2.39E+12	1.32E+12	2.12E+12	2.18E+12
ICEC to money ratio (J/$)															
ICEC/$	2.51E+10	4.54E+10	3.58E+10	4.62E+10	2.69E+10	1.79E+10	6.10E+10	3.53E+10	1.19E+10	2.49E+10	7.32E+09	1.37E+10	1.51E+10	1.27E+10	3.07E+10

Continued

Table B.3 continued

NAICS	311823	311830	311911	311919	311920	311930	311941	311942	311990	312110	312120	312130	312140	312210	312221
Econ.	1759	1064.8	3988	9558.5	7777.7	6431.4	5764.8	3820.4	10983.7	30114.8	21444.9	7704.2	6770.1	3714.1	34763.4
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	4.56E+11	5.10E+11	4.90E+11	5.13E+11	3.89E+11	2.92E+11	8.15E+11	4.01E+11	6.08E+11	8.12E+11	8.66E+11	5.77E+11	4.09E+11	1.15E+12	2.39E+11
BS/$	4.78E+10	3.13E+10	4.44E+10	3.30E+10	4.46E+10	4.14E+10	4.33E+10	3.18E+10	5.62E+10	4.90E+10	3.61E+10	4.37E+10	3.91E+10	1.64E+10	2.45E+10
HS/$	4.50E+09	4.46E+09	1.12E+10	5.39E+09	9.95E+09	2.29E+09	3.44E+09	4.10E+09	7.62E+09	5.11E+09	3.61E+09	4.74E+09	2.35E+09	5.71E+09	1.89E+09
AS/$	3.15E+10	5.35E+10	1.77E+11	6.66E+10	1.48E+11	2.04E+10	2.14E+10	6.71E+10	8.12E+10	1.49E+10	1.14E+10	6.58E+10	3.52E+09	2.60E+11	3.12E+10
sltot/$	1.50E+10	2.36E+10	7.66E+10	2.92E+10	6.39E+10	1.75E+10	1.19E+10	3.08E+10	3.72E+10	1.03E+10	6.19E+09	2.94E+10	3.49E+09	1.09E+11	1.40E+10
hydrotot/$	3.51E+09	3.63E+09	2.81E+09	2.67E+09	2.55E+09	1.44E+09	3.42E+09	2.38E+09	3.90E+09	3.66E+09	3.04E+09	2.68E+09	1.30E+09	4.94E+09	1.33E+09
geotot/$	3.18E+07	3.29E+07	2.54E+07	2.41E+07	2.30E+07	1.30E+07	3.09E+07	2.15E+07	3.52E+07	3.31E+07	2.75E+07	2.42E+07	1.17E+07	4.47E+07	1.20E+07
windtot/$	1.75E+06	1.81E+06	1.40E+06	1.33E+06	1.27E+06	7.16E+05	1.71E+06	1.19E+06	1.94E+06	1.82E+06	1.52E+06	1.33E+06	6.47E+05	2.46E+06	6.61E+05
erotot/$	8.10E+10	1.38E+11	4.54E+11	1.71E+11	3.80E+11	5.25E+10	5.51E+10	1.73E+11	2.09E+11	3.82E+10	2.92E+10	1.69E+11	9.06E+09	6.68E+11	8.02E+10
HR/$	1.29E+12	1.63E+12	1.16E+12	1.35E+12	1.64E+12	6.01E+11	1.38E+12	1.24E+12	1.56E+12	1.44E+12	1.15E+12	1.29E+12	7.17E+11	1.23E+12	7.61E+11
ESO2/$	8.41E+09	8.57E+09	7.69E+09	7.52E+09	7.39E+09	4.68E+09	1.00E+10	6.47E+09	9.64E+09	1.04E+10	8.60E+09	7.20E+09	3.91E+09	1.11E+10	3.61E+09
ENO2/$	4.17E+07	5.22E+07	8.62E+07	5.51E+07	7.83E+07	2.61E+07	4.80E+07	4.85E+07	7.10E+07	4.14E+07	3.72E+07	5.26E+07	2.16E+07	1.27E+08	2.32E+07
EPM10/$	1.46E+07	1.64E+07	1.88E+07	1.50E+07	1.65E+07	9.76E+06	1.96E+07	1.40E+07	1.88E+07	2.01E+07	1.81E+07	1.74E+07	1.06E+07	1.91E+07	6.47E+06
ECO2/$	1.03E+10	1.18E+10	1.31E+10	1.14E+10	1.22E+10	6.61E+09	1.33E+10	9.54E+09	1.41E+10	1.27E+10	1.10E+10	1.05E+10	5.67E+09	2.50E+10	5.57E+09
EMETH/$	2.62E+05	2.07E+05	1.34E+05	2.09E+05	1.52E+05	7.70E+04	2.65E+05	1.47E+05	2.04E+05	1.84E+05	1.70E+05	1.71E+05	8.00E+04	5.40E+04	1.07E+05
EAMM/$	1.18E+07	8.90E+06	1.01E+07	1.10E+07	9.96E+06	6.95E+06	4.05E+07	1.01E+07	1.34E+07	2.49E+07	4.38E+07	3.37E+07	2.74E+07	7.54E+06	5.56E+06
ETOL/$	1.92E+05	1.74E+05	1.45E+05	2.10E+05	1.52E+05	8.63E+04	6.09E+05	1.18E+05	1.44E+05	3.26E+05	2.19E+05	2.20E+05	1.95E+05	1.42E+05	7.55E+04
ETCE/$	4.51E+06	3.94E+06	2.59E+06	5.28E+06	2.73E+06	1.62E+06	1.87E+07	2.57E+06	2.43E+06	9.10E+06	5.72E+06	4.96E+06	4.91E+06	1.71E+06	9.07E+05
ESTY-A/$	2.26E+03	2.00E+03	1.12E+03	2.66E+03	1.23E+03	7.29E+02	8.88E+03	1.15E+03	8.29E+02	4.22E+03	1.58E+03	1.41E+03	1.57E+03	6.10E+02	3.63E+02
ESTY-W/$	8.43E+00	6.86E+00	5.24E+00	8.70E+00	5.48E+00	4.77E+00	2.30E+01	4.88E+00	5.98E+00	1.16E+01	6.88E+00	6.83E+00	5.55E+00	3.79E+00	3.11E+00
ESTY-S/$	1.48E+01	1.06E+01	1.09E+01	1.56E+01	1.10E+01	2.03E+01	4.16E+01	9.95E+00	1.61E+01	1.94E+01	7.43E+00	9.43E+00	4.96E+00	1.19E+01	1.01E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	5.04E+11	5.41E+11	5.35E+11	5.46E+11	4.34E+11	3.34E+11	8.58E+11	4.33E+11	6.64E+11	8.61E+11	9.02E+11	6.21E+11	4.48E+11	1.17E+12	2.63E+11
REN/$	8.10E+10	1.38E+11	4.54E+11	1.71E+11	3.80E+11	5.25E+10	5.51E+10	1.73E+11	2.09E+11	3.82E+10	2.92E+10	1.69E+11	9.06E+09	6.68E+11	8.02E+10
Impact/$	1.88E+10	2.04E+10	2.09E+10	1.90E+10	1.97E+10	1.13E+10	2.35E+10	1.61E+10	2.39E+10	2.32E+10	1.97E+10	1.78E+10	9.65E+09	3.63E+10	9.21E+09
HR/$	1.29E+12	1.63E+12	1.16E+12	1.35E+12	1.64E+12	6.01E+11	1.38E+12	1.24E+12	1.56E+12	1.44E+12	1.15E+12	1.29E+12	7.17E+11	1.23E+12	7.61E+11
Total/$	1.90E+12	2.33E+12	2.17E+12	2.09E+12	2.47E+12	9.98E+11	2.32E+12	1.86E+12	2.45E+12	2.36E+12	2.10E+12	2.10E+12	1.18E+12	3.10E+12	1.11E+12
ICEC to money ratio (J/$)															
ICEC/$	1.50E+10	2.36E+10	7.66E+10	2.92E+10	6.38E+10	1.75E+10	1.19E+10	3.08E+10	3.72E+10	1.03E+10	6.19E+09	2.93E+10	3.49E+09	1.09E+11	1.40E+10

Continued

Table B.3 continued

NAICS	312229	313100	313210	313220	313230	313240	313310	313320	314110	314120	314910	314992	31499A	315111	315119
Econ.	3211.8	12794.8	17985.5	1645.8	4339.5	5697.3	13550.3	2214.3	11631.2	8820.7	2480.1	1191.2	6768.8	1546.7	2868
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	2.89E+11	9.28E+11	9.35E+11	6.13E+11	1.06E+12	8.19E+11	1.30E+12	8.57E+11	8.74E+11	5.59E+11	5.22E+11	9.79E+11	6.28E+11	6.73E+11	6.08E+11
BS/$	1.52E+10	2.50E+10	2.62E+10	2.14E+10	5.44E+10	2.22E+10	4.35E+10	3.81E+10	2.18E+10	2.93E+10	1.98E+10	2.10E+10	2.86E+10	5.58E+10	3.82E+10
HS/$	3.12E+09	1.07E+10	7.72E+09	4.69E+09	4.78E+09	5.14E+09	4.57E+09	4.45E+09	4.56E+09	5.03E+09	4.55E+09	5.29E+09	4.96E+09	4.26E+09	4.19E+09
AS/$	3.54E+10	7.19E+10	4.75E+10	1.02E+10	9.43E+09	2.12E+10	1.60E+10	7.03E+09	1.75E+10	1.66E+10	1.01E+10	9.81E+09	1.35E+10	1.52E+10	1.64E+10
sltot/$	1.54E+10	3.15E+10	2.13E+10	6.13E+09	6.35E+09	1.01E+10	8.81E+09	7.21E+09	8.60E+09	8.43E+09	5.36E+09	5.35E+09	7.12E+09	8.60E+09	8.50E+09
hydrotot/$	1.93E+09	7.59E+09	7.28E+09	4.84E+09	5.73E+09	6.21E+09	6.84E+09	4.38E+09	4.96E+09	4.08E+09	3.48E+09	7.88E+09	4.33E+09	5.63E+09	5.27E+09
geotot/$	1.75E+07	6.86E+07	6.58E+07	4.38E+07	5.18E+07	5.62E+07	6.18E+07	3.96E+07	4.48E+07	3.69E+07	3.15E+07	7.13E+07	3.91E+07	5.09E+07	4.77E+07
windtot/$	9.62E+05	3.78E+06	3.63E+06	2.41E+06	2.86E+06	3.10E+06	3.41E+06	2.19E+06	2.47E+06	2.04E+06	1.74E+06	3.93E+06	2.16E+06	2.80E+06	2.63E+06
erotot/$	9.11E+10	1.85E+11	1.22E+11	2.61E+10	2.42E+10	5.46E+10	4.10E+10	1.81E+10	4.49E+10	4.26E+10	2.58E+10	2.52E+10	3.47E+10	3.90E+10	4.22E+10
HR/$	9.30E+11	1.88E+12	2.02E+12	2.18E+12	1.80E+12	2.07E+12	2.13E+12	1.84E+12	1.72E+12	1.91E+12	2.32E+12	1.81E+12	2.06E+12	2.09E+12	2.19E+12
ESO2/$	4.28E+09	2.14E+10	1.88E+10	1.43E+10	1.68E+10	1.51E+10	1.80E+10	1.40E+10	1.58E+10	1.15E+10	1.20E+10	2.19E+10	1.17E+10	1.39E+10	1.20E+10
ENO2/$	2.63E+07	9.14E+07	7.47E+07	4.76E+07	7.03E+07	5.88E+07	6.32E+07	4.93E+07	6.88E+07	4.14E+07	4.45E+07	8.38E+07	5.22E+07	5.23E+07	4.55E+07
EPM10/$	7.01E+06	2.82E+07	2.57E+07	1.96E+07	2.28E+07	2.03E+07	2.54E+07	1.96E+07	2.09E+07	1.51E+07	1.96E+07	2.55E+07	1.63E+07	1.84E+07	1.63E+07
ECO2/$	6.67E+09	2.38E+10	2.11E+10	1.54E+10	2.12E+10	1.85E+10	2.13E+10	1.73E+10	1.88E+10	1.32E+10	1.23E+10	2.42E+10	1.45E+10	1.59E+10	1.43E+10
EMETH/$	6.68E+04	4.90E+05	4.88E+05	4.54E+05	3.47E+05	2.64E+05	6.08E+05	5.08E+05	2.71E+05	2.37E+05	1.94E+05	2.69E+05	2.12E+05	3.69E+05	2.81E+05
EAMM/$	4.21E+06	7.19E+07	7.48E+07	6.33E+07	3.27E+07	3.73E+07	7.41E+07	7.07E+07	4.02E+07	3.11E+07	2.46E+07	4.37E+07	2.43E+07	3.31E+07	2.76E+07
ETOL/$	7.91E+04	1.96E+06	2.16E+06	2.04E+06	4.74E+05	8.51E+05	2.40E+06	2.17E+06	7.75E+05	8.69E+05	6.92E+05	4.99E+05	5.65E+05	5.79E+05	6.28E+05
ETCE/$	1.37E+06	1.85E+07	2.10E+07	2.04E+07	5.81E+06	8.49E+06	2.24E+07	2.29E+07	8.46E+06	8.70E+06	7.58E+06	5.65E+06	6.44E+06	5.90E+06	6.17E+06
ESTY-A/$	3.75E+02	2.19E+03	2.40E+03	2.97E+03	1.36E+03	1.36E+03	2.31E+03	3.59E+03	1.81E+03	1.33E+03	1.54E+03	1.55E+03	1.43E+03	1.13E+03	9.78E+02
ESTY-W/$	2.06E+00	2.74E+01	1.82E+01	1.77E+01	2.89E+01	1.78E+01	1.36E+01	2.00E+01	2.41E+01	1.05E+01	9.12E+00	3.52E+01	1.28E+01	1.78E+01	1.16E+01
ESTY-S/$	5.04E+00	1.86E+02	1.11E+02	1.08E+02	1.22E+02	1.16E+02	7.24E+01	7.95E+01	1.58E+02	5.82E+01	4.47E+01	2.44E+02	6.26E+01	1.05E+02	6.56E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	3.05E+11	9.53E+11	9.61E+11	6.35E+11	1.11E+12	8.41E+11	1.35E+12	8.95E+11	8.96E+11	5.88E+11	5.42E+11	1.00E+12	6.57E+11	7.29E+11	6.47E+11
REN/$	9.11E+10	1.85E+11	1.22E+11	2.61E+10	2.42E+10	5.46E+10	4.10E+10	1.81E+10	4.49E+10	4.26E+10	2.58E+10	2.52E+10	3.47E+10	3.90E+10	4.22E+10
Impact/$	1.10E+10	4.54E+10	4.01E+10	2.99E+10	3.81E+10	3.37E+10	3.95E+10	3.14E+10	3.48E+10	2.47E+10	2.44E+10	4.63E+10	2.63E+10	3.00E+10	2.64E+10
HR/$	9.30E+11	1.88E+12	2.02E+12	2.18E+12	1.80E+12	2.07E+12	2.13E+12	1.84E+12	1.72E+12	1.91E+12	2.32E+12	1.81E+12	2.06E+12	2.09E+12	2.19E+12
Total/$	1.34E+12	3.06E+12	3.14E+12	2.87E+12	2.98E+12	3.00E+12	3.56E+12	2.78E+12	2.70E+12	2.56E+12	2.91E+12	2.88E+12	2.77E+12	2.89E+12	2.91E+12
ICEC to money ratio (J/$)															
ICEC/$	1.54E+10	3.14E+10	2.12E+10	6.14E+09	6.37E+09	1.01E+10	8.81E+09	7.22E+09	8.60E+09	8.43E+09	5.36E+09	5.36E+09	7.12E+09	8.60E+09	8.50E+09

Continued

Table B.3 continued

NAICS	315190	315200	315900	316100	316200	316900	321113	321114	321219	32121A	32121B	321911	321912	321918	321920
Econ.	5021.8	52156	4577.4	3390.2	3862.5	2723.8	24671.5	4478	5284.8	8579.1	4812.2	8497	5786.5	4501.1	4490.3
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	7.18E+11	4.97E+11	5.03E+11	7.97E+11	5.45E+11	4.34E+11	4.26E+11	5.69E+11	1.16E+12	4.91E+11	3.90E+11	5.07E+11	4.21E+11	4.97E+11	3.71E+11
BS/$	2.09E+10	2.49E+10	4.47E+10	6.85E+10	9.07E+10	2.72E+10	6.25E+12	3.99E+12	1.91E+12	5.51E+12	1.87E+12	1.20E+12	3.20E+12	2.35E+12	2.71E+12
HS/$	4.97E+09	4.54E+09	4.60E+09	8.91E+09	4.77E+09	4.71E+09	2.33E+09	4.03E+09	2.97E+09	2.49E+09	3.17E+09	2.00E+09	2.29E+09	2.42E+09	3.41E+09
AS/$	2.18E+10	1.06E+10	1.14E+10	5.61E+10	1.21E+10	1.24E+10	9.24E+09	5.62E+09	2.52E+09	6.38E+09	3.01E+09	2.06E+09	4.72E+09	3.60E+09	3.87E+09
sltot/$	1.03E+10	6.29E+09	1.21E+10	2.46E+10	1.51E+10	6.23E+09	3.94E+11	2.12E+11	6.79E+10	2.44E+11	1.14E+11	6.81E+10	1.89E+11	1.38E+11	1.52E+11
hydrotot/$	5.06E+09	3.88E+09	3.44E+09	4.54E+09	3.36E+09	2.84E+09	3.38E+09	3.33E+09	8.72E+09	4.17E+09	2.85E+09	3.05E+09	3.71E+09	3.60E+09	3.37E+09
geotot/$	4.57E+07	3.51E+07	3.11E+07	4.10E+07	3.04E+07	2.57E+07	3.05E+07	3.01E+07	7.88E+07	3.77E+07	2.58E+07	2.76E+07	3.36E+07	3.26E+07	3.05E+07
windtot/$	2.52E+06	1.93E+06	1.72E+06	2.26E+06	1.68E+06	1.42E+06	1.68E+06	1.66E+06	4.35E+06	2.08E+06	1.42E+06	1.52E+06	1.85E+06	1.80E+06	1.68E+06
erotot/$	5.59E+10	2.73E+10	2.93E+10	1.44E+11	3.10E+10	3.18E+10	2.38E+10	1.45E+10	6.47E+09	1.64E+10	7.74E+09	5.30E+09	1.21E+10	9.26E+09	9.94E+09
HR/$	2.16E+12	2.02E+12	2.15E+12	1.85E+12	2.23E+12	1.91E+12	1.64E+12	1.79E+12	1.60E+12	1.81E+12	1.94E+12	1.93E+12	1.87E+12	2.02E+12	2.03E+12
ESO2/$	1.23E+10	8.78E+09	8.11E+09	1.02E+10	8.14E+09	6.66E+09	8.26E+09	9.96E+09	1.86E+10	9.96E+09	7.90E+09	7.04E+09	7.74E+09	7.71E+09	6.83E+09
ENO2/$	4.92E+07	3.35E+07	3.42E+07	7.57E+07	3.78E+07	3.05E+07	8.30E+07	1.12E+08	1.11E+08	8.96E+07	9.10E+07	4.23E+07	5.53E+07	5.05E+07	4.75E+07
EPM10/$	1.82E+07	1.32E+07	1.29E+07	2.17E+07	1.57E+07	1.19E+07	6.34E+07	8.74E+07	7.33E+07	6.79E+07	7.44E+07	2.39E+07	3.44E+07	3.05E+07	3.00E+07
ECO2/$	1.55E+10	1.10E+10	1.09E+10	1.67E+10	1.20E+10	9.85E+09	1.45E+10	1.78E+10	2.66E+10	1.61E+10	1.38E+10	1.03E+10	1.19E+10	1.14E+10	1.05E+10
EMETH/$	2.26E+05	1.95E+05	1.75E+05	9.22E+04	2.10E+05	1.07E+05	1.49E+06	2.06E+06	1.64E+06	1.58E+06	1.82E+06	8.08E+05	1.03E+06	9.37E+05	9.28E+05
EAMM/$	3.22E+07	2.36E+07	1.90E+07	9.61E+06	1.49E+07	1.21E+07	4.13E+07	5.91E+07	5.37E+07	4.56E+07	5.08E+07	2.86E+07	2.03E+07	3.09E+07	1.66E+07
ETOL/$	8.07E+05	6.54E+05	4.96E+05	1.36E+05	5.20E+05	3.04E+05	8.01E+05	1.20E+06	9.53E+05	7.99E+05	1.19E+06	3.29E+06	3.10E+06	3.20E+06	3.02E+06
ETCE/$	8.22E+06	6.47E+06	5.44E+06	2.30E+06	1.06E+07	4.36E+06	1.12E+06	1.90E+06	4.33E+06	1.32E+06	3.49E+06	1.35E+07	8.83E+06	1.13E+07	8.48E+06
ESTY-A/$	1.29E+03	9.24E+02	1.05E+03	9.96E+02	4.91E+03	1.39E+03	9.77E+02	1.36E+03	2.10E+03	1.15E+03	1.22E+03	2.41E+03	9.31E+02	1.51E+03	7.68E+02
ESTY-W/$	1.19E+01	7.04E+00	9.16E+00	6.42E+00	1.46E+01	6.48E+00	1.29E+02	1.78E+02	1.46E+02	1.38E+02	1.54E+02	3.27E+01	5.52E+01	4.57E+01	4.63E+01
ESTY-S/$	7.09E+01	3.74E+01	3.39E+01	2.80E+01	3.42E+01	2.28E+01	5.64E+00	2.84E+01	3.00E+01	2.00E+01	5.64E+00	1.40E+01	7.56E+00	8.35E+00	4.11E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	7.39E+11	5.22E+11	5.47E+11	8.65E+11	6.36E+11	4.61E+11	6.68E+12	4.56E+12	3.07E+12	6.00E+12	2.26E+12	1.70E+12	3.62E+12	2.85E+12	3.08E+12
REN/$	5.59E+10	2.73E+10	2.93E+10	1.44E+11	3.10E+10	3.18E+10	3.94E+11	2.12E+11	6.79E+10	2.44E+11	1.14E+11	6.81E+10	1.89E+11	1.38E+11	1.52E+11
Impact/$	2.79E+10	1.99E+10	1.91E+10	2.70E+10	2.02E+10	1.66E+10	2.30E+10	2.80E+10	4.55E+10	2.62E+10	2.19E+10	1.74E+10	1.97E+10	1.93E+10	1.74E+10
HR/$	2.16E+12	2.02E+12	2.15E+12	1.85E+12	2.23E+12	1.91E+12	1.64E+12	1.79E+12	1.60E+12	1.81E+12	1.94E+12	1.93E+12	1.87E+12	2.02E+12	2.03E+12
Total/$	2.98E+12	2.59E+12	2.74E+12	2.89E+12	2.92E+12	2.42E+12	8.73E+12	6.59E+12	4.79E+12	8.08E+12	4.33E+12	3.72E+12	5.70E+12	5.03E+12	5.28E+12
ICEC to money ratio (J/$)															
ICEC/$	1.03E+10	6.29E+09	1.22E+10	2.46E+10	1.51E+10	6.24E+09	3.94E+11	2.12E+11	6.80E+10	2.45E+11	1.14E+11	6.82E+10	1.89E+11	1.38E+11	1.52E+11

Continued

Table B.3 continued

NAICS	321991	321992	321999	322110	3221A0	322210	322225	322226	32222A	32222B	322231	322232	322233	322291	322299
Econ.	10183	2956.2	3779.7	3198.9	68052.7	38913.1	1544.8	1131.6	13125.8	3276.8	1974.8	3478.6	1823	7711.9	3688.4
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	9.68E+11	5.97E+11	4.46E+11	1.80E+12	1.99E+12	1.21E+12	1.30E+12	1.16E+12	9.80E+11	1.00E+12	9.20E+11	8.82E+11	8.63E+11	8.23E+11	7.75E+11
BS/$	6.09E+11	1.42E+12	1.59E+12	3.11E+12	1.38E+12	6.18E+11	7.64E+10	5.73E+11	2.94E+11	4.35E+11	4.95E+11	4.14E+11	4.57E+11	2.66E+11	3.57E+11
HS/$	3.38E+09	3.52E+09	2.37E+09	4.49E+09	4.31E+09	3.27E+09	2.99E+09	4.39E+09	2.87E+09	4.12E+09	4.09E+09	4.15E+09	3.98E+09	2.62E+09	3.87E+09
AS/$	1.87E+09	2.53E+09	3.20E+09	6.94E+09	4.70E+09	2.34E+09	1.33E+09	2.64E+09	2.78E+09	1.91E+09	2.14E+09	1.70E+09	1.87E+09	2.24E+09	1.73E+09
sltot/$	3.57E+10	8.31E+10	8.52E+10	1.05E+11	4.96E+10	2.25E+10	3.71E+09	2.12E+10	1.19E+10	1.61E+10	1.82E+10	1.55E+10	1.70E+10	1.05E+10	1.31E+10
hydrotot/$	2.86E+09	2.82E+09	3.64E+09	7.09E+09	7.37E+09	5.22E+09	5.00E+09	5.27E+09	4.13E+09	4.41E+09	4.12E+09	4.83E+09	3.85E+09	3.94E+09	4.31E+09
geotot/$	2.58E+07	2.55E+07	3.29E+07	6.42E+07	6.66E+07	4.72E+07	4.52E+07	4.76E+07	3.73E+07	3.99E+07	3.72E+07	4.37E+07	3.48E+07	3.56E+07	3.90E+07
windtot/$	1.42E+06	1.41E+06	1.82E+06	3.54E+06	3.67E+06	2.60E+06	2.49E+06	2.63E+06	2.06E+06	2.20E+06	2.05E+06	2.41E+06	1.92E+06	1.96E+06	2.15E+06
erotot/$	4.82E+09	6.50E+09	8.22E+09	1.78E+10	1.21E+10	6.02E+09	3.41E+09	6.80E+09	7.14E+09	4.91E+09	5.52E+09	4.38E+09	4.82E+09	5.77E+09	4.44E+09
HR/$	1.94E+12	2.11E+12	2.06E+12	1.78E+12	1.60E+12	1.92E+12	1.83E+12	1.91E+12	1.15E+12	2.41E+12	1.98E+12	2.18E+12	1.72E+12	1.57E+12	1.82E+12
ESO2/$	8.50E+09	7.09E+09	7.43E+09	3.60E+10	3.78E+10	2.09E+10	3.98E+10	4.25E+10	3.63E+10	3.87E+10	3.86E+10	3.84E+10	3.76E+10	3.57E+10	3.55E+10
ENO2/$	4.14E+07	4.31E+07	4.06E+07	1.25E+08	1.27E+08	7.37E+07	1.25E+08	1.47E+08	1.24E+08	1.33E+08	1.32E+08	1.29E+08	1.28E+08	1.20E+08	1.17E+08
EPM10/$	2.84E+07	2.85E+07	2.39E+07	6.11E+07	6.07E+07	3.52E+07	6.18E+07	6.51E+07	5.58E+07	5.97E+07	5.97E+07	5.80E+07	5.80E+07	5.49E+07	5.37E+07
ECO2/$	1.18E+10	1.07E+10	1.02E+10	3.21E+10	3.17E+10	2.19E+10	2.80E+10	3.03E+10	2.62E+10	2.70E+10	2.61E+10	2.60E+10	2.52E+10	2.49E+10	2.39E+10
EMETH/$	6.95E+05	8.56E+05	8.14E+05	5.48E+06	5.82E+06	2.66E+06	6.06E+06	7.74E+06	6.51E+06	7.10E+06	7.35E+06	7.04E+06	7.23E+06	6.44E+06	6.60E+06
EAMM/$	2.18E+07	2.00E+07	1.98E+07	1.61E+08	1.71E+08	8.15E+07	1.99E+08	2.23E+08	1.92E+08	2.06E+08	2.10E+08	2.02E+08	2.07E+08	1.91E+08	1.89E+08
ETOL/$	3.11E+06	3.36E+06	3.09E+06	4.91E+05	4.82E+05	2.92E+05	9.21E+05	7.43E+05	6.04E+05	5.57E+05	5.30E+05	5.46E+05	5.16E+05	7.20E+05	4.62E+05
ETCE/$	1.65E+07	1.47E+07	1.00E+07	2.38E+06	2.81E+06	2.63E+06	1.85E+07	9.19E+06	6.50E+06	4.55E+06	3.17E+06	4.49E+06	2.69E+06	1.07E+07	2.62E+06
ESTY-A/$	3.29E+03	1.82E+03	1.07E+03	1.42E+03	1.60E+03	1.30E+03	9.46E+03	5.17E+03	3.40E+03	2.61E+03	1.95E+03	2.69E+03	1.59E+03	5.16E+03	1.59E+03
ESTY-W/$	2.40E+01	3.50E+01	3.05E+01	6.92E+01	6.87E+01	3.41E+01	8.44E+01	8.85E+01	7.61E+01	7.95E+01	7.78E+01	7.63E+01	7.56E+01	7.72E+01	6.91E+01
ESTY-S/$	2.02E+01	1.00E+01	7.84E+00	4.31E+01	4.22E+01	3.14E+01	9.53E+01	3.92E+01	4.77E+01	4.25E+01	2.59E+01	3.02E+01	2.18E+01	4.89E+01	2.20E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.58E+12	2.01E+12	2.03E+12	4.91E+12	3.37E+12	1.82E+12	1.38E+12	1.74E+12	1.27E+12	1.44E+12	1.41E+12	1.30E+12	1.32E+12	1.09E+12	1.13E+12
REN/$	3.57E+10	8.31E+10	8.52E+10	1.05E+11	4.96E+10	2.25E+10	5.00E+09	2.12E+10	1.19E+10	1.61E+10	1.82E+10	1.55E+10	1.70E+10	1.05E+10	1.31E+10
Impact/$	2.04E+10	1.79E+10	1.78E+10	6.84E+10	6.99E+10	4.31E+10	6.82E+10	7.32E+10	6.29E+10	6.62E+10	6.52E+10	6.48E+10	6.32E+10	6.10E+10	5.97E+10
HR/$	1.94E+12	2.11E+12	2.06E+12	1.78E+12	1.60E+12	1.92E+12	1.83E+12	1.91E+12	1.15E+12	2.41E+12	1.98E+12	2.18E+12	1.72E+12	1.57E+12	1.82E+12
Total/$	3.57E+12	4.22E+12	4.19E+12	6.87E+12	5.09E+12	3.81E+12	3.29E+12	3.74E+12	2.49E+12	3.93E+12	3.48E+12	3.55E+12	3.12E+12	2.73E+12	3.03E+12
ICEC to money ratio (J/$)															
ICEC/$	3.58E+10	8.32E+10	8.53E+10	1.06E+11	4.97E+10	2.26E+10	3.74E+09	2.12E+10	1.19E+10	1.61E+10	1.82E+10	1.55E+10	1.70E+10	1.05E+10	1.32E+10

Continued

Table B.3 continued

NAICS	323116	323117	323118	32311A	323121	323122	324110	324121	324122	324191	324199	325110	325120	325130	325180
Econ.	9225.2	5538.5	2360.6	72168.1	1963.3	5012.8	155524.7	5842.8	4743.1	5942	1665.1	18357.1	5140.2	6266	24001
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	7.09E+11	6.35E+11	6.20E+11	6.95E+11	4.20E+11	2.51E+11	1.28E+13	2.39E+13	4.91E+12	4.15E+12	5.62E+12	4.10E+12	1.21E+12	7.90E+12	2.95E+12
BS/$	2.69E+11	2.61E+11	1.75E+11	2.45E+11	7.20E+10	4.37E+10	1.22E+10	1.80E+10	5.65E+10	3.30E+10	1.01E+10	2.27E+10	1.67E+10	2.21E+10	2.02E+10
HS/$	3.44E+09	2.28E+09	3.66E+09	2.43E+09	3.12E+09	2.73E+09	3.86E+09	4.84E+09	3.90E+09	3.21E+09	3.72E+09	4.52E+09	3.05E+09	3.98E+09	1.07E+10
AS/$	1.28E+09	1.44E+09	1.08E+09	1.67E+09	7.12E+08	4.30E+08	4.88E+08	5.36E+08	6.34E+08	6.00E+09	3.55E+08	5.07E+09	2.74E+08	1.28E+09	4.85E+08
sltot/$	1.03E+10	9.99E+09	6.91E+09	9.51E+09	3.09E+09	5.51E+09	8.64E+08	1.23E+09	2.64E+09	4.50E+09	6.80E+08	3.55E+09	1.01E+09	1.90E+09	1.30E+09
hydrotot/$	3.18E+09	3.61E+09	3.22E+09	3.67E+09	2.81E+09	2.01E+09	5.25E+09	6.66E+09	4.14E+09	3.64E+09	4.53E+09	5.71E+09	1.86E+10	6.48E+09	1.03E+10
geotot/$	2.88E+07	3.26E+07	2.91E+07	3.32E+07	2.54E+07	1.81E+07	4.75E+07	6.02E+07	3.74E+07	3.29E+07	4.10E+07	5.16E+07	1.69E+08	5.86E+07	9.29E+07
windtot/$	1.59E+06	1.80E+06	1.61E+06	1.83E+06	1.40E+06	1.00E+06	2.62E+06	3.32E+06	2.06E+06	1.81E+06	2.26E+06	2.85E+06	9.30E+06	3.23E+06	5.12E+06
erotot/$	3.30E+09	3.71E+09	2.79E+09	4.29E+09	1.83E+09	1.11E+09	1.25E+09	1.38E+09	1.63E+09	1.54E+10	9.12E+08	1.30E+10	7.04E+08	3.28E+09	1.25E+09
HR/$	1.67E+12	2.01E+12	2.05E+12	1.02E+12	2.34E+12	2.33E+12	1.05E+12	1.66E+12	1.51E+12	1.47E+12	1.19E+12	1.32E+12	1.11E+12	1.57E+12	1.45E+12
ESO2/$	1.26E+10	1.17E+10	9.88E+09	1.23E+10	6.80E+09	4.78E+09	3.14E+10	3.03E+10	2.46E+10	2.45E+10	2.47E+10	2.91E+10	4.08E+10	1.76E+10	3.19E+10
ENO2/$	4.77E+07	4.41E+07	3.65E+07	4.62E+07	2.43E+07	1.71E+07	1.43E+08	1.19E+08	9.46E+07	9.38E+07	9.62E+07	1.07E+08	1.12E+08	5.90E+07	9.87E+07
EPM10/$	2.21E+07	1.98E+07	1.76E+07	2.03E+07	1.22E+07	1.01E+07	2.99E+07	1.48E+08	5.02E+07	3.00E+07	2.70E+07	3.71E+07	3.89E+07	5.20E+07	5.68E+07
ECO2/$	1.28E+10	1.20E+10	1.12E+10	1.28E+10	8.03E+09	5.61E+09	1.33E+11	6.92E+10	4.21E+10	5.44E+10	6.84E+10	5.78E+10	3.52E+10	2.05E+10	2.78E+10
EMETH/$	1.51E+06	1.16E+06	8.60E+05	1.21E+06	3.32E+05	1.45E+05	7.50E+04	8.42E+04	2.64E+05	1.76E+05	6.10E+04	1.43E+05	3.58E+05	1.26E+05	4.06E+05
EAMM/$	4.85E+07	3.85E+07	3.08E+07	4.08E+07	1.53E+07	9.67E+06	6.77E+07	8.16E+07	1.12E+08	8.23E+07	6.97E+07	8.99E+07	6.67E+07	2.14E+07	7.53E+07
ETOL/$	2.12E+05	1.88E+05	4.38E+05	2.09E+05	2.76E+05	1.44E+05	1.22E+06	1.51E+06	1.48E+06	1.54E+06	1.29E+06	1.55E+06	3.92E+05	1.95E+05	4.76E+05
ETCE/$	2.62E+06	2.08E+06	9.47E+06	2.21E+06	3.78E+06	1.18E+06	2.73E+06	3.20E+06	7.94E+06	6.83E+06	2.25E+06	4.45E+06	4.82E+06	2.68E+06	6.50E+06
ESTY-A/$	1.22E+03	9.26E+02	4.72E+03	9.49E+02	1.23E+03	4.33E+02	6.93E+02	7.97E+02	2.07E+03	2.76E+03	5.03E+02	1.31E+03	1.81E+03	9.57E+02	2.34E+03
ESTY-W/$	1.98E+01	1.74E+01	1.94E+01	1.85E+01	8.34E+00	6.01E+00	2.59E+01	3.11E+01	3.36E+01	3.54E+01	2.61E+01	3.99E+01	5.89E+01	1.45E+01	6.44E+01
ESTY-S/$	1.80E+01	3.09E+01	2.44E+01	3.57E+01	2.38E+01	3.22E+01	1.79E+01	1.28E+01	1.62E+01	3.34E+01	7.67E+00	7.12E+01	4.73E+02	8.99E+01	5.09E+02
Aggregate ECEC to money ratios (sej/$)															
NR/$	9.78E+11	8.96E+11	7.95E+11	9.40E+11	4.92E+11	2.95E+11	1.28E+13	2.40E+13	4.97E+12	4.18E+12	5.63E+12	4.12E+12	1.23E+12	7.92E+12	2.97E+12
REN/$	1.03E+10	9.99E+09	6.91E+09	9.51E+09	3.12E+09	5.51E+09	5.25E+09	6.66E+09	4.14E+09	1.54E+10	4.53E+09	1.30E+10	1.86E+10	6.48E+09	1.07E+10
Impact/$	2.55E+10	2.38E+10	2.12E+10	2.51E+10	1.49E+10	1.04E+10	1.65E+11	9.98E+10	6.70E+10	7.91E+10	9.34E+10	8.72E+10	7.62E+10	3.83E+10	5.99E+10
HR/$	1.67E+12	2.01E+12	2.05E+12	1.02E+12	2.34E+12	2.33E+12	1.05E+12	1.66E+12	1.51E+12	1.47E+12	1.19E+12	1.32E+12	1.11E+12	1.57E+12	1.45E+12
Total/$	2.68E+12	2.94E+12	2.87E+12	1.99E+12	2.85E+12	2.64E+12	1.40E+13	2.57E+13	6.55E+12	5.74E+12	6.92E+12	5.54E+12	2.44E+12	9.54E+12	4.50E+12
ICEC to money ratio (J/$)															
ICEC/$	1.03E+10	1.00E+10	6.93E+09	9.53E+09	3.10E+09	5.51E+09	1.36E+09	1.42E+09	2.74E+09	4.66E+09	8.97E+08	3.69E+09	1.04E+09	1.93E+09	1.32E+09

Continued

Table B.3 continued

NAICS	325190	325211	325212	325221	325222	325311	325312	325314	325320	325400	325510	325520	325611	325612	325613
Econ.	59318.4	44981.8	6032.4	1104.9	11940.4	3788.9	5724.1	2955.5	11258.6	84872.5	18075.9	7041	15569.1	7059.3	4647.4
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	2.79E+12	2.87E+12	2.28E+12	9.65E+11	1.45E+12	6.12E+12	2.63E+12	5.57E+12	1.01E+12	3.54E+11	2.91E+12	1.56E+12	8.76E+11	7.35E+11	2.05E+12
BS/$	4.08E+10	2.90E+10	2.77E+10	7.95E+10	3.02E+10	1.26E+10	2.16E+10	2.82E+10	3.83E+10	2.58E+10	2.60E+10	4.22E+10	5.02E+10	3.86E+10	2.68E+10
HS/$	4.69E+09	3.73E+09	3.59E+09	4.94E+09	4.57E+09	5.23E+09	5.80E+09	5.08E+09	2.98E+09	2.10E+09	3.16E+09	3.08E+09	3.14E+09	2.35E+09	4.20E+09
AS/$	6.56E+09	3.11E+09	2.19E+09	2.26E+09	2.94E+09	4.65E+08	7.59E+08	8.70E+08	8.16E+09	3.11E+09	6.13E+09	3.01E+09	5.50E+09	1.49E+09	1.15E+10
sltot/$	6.80E+09	3.20E+09	3.06E+09	4.26E+09	3.11E+09	8.87E+08	1.68E+09	1.73E+09	8.48E+09	2.47E+09	5.39E+09	3.86E+09	4.52E+09	2.31E+09	6.43E+09
hydrotot/$	6.12E+09	5.84E+09	5.10E+09	4.16E+09	6.08E+09	8.79E+09	6.97E+09	4.94E+09	3.29E+09	2.25E+09	3.78E+09	4.21E+09	3.08E+09	2.67E+09	5.21E+09
geotot/$	5.53E+07	5.28E+07	4.61E+07	3.76E+07	5.50E+07	7.95E+07	6.31E+07	4.46E+07	2.98E+07	2.03E+07	3.42E+07	3.81E+07	2.78E+07	2.42E+07	4.71E+07
windtot/$	3.05E+06	2.91E+06	2.54E+06	2.07E+06	3.03E+06	4.38E+06	3.48E+06	2.46E+06	1.64E+06	1.12E+06	1.88E+06	2.10E+06	1.53E+06	1.33E+06	2.60E+06
erotot/$	1.69E+10	7.99E+09	5.62E+09	5.81E+09	7.56E+09	1.19E+09	1.95E+09	2.24E+09	2.10E+10	8.01E+09	1.57E+10	7.73E+09	1.41E+10	3.83E+09	2.94E+10
HR/$	1.58E+12	1.43E+12	1.42E+12	1.67E+12	1.66E+12	1.31E+12	1.64E+12	1.56E+12	1.10E+12	1.31E+12	1.56E+12	1.54E+12	1.37E+12	1.35E+12	1.59E+12
ESO2/$	3.14E+10	2.52E+10	1.62E+10	2.57E+10	2.95E+10	3.63E+10	3.36E+10	3.35E+10	2.56E+10	5.61E+09	1.25E+10	2.63E+10	9.84E+09	8.14E+09	1.59E+10
ENO2/$	1.17E+08	9.70E+07	6.14E+07	9.08E+07	1.06E+08	1.34E+08	1.33E+08	1.20E+08	9.09E+07	2.16E+07	5.17E+07	9.78E+07	3.99E+07	3.00E+07	6.57E+07
EPM10/$	4.46E+07	3.36E+07	2.49E+07	3.49E+07	3.86E+07	4.82E+07	1.86E+08	1.03E+08	5.49E+07	1.13E+07	3.16E+07	5.07E+07	1.88E+07	1.45E+07	2.27E+07
ECO2/$	4.42E+10	4.38E+10	3.13E+10	2.38E+10	3.18E+10	9.10E+10	5.63E+10	5.59E+10	3.98E+10	6.60E+09	1.87E+10	2.95E+10	1.39E+10	1.12E+10	2.91E+10
EMETH/$	4.88E+05	4.15E+05	3.96E+05	7.29E+05	5.22E+05	5.62E+04	1.10E+05	2.99E+05	1.52E+05	3.38E+05	1.47E+05	5.63E+05	2.65E+05	2.08E+05	1.74E+05
EAMM/$	9.68E+07	4.51E+07	3.76E+07	9.10E+07	9.11E+07	8.80E+06	1.62E+07	1.93E+07	2.19E+07	3.19E+07	2.36E+07	8.93E+07	2.22E+07	1.83E+07	3.01E+07
ETOL/$	7.84E+05	9.70E+05	2.62E+06	5.77E+05	6.57E+05	1.22E+05	1.68E+05	1.56E+05	2.38E+05	5.04E+05	3.19E+05	7.31E+05	3.15E+05	3.36E+05	3.61E+05
ETCE/$	8.74E+06	1.55E+07	8.31E+07	6.89E+06	8.19E+06	1.35E+06	2.24E+06	2.00E+06	3.34E+06	7.11E+06	5.10E+06	1.15E+07	6.36E+06	8.00E+06	4.26E+06
ESTY-A/$	3.39E+03	1.98E+03	4.54E+04	2.53E+03	2.88E+03	4.54E+02	8.47E+02	7.95E+02	1.37E+03	1.61E+03	1.67E+03	4.82E+03	3.08E+03	3.98E+03	1.75E+03
ESTY-W/$	8.10E+01	1.11E+02	8.18E+01	7.91E+01	8.49E+01	4.27E+00	1.12E+01	1.17E+01	1.73E+01	6.71E+00	2.42E+01	8.22E+01	1.90E+01	1.53E+01	2.32E+01
ESTY-S/$	5.85E+02	1.38E+02	1.49E+02	5.71E+02	6.04E+02	1.58E+01	6.90E+01	5.98E+01	9.95E+01	2.16E+01	8.05E+01	5.63E+02	8.59E+01	5.19E+01	1.28E+02
Aggregate ECEC to money ratios (sej/$)															
NR/$	2.83E+12	2.90E+12	2.30E+12	1.04E+12	1.48E+12	6.13E+12	2.65E+12	5.60E+12	1.04E+12	3.80E+11	2.94E+12	1.61E+12	9.26E+11	7.73E+11	2.08E+12
REN/$	1.69E+10	7.99E+09	5.62E+09	5.81E+09	7.56E+09	8.79E+09	6.97E+09	5.08E+09	2.10E+10	8.01E+09	1.57E+10	7.73E+09	1.41E+10	3.83E+09	2.94E+10
Impact/$	7.59E+10	6.92E+10	4.77E+10	4.97E+10	6.16E+10	1.27E+11	9.02E+10	8.96E+10	6.55E+10	1.23E+10	3.13E+10	5.60E+10	2.38E+10	1.94E+10	4.51E+10
HR/$	1.58E+12	1.43E+12	1.42E+12	1.67E+12	1.66E+12	1.31E+12	1.64E+12	1.56E+12	1.10E+12	1.31E+12	1.56E+12	1.54E+12	1.37E+12	1.35E+12	1.59E+12
Total/$	4.51E+12	4.41E+12	3.78E+12	2.77E+12	3.20E+12	7.58E+12	4.39E+12	7.26E+12	2.23E+12	1.72E+12	4.55E+12	3.21E+12	2.33E+12	2.14E+12	3.74E+12
ICEC to money ratio (J/$)															
ICEC/$	6.89E+09	3.30E+09	3.14E+09	4.29E+09	3.15E+09	1.10E+09	1.73E+09	1.78E+09	8.50E+09	2.48E+09	5.42E+09	3.91E+09	4.54E+09	2.33E+09	6.49E+09

Continued

Table B.3 continued

NAICS	325620	325910	325920	325991	325992	325998	326110	326120	326130	326160	326192	32619A	3261A0	326210	326220
Econ.	23124.3	4129.8	1271.9	7542.2	12765	11796.1	24203.6	9136.6	3152.1	6413.7	1868	65916.1	11494.6	15616.5	3945.9
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	5.76E+11	2.48E+12	1.18E+12	1.69E+12	5.88E+11	2.72E+12	1.29E+12	1.37E+12	9.68E+11	1.21E+12	9.56E+11	1.08E+12	1.18E+12	1.09E+12	8.94E+11
BS/$	3.58E+10	1.77E+10	3.16E+10	2.87E+10	1.13E+11	3.05E+10	4.74E+10	3.05E+10	1.50E+11	4.56E+10	5.30E+10	3.95E+10	4.91E+10	3.21E+11	5.15E+10
HS/$	1.93E+09	4.02E+09	3.03E+09	4.27E+09	1.89E+09	3.94E+09	2.98E+09	3.99E+09	3.62E+09	3.70E+09	3.10E+09	2.35E+09	2.74E+09	3.10E+09	2.86E+09
AS/$	2.45E+09	1.56E+09	5.20E+08	2.07E+09	1.01E+09	1.02E+10	1.67E+09	1.66E+09	1.57E+09	1.38E+09	1.41E+09	1.44E+09	3.95E+09	3.91E+09	3.54E+09
sltot/$	2.61E+09	1.81E+09	4.35E+09	2.64E+09	4.71E+09	5.89E+09	2.93E+09	2.37E+09	6.33E+09	2.64E+09	2.84E+09	2.45E+09	4.20E+09	9.92E+10	1.13E+10
hydrotot/$	2.24E+09	3.66E+09	3.63E+09	5.19E+09	2.74E+09	4.28E+09	5.35E+09	5.80E+09	4.16E+09	7.31E+09	4.08E+09	4.74E+09	4.67E+09	4.55E+09	4.03E+09
geotot/$	2.03E+07	3.31E+07	3.28E+07	4.69E+07	2.48E+07	3.87E+07	4.84E+07	5.24E+07	3.76E+07	6.61E+07	3.69E+07	4.28E+07	4.23E+07	4.12E+07	3.64E+07
windtot/$	1.12E+06	1.82E+06	1.81E+06	2.59E+06	1.37E+06	2.13E+06	2.67E+06	2.89E+06	2.07E+06	3.65E+06	2.04E+06	2.36E+06	2.33E+06	2.27E+06	2.01E+06
erotot/$	6.29E+09	4.01E+09	1.34E+09	5.33E+09	2.59E+09	2.62E+10	4.29E+09	4.28E+09	4.05E+09	3.55E+09	3.62E+09	3.70E+09	1.02E+10	1.00E+10	9.10E+09
HR/$	1.21E+12	1.65E+12	1.73E+12	1.72E+12	1.41E+12	1.60E+12	1.67E+12	1.77E+12	1.83E+12	1.65E+12	1.40E+12	2.74E+12	1.70E+12	1.83E+12	1.76E+12
ESO2/$	6.45E+09	2.43E+10	2.39E+10	2.95E+10	2.33E+10	2.60E+10	1.54E+10	1.63E+10	1.28E+10	1.72E+10	1.16E+10	1.27E+10	1.40E+10	1.24E+10	1.09E+10
ENO2/$	2.55E+07	9.01E+07	8.77E+07	1.09E+08	8.22E+07	9.79E+07	5.83E+07	6.18E+07	5.00E+07	5.96E+07	4.21E+07	4.67E+07	5.34E+07	4.89E+07	3.91E+07
EPM10/$	1.17E+07	3.91E+07	3.32E+07	4.11E+07	3.41E+07	4.74E+07	2.29E+07	2.34E+07	2.20E+07	2.16E+07	1.74E+07	1.95E+07	2.21E+07	2.24E+07	1.94E+07
ECO2/$	8.85E+09	2.66E+10	2.76E+10	3.08E+10	1.86E+10	2.81E+10	2.16E+10	2.31E+10	1.63E+10	2.22E+10	1.55E+10	1.77E+10	1.99E+10	1.81E+10	1.54E+10
EMETH/$	1.91E+05	4.31E+05	4.39E+05	5.63E+05	9.13E+05	4.98E+05	5.40E+05	4.73E+05	9.47E+05	5.26E+05	5.15E+05	4.69E+05	5.22E+05	3.91E+05	4.23E+05
EAMM/$	1.74E+07	8.10E+07	7.27E+07	9.57E+07	9.32E+07	8.78E+07	3.57E+07	3.24E+07	5.27E+07	2.87E+07	2.65E+07	3.08E+07	3.76E+07	3.02E+07	2.93E+07
ETOL/$	3.56E+05	5.62E+05	4.17E+05	7.75E+05	5.52E+05	6.24E+05	2.70E+06	2.63E+06	2.66E+06	2.67E+06	2.44E+06	2.64E+06	2.71E+06	2.73E+06	2.76E+06
ETCE/$	8.91E+06	6.77E+06	5.12E+06	1.13E+07	7.78E+06	8.36E+06	9.03E+07	8.73E+07	9.05E+07	9.00E+07	8.35E+07	8.95E+07	8.96E+07	9.42E+07	9.30E+07
ESTY-A/$	4.39E+03	2.35E+03	1.98E+03	3.65E+03	3.26E+03	3.15E+03	4.81E+04	4.63E+04	4.86E+04	4.81E+04	4.54E+04	4.81E+04	4.79E+04	5.13E+04	5.02E+04
ESTY-W/$	1.38E+01	7.27E+01	6.41E+01	9.86E+01	7.76E+01	7.62E+01	9.83E+01	9.98E+01	8.73E+01	9.59E+01	8.15E+01	8.83E+01	9.00E+01	8.20E+01	8.00E+01
ESTY-S/$	3.61E+01	5.28E+02	5.11E+02	6.06E+02	5.66E+02	5.70E+02	1.39E+02	1.44E+02	9.98E+01	1.16E+02	1.18E+02	1.14E+02	1.54E+02	1.37E+02	1.09E+02
Aggregate ECEC to money ratios (sej/$)															
NR/$	6.11E+11	2.50E+12	1.21E+12	1.72E+12	7.01E+11	2.75E+12	1.34E+12	1.41E+12	1.12E+12	1.25E+12	1.01E+12	1.12E+12	1.23E+12	1.41E+12	9.45E+11
REN/$	6.29E+09	4.02E+09	4.35E+09	5.33E+09	4.71E+09	2.62E+10	5.35E+09	5.80E+09	6.33E+09	7.31E+09	4.08E+09	4.74E+09	1.02E+10	9.92E+10	1.13E+10
Impact/$	1.54E+10	5.11E+10	5.17E+10	6.06E+10	4.20E+10	5.44E+10	3.72E+10	3.97E+10	2.93E+10	3.96E+10	2.72E+10	3.06E+10	3.41E+10	3.07E+10	2.65E+10
HR/$	1.21E+12	1.65E+12	1.73E+12	1.72E+12	1.41E+12	1.60E+12	1.67E+12	1.77E+12	1.83E+12	1.65E+12	1.40E+12	2.74E+12	1.70E+12	1.83E+12	1.76E+12
Total/$	1.85E+12	4.21E+12	3.00E+12	3.50E+12	2.16E+12	4.43E+12	3.06E+12	3.22E+12	2.98E+12	2.96E+12	2.44E+12	3.90E+12	2.97E+12	3.37E+12	2.74E+12
ICEC to money ratio (J/$)															
ICEC/$	2.62E+09	1.86E+09	4.38E+09	2.68E+09	4.72E+09	5.93E+09	2.97E+09	2.41E+09	6.36E+09	2.68E+09	2.87E+09	2.48E+09	4.23E+09	9.93E+10	1.14E+10

Continued

Table B.3 continued

NAICS	326290	327111	327112	327113	327121	327122	327125	32712A	327213	32721A	327310	327320	327331	327332	327390
Econ.	14361.7	1068.5	1602	1186	1370.6	830.3	1538.3	1211.5	4153.2	18250.5	6341.4	17808.5	2379	1925	5802.5
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.05E+12	7.46E+12	9.24E+12	1.04E+13	6.88E+12	1.13E+13	1.53E+13	2.19E+13	4.95E+12	3.20E+12	4.95E+12	2.22E+13	1.35E+13	7.16E+12	8.22E+12
BS/$	1.57E+11	3.85E+10	4.57E+10	3.54E+10	6.41E+10	7.01E+10	3.12E+10	4.94E+10	7.10E+10	5.10E+10	2.99E+10	1.85E+10	2.16E+10	3.39E+10	3.27E+10
HS/$	2.74E+09	2.60E+09	3.11E+09	2.96E+09	3.33E+09	4.08E+09	3.10E+09	3.12E+09	2.38E+09	2.26E+09	3.86E+09	3.79E+09	3.59E+09	3.68E+09	3.49E+09
AS/$	2.87E+09	4.20E+08	4.38E+08	3.89E+08	5.83E+08	8.44E+08	4.34E+08	5.86E+08	5.39E+08	6.35E+08	3.23E+08	3.99E+08	4.24E+08	3.94E+08	4.36E+08
sltot/$	4.41E+10	2.00E+09	2.47E+09	2.05E+09	3.83E+09	4.24E+09	1.98E+09	3.00E+09	3.00E+09	3.00E+09	1.75E+09	1.27E+09	1.36E+09	2.13E+09	2.11E+09
hydrotot/$	4.46E+09	3.85E+09	3.81E+09	4.80E+09	8.89E+09	5.13E+09	4.93E+09	4.60E+09	8.16E+09	5.12E+09	1.39E+10	5.03E+09	4.72E+09	4.04E+09	3.41E+09
geotot/$	4.03E+07	3.48E+07	3.44E+07	4.34E+07	8.04E+07	4.64E+07	4.46E+07	4.16E+07	7.38E+07	4.63E+07	1.25E+08	4.55E+07	4.27E+07	3.65E+07	3.08E+07
windtot/$	2.22E+06	1.92E+06	1.90E+06	2.39E+06	4.43E+06	2.56E+06	2.46E+06	2.29E+06	4.07E+06	2.55E+06	6.91E+06	2.51E+06	2.35E+06	2.02E+06	1.70E+06
erotot/$	7.37E+09	1.08E+09	1.13E+09	1.00E+09	1.50E+09	2.17E+09	1.12E+09	1.51E+09	1.39E+09	1.63E+09	8.32E+08	1.03E+09	1.09E+09	1.01E+09	1.12E+09
HR/$	1.87E+12	1.82E+12	2.13E+12	1.99E+12	1.94E+12	1.97E+12	1.75E+12	1.88E+12	1.70E+12	1.86E+12	1.29E+12	1.75E+12	1.94E+12	1.92E+12	2.00E+12
ESO2/$	1.18E+10	2.57E+10	2.57E+10	2.71E+10	3.29E+10	2.74E+10	2.93E+10	2.91E+10	2.12E+10	1.64E+10	4.10E+10	3.08E+10	2.86E+10	2.84E+10	2.65E+10
ENO2/$	4.28E+07	1.13E+08	1.14E+08	1.18E+08	1.35E+08	1.23E+08	1.35E+08	1.41E+08	1.21E+08	1.12E+08	1.52E+08	1.42E+08	1.29E+08	1.21E+08	1.16E+08
EPM10/$	2.13E+07	1.19E+08	1.30E+08	1.46E+08	1.16E+08	1.44E+08	1.74E+08	2.14E+08	7.11E+07	5.92E+07	1.11E+08	2.23E+08	1.75E+08	1.31E+08	1.35E+08
ECO2/$	1.64E+10	2.43E+10	2.34E+10	2.48E+10	3.82E+10	2.84E+10	2.81E+10	3.07E+10	3.26E+10	2.59E+10	4.27E+10	3.06E+10	2.74E+10	2.83E+10	2.51E+10
EMETH/$	4.30E+05	1.31E+05	1.36E+05	8.62E+04	7.22E+04	8.17E+04	4.75E+04	6.97E+04	5.27E+05	3.82E+05	1.07E+05	6.40E+04	7.09E+04	7.54E+04	6.91E+04
EAMM/$	2.95E+07	9.14E+06	8.39E+06	8.79E+06	8.07E+06	9.08E+06	5.36E+06	8.00E+06	4.66E+08	5.10E+08	6.64E+06	7.74E+06	6.16E+06	1.95E+07	1.30E+07
ETOL/$	2.82E+06	1.14E+05	1.35E+05	1.22E+05	1.70E+05	1.68E+05	9.53E+04	1.69E+05	1.96E+06	2.22E+06	8.78E+04	9.88E+04	1.01E+05	1.69E+05	1.81E+05
ETCE/$	9.56E+07	2.10E+06	2.43E+06	2.38E+06	2.56E+06	2.21E+06	1.04E+06	2.30E+06	6.48E+07	7.29E+07	1.09E+06	1.37E+06	1.21E+06	4.35E+06	4.33E+06
ESTY-A/$	5.13E+04	7.97E+02	9.09E+02	1.00E+03	6.56E+02	7.07E+02	3.60E+02	7.59E+02	1.66E+04	1.90E+04	4.12E+02	5.02E+02	4.25E+02	1.09E+03	1.08E+03
ESTY-W/$	8.21E+01	4.46E+00	4.78E+00	3.78E+00	5.23E+00	7.03E+00	3.34E+00	5.13E+00	5.75E+01	6.40E+01	3.36E+00	4.49E+00	2.82E+00	3.85E+00	3.85E+00
ESTY-S/$	1.19E+02	1.22E+01	1.13E+01	6.57E+00	1.76E+01	2.71E+01	1.20E+01	1.66E+01	2.25E+01	3.63E+01	8.27E+00	2.11E+01	6.72E+00	7.38E+00	7.92E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.21E+12	7.50E+12	9.28E+12	1.04E+13	6.94E+12	1.14E+13	1.53E+13	2.20E+13	5.02E+12	3.25E+12	4.98E+12	2.22E+13	1.35E+13	7.19E+12	8.25E+12
REN/$	4.41E+10	3.85E+09	3.81E+09	4.80E+09	8.89E+09	5.13E+09	4.93E+09	4.60E+09	8.16E+09	5.12E+09	1.39E+10	5.03E+09	4.72E+09	4.04E+09	3.49E+09
Impact/$	2.84E+10	5.02E+10	4.94E+10	5.21E+10	7.14E+10	5.61E+10	5.78E+10	6.01E+10	5.45E+10	4.31E+10	8.39E+10	6.18E+10	5.63E+10	5.70E+10	5.18E+10
HR/$	1.87E+12	1.82E+12	2.13E+12	1.99E+12	1.94E+12	1.97E+12	1.75E+12	1.88E+12	1.70E+12	1.86E+12	1.29E+12	1.75E+12	1.94E+12	1.92E+12	2.00E+12
Total/$	3.15E+12	9.37E+12	1.15E+13	1.25E+13	8.97E+12	1.34E+13	1.72E+13	2.39E+13	6.79E+12	5.16E+12	6.37E+12	2.40E+13	1.55E+13	9.17E+12	1.03E+13
ICEC to money ratio (J/$)															
ICEC/$	4.41E+10	2.02E+09	2.49E+09	2.06E+09	3.87E+09	4.26E+09	2.00E+09	3.03E+09	3.02E+09	3.02E+09	1.78E+09	1.29E+09	1.38E+09	2.15E+09	2.13E+09

Continued

Table B.3 continued

NAICS	327410	327420	327910	327991	327992	327993	327999	331111	331112	331210	331221	331222	331311	331312	331314
Econ.	1139.4	4290.8	4561.5	1221.5	2359.4	4298.7	1677.9	57131.8	1200.6	7438.6	6386.6	4817.6	1193.4	6151.1	3581.2
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.82E+13	9.38E+12	1.52E+12	1.98E+13	3.78E+12	2.07E+12	9.19E+12	9.27E+12	4.20E+12	3.70E+12	3.79E+12	3.19E+12	4.72E+12	1.00E+13	1.98E+12
BS/$	6.72E+10	2.15E+11	6.00E+10	7.03E+10	8.81E+09	4.62E+10	3.11E+10	2.01E+10	2.40E+10	1.58E+10	2.22E+10	1.66E+10	1.92E+10	2.10E+10	1.80E+10
HS/$	3.83E+09	3.74E+09	2.10E+09	3.38E+09	3.31E+09	2.30E+09	3.14E+09	1.36E+10	2.84E+09	7.01E+09	6.17E+09	6.46E+09	4.26E+09	5.23E+09	2.05E+09
AS/$	5.04E+08	1.00E+09	2.06E+09	5.92E+08	2.37E+08	1.72E+09	6.18E+08	4.18E+08	4.79E+08	3.79E+08	4.97E+08	3.89E+08	9.80E+08	5.53E+08	3.70E+08
sltot/$	3.69E+09	8.20E+09	3.53E+09	4.24E+09	5.74E+08	2.87E+09	2.67E+09	1.34E+09	1.55E+09	1.04E+09	1.49E+09	1.09E+09	1.57E+09	1.56E+09	1.19E+09
hydrotot/$	1.32E+10	6.92E+09	3.68E+09	4.00E+09	5.86E+09	7.66E+09	4.64E+09	7.99E+09	1.41E+10	5.40E+09	6.05E+09	5.69E+09	8.44E+09	2.81E+10	4.80E+09
geotot/$	1.20E+08	6.26E+07	3.33E+07	3.62E+07	5.30E+07	6.92E+07	4.19E+07	7.23E+07	1.27E+08	4.88E+07	5.48E+07	5.15E+07	7.63E+07	2.54E+08	4.34E+07
windtot/$	6.59E+06	3.45E+06	1.84E+06	2.00E+06	2.92E+06	3.82E+06	2.31E+06	3.98E+06	7.01E+06	2.69E+06	3.02E+06	2.84E+06	4.21E+06	1.40E+07	2.39E+06
erotot/$	1.29E+09	2.57E+09	5.29E+09	1.52E+09	6.09E+08	4.43E+09	1.59E+09	1.08E+09	1.23E+09	9.74E+08	1.28E+09	1.00E+09	2.52E+09	1.42E+09	9.51E+08
HR/$	1.77E+12	1.59E+12	1.52E+12	2.12E+12	1.25E+12	1.58E+12	1.63E+12	1.66E+12	1.41E+12	1.69E+12	1.79E+12	1.73E+12	1.95E+12	1.81E+12	1.21E+12
ESO2/$	4.14E+10	3.53E+10	2.66E+10	2.60E+10	2.91E+10	3.26E+10	2.80E+10	3.46E+10	4.21E+10	3.34E+10	3.54E+10	3.27E+10	4.34E+10	7.24E+10	3.08E+10
ENO2/$	1.69E+08	1.55E+08	1.21E+08	1.19E+08	1.19E+08	1.34E+08	1.21E+08	1.10E+08	1.14E+08	1.01E+08	1.08E+08	9.79E+07	1.01E+08	1.44E+08	5.58E+07
EPM10/$	1.88E+08	1.98E+08	1.46E+08	1.92E+08	1.06E+08	1.32E+08	1.36E+08	1.15E+08	1.01E+08	1.09E+08	1.12E+08	1.05E+08	7.75E+07	9.62E+07	4.24E+07
ECO2/$	5.55E+10	3.73E+10	2.44E+10	2.53E+10	2.90E+10	3.22E+10	2.64E+10	8.08E+10	7.44E+10	8.15E+10	8.47E+10	7.88E+10	3.98E+10	4.68E+10	1.38E+10
EMETH/$	2.38E+05	1.01E+06	2.70E+05	8.17E+04	3.81E+04	2.98E+05	7.90E+04	8.09E+04	7.79E+04	7.88E+04	1.11E+05	7.78E+04	1.18E+05	7.87E+04	5.96E+04
EAMM/$	1.23E+07	3.41E+07	1.67E+07	7.19E+06	9.49E+06	2.93E+07	1.10E+07	1.61E+08	1.56E+08	1.99E+08	2.05E+08	1.92E+08	1.37E+08	1.39E+08	1.14E+08
ETOL/$	1.51E+05	1.58E+05	2.28E+05	1.48E+05	5.20E+04	2.32E+05	1.53E+05	2.41E+05	2.20E+05	2.62E+05	4.64E+05	2.55E+05	2.23E+05	1.52E+05	1.06E+05
ETCE/$	1.79E+06	1.78E+06	3.58E+06	1.57E+06	1.03E+06	5.11E+06	3.15E+06	1.12E+07	1.04E+07	1.36E+07	1.75E+07	1.32E+07	5.23E+06	4.53E+06	3.50E+06
ESTY-A/$	6.78E+02	7.70E+02	1.38E+03	5.38E+02	2.34E+02	1.87E+03	1.19E+03	5.10E+02	3.95E+02	4.03E+02	1.15E+03	4.00E+02	9.61E+02	6.54E+02	4.76E+02
ESTY-W/$	6.08E+00	1.39E+01	9.85E+00	4.47E+00	1.58E+00	1.14E+01	6.37E+00	3.63E+00	3.47E+00	2.63E+00	4.51E+00	2.73E+00	1.16E+01	4.96E+00	2.66E+00
ESTY-S/$	1.17E+01	1.40E+01	3.73E+01	1.33E+01	4.51E+00	2.79E+01	1.60E+01	1.26E+01	1.39E+01	7.90E+00	1.19E+01	9.15E+00	6.63E+01	2.07E+01	7.73E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.83E+13	9.60E+12	1.58E+12	1.99E+13	3.79E+12	2.12E+12	9.23E+12	9.29E+12	4.22E+12	3.72E+12	3.81E+12	3.21E+12	4.74E+12	1.00E+13	2.00E+12
REN/$	1.32E+10	8.20E+09	5.29E+09	4.24E+09	5.86E+09	7.66E+09	4.64E+09	1.36E+10	1.41E+10	7.01E+09	6.17E+09	6.46E+09	8.44E+09	2.81E+10	4.80E+09
Impact/$	9.72E+10	7.30E+10	5.14E+10	5.17E+10	5.83E+10	6.51E+10	5.46E+10	1.16E+11	1.17E+11	1.15E+11	1.21E+11	1.12E+11	8.35E+10	1.20E+11	4.48E+10
HR/$	1.77E+12	1.59E+12	1.52E+12	2.12E+12	1.25E+12	1.58E+12	1.63E+12	1.66E+12	1.41E+12	1.69E+12	1.79E+12	1.73E+12	1.95E+12	1.81E+12	1.21E+12
Total/$	2.01E+13	1.13E+13	3.15E+12	2.21E+13	5.10E+12	3.77E+12	1.09E+13	1.11E+13	5.77E+12	5.52E+12	5.73E+12	5.06E+12	6.78E+12	1.20E+13	3.25E+12
ICEC to money ratio (J/$)															
ICEC/$	3.75E+09	8.24E+09	3.55E+09	4.27E+09	5.89E+08	2.89E+09	2.69E+09	1.36E+09	1.57E+09	1.05E+09	1.51E+09	1.10E+09	1.62E+09	1.60E+09	1.20E+09

Continued

Table B.3 continued

NAICS	331315	331316	331319	331411	331419	331421	331422	331423	331491	331492	331510	33152A	33152B	332111	332112
Econ.	13440.3	6182.4	1646.6	6360.8	3471.3	7534	1030.7	1175.7	7197.1	3100.5	17207.6	7619.8	3787.1	4956.2	1859.8
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	3.52E+12	3.59E+12	5.96E+12	2.63E+13	1.80E+13	1.02E+13	4.36E+12	2.82E+12	1.20E+13	7.56E+12	4.43E+12	2.40E+12	2.94E+12	2.41E+12	3.02E+12
BS/$	1.87E+10	1.82E+10	1.87E+10	2.77E+10	2.65E+10	2.06E+10	7.34E+10	2.24E+10	4.94E+10	2.72E+10	2.07E+10	3.27E+10	2.43E+10	1.62E+10	1.39E+10
HS/$	4.26E+09	3.04E+09	4.70E+09	4.90E+09	3.91E+09	3.04E+09	2.62E+09	1.98E+09	2.82E+09	2.03E+09	2.50E+09	2.61E+09	3.50E+09	3.88E+09	3.33E+09
AS/$	4.42E+08	4.42E+08	4.47E+08	5.52E+08	4.48E+08	4.44E+08	1.12E+09	3.94E+08	6.26E+08	3.99E+08	3.68E+08	4.48E+08	4.61E+08	3.96E+08	3.32E+08
sltot/$	1.28E+09	1.24E+09	1.30E+09	2.20E+09	2.01E+09	1.50E+09	7.25E+09	1.47E+09	4.40E+09	1.83E+09	1.36E+09	2.03E+09	1.56E+09	1.12E+09	9.78E+08
hydrotot/$	1.08E+10	1.08E+10	1.20E+10	8.15E+09	1.04E+10	6.11E+09	4.81E+09	3.37E+09	6.63E+09	4.94E+09	6.57E+09	7.01E+09	5.66E+09	5.61E+09	5.39E+09
geotot/$	9.76E+07	9.74E+07	1.09E+08	7.37E+07	9.40E+07	5.52E+07	4.35E+07	3.05E+07	6.00E+07	4.47E+07	5.94E+07	6.34E+07	5.11E+07	5.07E+07	4.87E+07
windtot/$	5.38E+06	5.37E+06	6.00E+06	4.06E+06	5.18E+06	3.04E+06	2.40E+06	1.68E+06	3.31E+06	2.46E+06	3.28E+06	3.50E+06	2.82E+06	2.80E+06	2.68E+06
erotot/$	1.14E+09	1.14E+09	1.15E+09	1.42E+09	1.15E+09	1.14E+09	2.87E+09	1.01E+09	1.61E+09	1.02E+09	9.47E+08	1.15E+09	1.18E+09	1.02E+09	8.54E+08
HR/$	1.68E+12	1.82E+12	1.70E+12	1.80E+12	1.91E+12	1.67E+12	1.90E+12	1.33E+12	1.90E+12	1.52E+12	1.91E+12	1.62E+12	1.33E+12	1.81E+12	1.74E+12
ESO2/$	4.96E+10	4.87E+10	5.62E+10	6.69E+10	5.04E+10	5.07E+10	4.18E+10	3.02E+10	4.52E+10	3.27E+10	2.92E+10	3.79E+10	3.48E+10	3.07E+10	3.60E+10
ENO2/$	7.93E+07	7.69E+07	8.70E+07	1.17E+08	1.04E+08	7.73E+07	6.12E+07	5.39E+07	7.53E+07	6.10E+07	8.51E+07	5.74E+07	5.12E+07	8.92E+07	5.04E+07
EPM10/$	6.45E+07	6.40E+07	7.89E+07	1.58E+08	1.22E+08	9.03E+07	6.52E+07	4.80E+07	9.15E+07	6.23E+07	9.40E+07	5.33E+07	5.35E+07	9.33E+07	5.26E+07
ECO2/$	2.29E+10	2.24E+10	2.46E+10	2.70E+10	2.61E+10	1.82E+10	1.58E+10	1.18E+10	1.97E+10	1.45E+10	6.04E+10	1.71E+10	1.49E+10	7.05E+10	1.65E+10
EMETH/$	7.18E+04	7.34E+04	7.69E+04	9.09E+04	6.82E+04	7.55E+04	1.24E+05	6.50E+04	9.59E+04	6.46E+04	6.68E+04	1.57E+05	8.16E+04	8.06E+04	6.53E+04
EAMM/$	1.64E+08	1.59E+08	1.82E+08	2.10E+08	1.24E+08	1.85E+08	1.70E+08	1.18E+08	1.57E+08	1.10E+08	1.46E+08	1.37E+08	1.28E+08	1.76E+08	1.39E+08
ETOL/$	1.34E+05	1.35E+05	1.34E+05	1.74E+05	1.35E+05	1.32E+05	2.74E+05	1.13E+05	2.24E+05	1.22E+05	2.04E+05	1.41E+05	1.23E+05	2.99E+05	1.60E+05
ETCE/$	4.88E+06	4.92E+06	5.21E+06	6.44E+06	4.22E+06	5.19E+06	6.93E+06	3.64E+06	6.72E+06	3.67E+06	1.01E+07	4.60E+06	4.09E+06	1.39E+07	5.80E+06
ESTY-A/$	5.89E+02	6.63E+02	5.58E+02	8.61E+02	6.78E+02	5.67E+02	1.35E+03	5.00E+02	1.35E+03	5.61E+02	4.00E+02	6.98E+02	4.63E+02	5.47E+02	6.38E+02
ESTY-W/$	3.21E+00	3.45E+00	3.15E+00	4.13E+00	3.57E+00	2.86E+00	9.25E+00	2.81E+00	5.95E+00	3.15E+00	2.13E+00	4.06E+00	3.45E+00	2.77E+00	2.95E+00
ESTY-S/$	9.92E+00	1.10E+01	9.78E+00	1.15E+01	9.90E+00	7.48E+00	3.28E+01	7.97E+00	1.38E+01	9.12E+00	5.00E+00	9.07E+00	1.24E+01	9.17E+00	8.95E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	3.54E+12	3.61E+12	5.98E+12	2.64E+13	1.81E+13	1.02E+13	4.44E+12	2.84E+12	1.20E+13	7.59E+12	4.45E+12	2.43E+12	2.97E+12	2.43E+12	3.04E+12
REN/$	1.08E+10	1.08E+10	1.20E+10	8.15E+09	1.04E+10	6.11E+09	7.25E+09	3.37E+09	6.63E+09	4.94E+09	6.57E+09	7.01E+09	5.66E+09	5.61E+09	5.39E+09
Impact/$	7.29E+10	7.15E+10	8.11E+10	9.44E+10	7.68E+10	6.92E+10	5.79E+10	4.23E+10	6.52E+10	4.75E+10	9.00E+10	5.53E+10	4.99E+10	1.02E+11	5.28E+10
HR/$	1.68E+12	1.82E+12	1.70E+12	1.80E+12	1.91E+12	1.67E+12	1.90E+12	1.33E+12	1.90E+12	1.52E+12	1.91E+12	1.62E+12	1.33E+12	1.81E+12	1.74E+12
Total/$	5.31E+12	5.51E+12	7.78E+12	2.83E+13	2.01E+13	1.20E+13	6.41E+12	4.21E+12	1.40E+13	9.17E+12	6.46E+12	4.11E+12	4.35E+12	4.35E+12	4.84E+12
ICEC to money ratio (J/$)															
ICEC/$	1.30E+09	1.26E+09	1.32E+09	2.23E+09	2.04E+09	1.52E+09	7.27E+09	1.48E+09	4.42E+09	1.84E+09	1.37E+09	2.04E+09	1.58E+09	1.13E+09	9.90E+08

Continued

Table B.3 continued

NAICS	332114	33211A	332211	332212	332213	332214	332311	332312	332313	332321	332322	332323	332410	332420	332430
Econ.	3020	14083.4	2190.6	6017.9	1258.6	1265.9	3993.2	15140.2	2793.8	9823.3	15724.8	3895.6	3709.4	4668.9	14067.8
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	3.23E+12	1.85E+12	6.29E+11	1.16E+12	1.57E+12	1.51E+12	2.87E+12	1.84E+12	1.85E+12	1.98E+12	1.64E+12	1.92E+12	1.62E+12	1.93E+12	2.78E+12
BS/$	2.05E+10	2.65E+10	3.45E+10	4.02E+10	2.48E+10	4.06E+10	1.71E+10	1.54E+10	1.45E+10	1.69E+10	1.78E+10	1.47E+10	1.51E+10	1.51E+10	2.34E+10
HS/$	6.45E+09	3.30E+09	2.84E+09	2.99E+09	4.37E+09	2.83E+09	6.31E+09	4.48E+09	3.35E+09	3.10E+09	2.80E+09	4.88E+09	2.65E+09	3.45E+09	4.23E+09
AS/$	4.08E+08	5.56E+08	4.35E+08	4.56E+08	3.47E+08	6.49E+08	5.59E+08	4.82E+08	4.22E+08	5.83E+08	4.12E+08	4.44E+08	4.39E+08	4.69E+08	6.09E+08
sltot/$	1.30E+09	1.54E+09	1.76E+09	2.84E+09	1.26E+09	2.18E+09	1.20E+09	1.06E+09	9.67E+08	1.17E+09	1.07E+09	9.90E+08	1.02E+09	1.03E+09	1.50E+09
hydrotot/$	4.85E+09	4.01E+09	2.46E+09	3.38E+09	3.82E+09	4.60E+09	4.27E+09	3.66E+09	3.54E+09	4.21E+09	3.70E+09	3.62E+09	3.28E+09	3.68E+09	7.41E+09
geotot/$	4.39E+07	3.63E+07	2.22E+07	3.06E+07	3.45E+07	4.16E+07	3.86E+07	3.31E+07	3.20E+07	3.81E+07	3.34E+07	3.27E+07	2.96E+07	3.33E+07	6.70E+07
windtot/$	2.42E+06	2.00E+06	1.22E+06	1.69E+06	1.90E+06	2.29E+06	2.13E+06	1.82E+06	1.77E+06	2.10E+06	1.84E+06	1.80E+06	1.63E+06	1.83E+06	3.70E+06
erotot/$	1.05E+09	1.43E+09	1.12E+09	1.17E+09	8.92E+08	1.67E+09	1.44E+09	1.24E+09	1.08E+09	1.50E+09	1.06E+09	1.14E+09	1.13E+09	1.21E+09	1.57E+09
HR/$	1.87E+12	1.83E+12	1.42E+12	1.96E+12	1.82E+12	1.89E+12	2.09E+12	1.81E+12	1.98E+12	1.78E+12	1.89E+12	1.98E+12	1.86E+12	1.90E+12	1.78E+12
ESO2/$	3.55E+10	3.02E+10	6.58E+09	9.29E+09	1.09E+10	1.60E+10	1.57E+10	1.20E+10	1.10E+10	1.50E+10	1.18E+10	1.20E+10	1.12E+10	1.23E+10	2.62E+10
ENO2/$	6.45E+07	4.87E+07	2.28E+07	3.10E+07	3.58E+07	4.48E+07	5.15E+07	3.71E+07	3.55E+07	3.98E+07	3.41E+07	3.76E+07	3.09E+07	3.71E+07	6.19E+07
EPM10/$	6.88E+07	5.03E+07	1.53E+07	2.41E+07	2.85E+07	3.10E+07	4.36E+07	3.04E+07	2.94E+07	3.02E+07	2.64E+07	3.02E+07	2.67E+07	3.04E+07	4.64E+07
ECO2/$	3.32E+10	2.03E+10	1.02E+10	1.56E+10	1.96E+10	1.75E+10	3.00E+10	1.93E+10	2.04E+10	1.73E+10	1.71E+10	2.03E+10	1.62E+10	2.04E+10	2.64E+10
EMETH/$	8.48E+04	1.18E+05	1.46E+05	1.13E+05	9.98E+04	1.54E+05	2.96E+05	2.80E+05	2.60E+05	2.75E+05	2.85E+05	2.71E+05	5.68E+04	6.15E+04	9.14E+04
EAMM/$	1.59E+08	1.31E+08	1.62E+07	2.65E+07	3.34E+07	4.82E+07	8.02E+07	5.87E+07	5.54E+07	7.00E+07	5.60E+07	5.94E+07	3.52E+07	4.00E+07	8.26E+07
ETOL/$	2.94E+05	2.50E+05	2.05E+05	2.29E+05	1.69E+05	2.28E+05	2.50E+06	2.43E+06	2.25E+06	2.26E+06	2.34E+06	2.35E+06	1.42E+05	1.73E+05	1.44E+05
ETCE/$	1.06E+07	8.28E+06	5.46E+06	5.90E+06	3.98E+06	5.88E+06	7.24E+07	7.01E+07	6.48E+07	6.49E+07	6.72E+07	6.78E+07	3.97E+06	5.12E+06	4.40E+06
ESTY-A/$	5.79E+02	8.29E+02	2.21E+03	1.84E+03	6.35E+02	1.00E+03	3.24E+03	3.14E+03	2.90E+03	3.50E+03	3.03E+03	3.07E+03	4.72E+02	5.22E+02	6.14E+02
ESTY-W/$	2.74E+00	4.50E+00	7.25E+00	5.74E+00	3.34E+00	5.92E+00	3.56E+00	3.15E+00	2.78E+00	5.21E+00	2.99E+00	3.09E+00	2.87E+00	3.05E+00	4.44E+00
ESTY-S/$	8.35E+00	1.31E+01	1.09E+01	9.68E+00	7.15E+00	1.82E+01	1.47E+01	1.38E+01	1.13E+01	1.90E+01	1.10E+01	1.30E+01	1.03E+01	1.08E+01	1.58E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	3.25E+12	1.87E+12	6.63E+11	1.20E+12	1.60E+12	1.55E+12	2.89E+12	1.85E+12	1.86E+12	2.00E+12	1.66E+12	1.93E+12	1.64E+12	1.94E+12	2.80E+12
REN/$	6.45E+09	4.01E+09	2.84E+09	3.38E+09	4.37E+09	4.60E+09	6.31E+09	4.48E+09	3.54E+09	4.21E+09	3.70E+09	4.88E+09	3.28E+09	3.68E+09	7.41E+09
Impact/$	6.90E+10	5.08E+10	1.68E+10	2.50E+10	3.06E+10	3.36E+10	4.59E+10	3.16E+10	3.16E+10	3.24E+10	2.91E+10	3.25E+10	2.75E+10	3.27E+10	5.28E+10
HR/$	1.87E+12	1.83E+12	1.42E+12	1.96E+12	1.82E+12	1.89E+12	2.09E+12	1.81E+12	1.98E+12	1.78E+12	1.89E+12	1.98E+12	1.86E+12	1.90E+12	1.78E+12
Total/$	5.20E+12	3.76E+12	2.10E+12	3.19E+12	3.46E+12	3.48E+12	5.03E+12	3.70E+12	3.87E+12	3.81E+12	3.59E+12	3.95E+12	3.53E+12	3.87E+12	4.64E+12
ICEC to money ratio (J/$)															
ICEC/$	1.32E+09	1.55E+09	1.77E+09	2.85E+09	1.27E+09	2.20E+09	1.21E+09	1.07E+09	9.77E+08	1.18E+09	1.08E+09	1.00E+09	1.03E+09	1.04E+09	1.51E+09

Continued

Table B.3 continued

NAICS	332500	332600	332710	332720	332811	332812	332813	332910	332991	332994	332995	332996	332997	332998	332999
Econ.	10473.8	7983.7	25889.3	16015.3	3494.7	8441	5975.4	20969.7	6095.2	1327.1	1775.9	4037.2	658.9	1583.9	10374.6
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.54E+12	2.02E+12	1.02E+12	1.25E+12	1.23E+12	2.09E+12	1.22E+12	1.27E+12	1.13E+12	7.82E+11	4.27E+11	2.10E+12	5.25E+11	1.12E+12	1.47E+12
BS/$	2.40E+10	1.90E+10	1.45E+10	1.62E+10	1.54E+10	1.52E+10	2.54E+10	2.00E+10	1.76E+10	5.01E+10	1.17E+11	1.45E+10	8.72E+10	3.32E+10	4.74E+10
HS/$	2.63E+09	4.51E+09	3.69E+09	3.08E+09	3.23E+09	3.69E+09	3.25E+09	2.40E+09	2.59E+09	3.14E+09	2.40E+09	4.85E+09	3.26E+09	2.44E+09	2.77E+09
AS/$	4.04E+08	3.45E+08	3.56E+08	3.14E+08	7.34E+08	1.04E+09	1.02E+09	3.78E+08	3.34E+08	3.93E+08	4.78E+08	3.54E+08	3.27E+08	5.03E+08	6.90E+08
sltot/$	1.52E+09	1.26E+09	9.56E+08	9.67E+08	1.18E+09	1.37E+09	1.82E+09	1.34E+09	1.04E+09	2.97E+09	7.36E+09	9.44E+08	5.44E+09	1.56E+09	2.40E+09
hydrotot/$	3.25E+09	3.95E+09	3.33E+09	3.37E+09	6.89E+09	4.77E+09	5.62E+09	3.09E+09	4.05E+09	3.14E+09	2.40E+09	3.78E+09	2.85E+09	3.84E+09	4.41E+09
geotot/$	2.94E+07	3.57E+07	3.01E+07	3.05E+07	6.23E+07	4.31E+07	5.08E+07	2.80E+07	3.67E+07	2.84E+07	2.17E+07	3.41E+07	2.58E+07	3.47E+07	3.99E+07
windtot/$	1.62E+06	1.97E+06	1.66E+06	1.68E+06	3.44E+06	2.38E+06	2.80E+06	1.54E+06	2.02E+06	1.57E+06	1.20E+06	1.88E+06	1.42E+06	1.91E+06	2.20E+06
erotot/$	1.04E+09	8.88E+08	9.15E+08	8.08E+08	1.89E+09	2.67E+09	2.62E+09	9.73E+08	8.58E+08	1.01E+09	1.23E+09	9.11E+08	8.42E+08	1.29E+09	1.77E+09
HR/$	1.78E+12	1.95E+12	2.47E+12	2.01E+12	1.78E+12	1.66E+12	2.17E+12	1.67E+12	1.84E+12	1.82E+12	1.77E+12	1.83E+12	2.46E+12	1.43E+12	1.88E+12
ESO2/$	1.12E+10	1.27E+10	8.98E+09	9.63E+09	2.89E+10	1.34E+10	1.17E+10	1.03E+10	1.04E+10	8.37E+09	5.94E+09	1.25E+10	6.53E+09	1.01E+10	1.33E+10
ENO2/$	3.17E+07	3.81E+07	2.54E+07	2.74E+07	8.48E+07	4.59E+07	3.77E+07	2.73E+07	3.16E+07	2.48E+07	1.80E+07	3.86E+07	1.82E+07	3.07E+07	3.85E+07
EPM10/$	2.65E+07	3.46E+07	2.11E+07	2.29E+07	7.70E+07	3.28E+07	2.28E+07	2.35E+07	2.38E+07	1.59E+07	8.31E+06	3.40E+07	1.37E+07	1.81E+07	2.99E+07
ECO2/$	1.58E+10	2.24E+10	1.26E+10	1.43E+10	6.34E+10	2.46E+10	1.56E+10	1.30E+10	1.73E+10	1.09E+10	6.89E+09	2.26E+10	7.85E+09	1.40E+10	1.80E+10
EMETH/$	9.09E+04	5.73E+04	4.33E+04	5.43E+04	8.81E+04	6.92E+04	7.38E+04	7.74E+04	5.35E+04	8.83E+04	6.64E+04	5.52E+04	5.06E+04	3.56E+05	3.93E+05
EAMM/$	3.58E+07	4.36E+07	2.40E+07	2.80E+07	1.45E+08	3.83E+07	1.74E+07	3.13E+07	2.58E+07	1.90E+07	8.07E+06	4.38E+07	1.26E+07	4.17E+07	5.74E+07
ETOL/$	1.59E+05	1.56E+05	8.91E+04	1.01E+05	2.46E+05	1.43E+05	1.35E+05	1.55E+05	9.31E+04	1.97E+05	9.59E+04	1.60E+05	8.29E+04	2.22E+06	2.26E+06
ETCE/$	4.60E+06	4.85E+06	2.20E+06	2.90E+06	1.01E+07	3.57E+06	2.19E+06	4.65E+06	2.51E+06	4.86E+06	1.30E+06	5.04E+06	1.64E+06	6.31E+07	6.42E+07
ESTY-A/$	1.41E+03	7.29E+02	3.23E+02	4.98E+02	5.09E+02	5.85E+02	6.05E+02	1.60E+03	3.14E+02	8.27E+02	3.17E+02	5.64E+02	3.60E+02	3.45E+03	3.34E+03
ESTY-W/$	4.72E+00	3.19E+00	1.76E+00	2.15E+00	6.97E+00	6.98E+00	7.90E+00	4.42E+00	1.88E+00	3.64E+00	7.38E+00	2.69E+00	2.98E+00	7.14E+00	6.76E+00
ESTY-S/$	8.70E+00	9.47E+00	4.50E+00	4.80E+00	3.88E+01	3.01E+01	4.06E+01	7.81E+00	4.58E+00	7.38E+00	1.02E+01	6.77E+00	3.01E+00	1.67E+01	2.32E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.56E+12	2.04E+12	1.03E+12	1.27E+12	1.25E+12	2.11E+12	1.24E+12	1.29E+12	1.14E+12	8.32E+11	5.44E+11	2.12E+12	6.12E+11	1.15E+12	1.51E+12
REN/$	3.25E+09	4.51E+09	3.69E+09	3.37E+09	6.89E+09	4.77E+09	5.62E+09	3.09E+09	4.05E+09	3.14E+09	7.36E+09	4.85E+09	5.44E+09	3.84E+09	4.41E+09
Impact/$	2.71E+10	3.52E+10	2.17E+10	2.40E+10	9.27E+10	3.81E+10	2.73E+10	2.33E+10	2.78E+10	1.93E+10	1.29E+10	3.52E+10	1.44E+10	2.43E+10	3.15E+10
HR/$	1.78E+12	1.95E+12	2.47E+12	2.01E+12	1.78E+12	1.66E+12	2.17E+12	1.67E+12	1.84E+12	1.82E+12	1.77E+12	1.83E+12	2.46E+12	1.43E+12	1.88E+12
Total/$	3.38E+12	4.04E+12	3.53E+12	3.30E+12	3.13E+12	3.81E+12	3.44E+12	2.98E+12	3.02E+12	2.67E+12	2.34E+12	3.99E+12	3.09E+12	2.61E+12	3.43E+12
ICEC to money ratio (J/$)															
ICEC/$	1.53E+09	1.27E+09	9.63E+08	9.74E+08	1.20E+09	1.39E+09	1.84E+09	1.35E+09	1.05E+09	2.98E+09	7.37E+09	9.54E+08	5.45E+09	1.57E+09	2.41E+09

Continued

Table B.3 continued

NAICS	33299A	333111	333112	333120	333131	333132	333210	333220	333291	333292	333293	333294	333295	333298	333313
Econ.	2474.6	15537.7	6864.3	20388.4	2541.6	6155.5	1188.8	3372.7	3233.2	1656.8	3316	2767.1	10602.7	7985.5	2960.2
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	9.51E+11	1.41E+12	1.47E+12	1.44E+12	1.45E+12	1.19E+12	1.13E+12	8.43E+11	1.19E+12	9.53E+11	7.74E+11	9.95E+11	9.15E+11	1.10E+12	5.37E+11
BS/$	7.35E+10	2.46E+10	2.77E+10	2.61E+10	3.93E+10	3.40E+10	2.94E+10	2.31E+10	3.50E+10	5.33E+10	1.80E+10	3.56E+10	3.13E+10	2.33E+10	3.70E+10
HS/$	2.42E+09	2.86E+09	4.30E+09	2.94E+09	3.98E+09	4.19E+09	3.74E+09	2.04E+09	4.23E+09	3.50E+09	3.57E+09	3.51E+09	2.49E+09	2.59E+09	3.34E+09
AS/$	6.23E+08	5.51E+08	6.64E+08	6.42E+08	4.27E+08	6.80E+08	4.94E+08	3.94E+08	4.87E+08	4.49E+08	4.20E+08	4.19E+08	8.30E+08	7.02E+08	4.92E+08
sltot/$	4.63E+09	3.73E+09	3.80E+09	3.29E+09	2.68E+09	6.23E+09	1.81E+09	1.54E+09	2.47E+09	3.39E+09	1.23E+09	2.29E+09	1.98E+09	1.63E+09	1.80E+09
hydrotot/$	3.37E+09	2.98E+09	3.25E+09	3.30E+09	3.20E+09	3.15E+09	2.99E+09	2.42E+09	2.94E+09	3.00E+09	2.87E+09	2.64E+09	3.20E+09	2.99E+09	2.54E+09
geotot/$	3.05E+07	2.69E+07	2.94E+07	2.98E+07	2.89E+07	2.84E+07	2.71E+07	2.19E+07	2.66E+07	2.71E+07	2.59E+07	2.38E+07	2.89E+07	2.70E+07	2.30E+07
windtot/$	1.68E+06	1.48E+06	1.62E+06	1.64E+06	1.60E+06	1.57E+06	1.49E+06	1.21E+06	1.47E+06	1.50E+06	1.43E+06	1.31E+06	1.59E+06	1.49E+06	1.27E+06
erotot/$	1.60E+09	1.42E+09	1.71E+09	1.65E+09	1.10E+09	1.75E+09	1.27E+09	1.01E+09	1.25E+09	1.15E+09	1.08E+09	1.08E+09	2.13E+09	1.80E+09	1.26E+09
HR/$	2.59E+12	1.70E+12	1.81E+12	1.87E+12	1.90E+12	1.99E+12	2.21E+12	1.81E+12	2.27E+12	2.12E+12	2.21E+12	2.12E+12	1.86E+12	2.13E+12	1.79E+12
ESO2/$	1.07E+10	1.05E+10	1.12E+10	1.08E+10	1.03E+10	9.61E+09	8.84E+09	6.88E+09	8.89E+09	8.38E+09	7.70E+09	8.25E+09	9.30E+09	9.22E+09	7.33E+09
ENO2/$	3.62E+07	3.43E+07	3.70E+07	3.63E+07	3.26E+07	3.11E+07	2.80E+07	2.20E+07	2.83E+07	2.53E+07	2.32E+07	2.41E+07	2.81E+07	2.98E+07	2.41E+07
EPM10/$	1.84E+07	2.57E+07	2.69E+07	2.61E+07	2.53E+07	2.31E+07	2.35E+07	1.64E+07	2.24E+07	2.03E+07	1.80E+07	1.92E+07	1.84E+07	2.32E+07	1.45E+07
ECO2/$	1.19E+10	1.71E+10	1.71E+10	1.80E+10	1.68E+10	1.40E+10	1.37E+10	1.08E+10	1.41E+10	1.20E+10	1.02E+10	1.15E+10	1.15E+10	1.32E+10	8.06E+09
EMETH/$	1.45E+05	6.98E+04	9.15E+04	9.52E+04	7.09E+04	1.06E+05	1.01E+05	7.10E+04	6.79E+04	7.93E+04	6.72E+04	6.88E+04	1.32E+05	9.16E+04	3.82E+05
EAMM/$	2.49E+07	3.45E+07	3.52E+07	3.34E+07	3.29E+07	2.60E+07	2.73E+07	2.04E+07	2.71E+07	2.36E+07	1.99E+07	2.47E+07	2.43E+07	2.59E+07	3.20E+07
ETOL/$	2.85E+05	2.40E+05	3.30E+05	3.90E+05	2.55E+05	4.64E+05	2.43E+05	1.98E+05	1.60E+05	2.34E+05	1.76E+05	1.88E+05	1.49E+05	1.71E+05	3.82E+05
ETCE/$	6.21E+06	7.52E+06	1.01E+07	1.14E+07	7.39E+06	1.48E+07	6.16E+06	5.80E+06	4.25E+06	6.41E+06	4.44E+06	5.05E+06	3.13E+06	4.23E+06	8.65E+06
ESTY-A/$	1.11E+03	2.61E+03	3.82E+03	3.70E+03	1.06E+03	6.56E+03	1.97E+03	2.40E+03	9.59E+02	2.25E+03	9.45E+02	1.76E+03	9.61E+02	1.29E+03	2.39E+03
ESTY-W/$	9.78E+00	5.80E+00	8.27E+00	8.36E+00	3.52E+00	1.19E+01	5.51E+00	5.81E+00	3.71E+00	5.92E+00	3.24E+00	4.87E+00	6.60E+00	5.75E+00	9.09E+00
ESTY-S/$	4.85E+01	1.13E+01	1.51E+01	1.70E+01	7.07E+00	1.95E+01	9.58E+00	9.66E+00	7.74E+00	9.06E+00	8.17E+00	8.67E+00	2.63E+01	1.89E+01	1.41E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.02E+12	1.44E+12	1.50E+12	1.46E+12	1.48E+12	1.22E+12	1.16E+12	8.66E+11	1.22E+12	1.01E+12	7.92E+11	1.03E+12	9.47E+11	1.12E+12	5.74E+11
REN/$	4.63E+09	3.73E+09	4.30E+09	3.30E+09	3.98E+09	6.23E+09	3.74E+09	2.42E+09	4.23E+09	3.50E+09	3.57E+09	3.51E+09	3.20E+09	2.99E+09	3.34E+09
Impact/$	2.27E+10	2.77E+10	2.85E+10	2.89E+10	2.72E+10	2.37E+10	2.27E+10	1.77E+10	2.31E+10	2.04E+10	1.80E+10	1.98E+10	2.08E+10	2.25E+10	1.55E+10
HR/$	2.59E+12	1.70E+12	1.81E+12	1.87E+12	1.90E+12	1.99E+12	2.21E+12	1.81E+12	2.27E+12	2.12E+12	2.21E+12	2.12E+12	1.86E+12	2.13E+12	1.79E+12
Total/$	3.64E+12	3.17E+12	3.34E+12	3.37E+12	3.41E+12	3.24E+12	3.39E+12	2.70E+12	3.52E+12	3.15E+12	3.02E+12	3.17E+12	2.83E+12	3.28E+12	2.38E+12
ICEC to money ratio (J/$)															
ICEC/$	4.64E+09	3.74E+09	3.81E+09	3.31E+09	2.69E+09	6.24E+09	1.82E+09	1.55E+09	2.48E+09	3.40E+09	1.24E+09	2.30E+09	1.99E+09	1.64E+09	1.81E+09

Continued

Table B.3 continued

NAICS	333314	333315	333319	33331A	333411	333412	333414	333415	333511	333512	333513	333514	333515	33351A	333611
Econ.	3132.7	7612.3	8850.7	1864.8	2072.1	1838.4	3619.2	21887.1	5016.9	4974.5	2124.6	8152.3	5111.6	3966.6	5306.7
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	6.63E+11	6.27E+11	1.21E+12	1.20E+12	1.39E+12	1.27E+12	1.05E+12	1.41E+12	8.57E+11	1.04E+12	9.05E+11	9.38E+11	1.36E+12	8.09E+11	1.16E+12
BS/$	1.98E+10	3.13E+10	2.39E+10	2.73E+10	2.98E+10	2.42E+10	2.62E+10	3.51E+10	1.47E+10	3.25E+10	2.96E+10	1.44E+10	1.52E+10	1.93E+10	1.57E+10
HS/$	3.04E+09	1.85E+09	3.90E+09	3.96E+09	3.82E+09	3.82E+09	3.25E+09	2.87E+09	3.42E+09	2.29E+09	3.49E+09	3.73E+09	2.62E+09	3.62E+09	3.51E+09
AS/$	4.38E+08	5.98E+08	5.82E+08	6.20E+08	7.05E+08	6.89E+08	5.11E+08	5.30E+08	3.54E+08	5.10E+08	3.98E+08	3.24E+08	3.40E+08	3.84E+08	3.39E+08
sltot/$	1.28E+09	2.21E+09	1.69E+09	1.83E+09	1.82E+09	1.60E+09	1.57E+09	2.07E+09	9.51E+08	2.09E+09	1.89E+09	9.36E+08	1.01E+09	1.26E+09	1.07E+09
hydrotot/$	2.89E+09	2.65E+09	2.98E+09	3.02E+09	3.33E+09	3.42E+09	2.57E+09	3.35E+09	3.03E+09	2.73E+09	2.50E+09	2.93E+09	3.59E+09	2.58E+09	2.91E+09
geotot/$	2.61E+07	2.40E+07	2.70E+07	2.73E+07	3.01E+07	3.10E+07	2.32E+07	3.03E+07	2.74E+07	2.47E+07	2.26E+07	2.65E+07	3.25E+07	2.34E+07	2.63E+07
windtot/$	1.44E+06	1.32E+06	1.49E+06	1.51E+06	1.66E+06	1.71E+06	1.28E+06	1.67E+06	1.51E+06	1.36E+06	1.25E+06	1.46E+06	1.79E+06	1.29E+06	1.45E+06
erotot/$	1.13E+09	1.54E+09	1.50E+09	1.59E+09	1.81E+09	1.77E+09	1.31E+09	1.36E+09	9.09E+08	1.31E+09	1.02E+09	8.33E+08	8.74E+08	9.87E+08	8.71E+08
HR/$	2.06E+12	1.61E+12	2.10E+12	1.98E+12	1.95E+12	1.96E+12	1.69E+12	1.96E+12	2.55E+12	2.06E+12	2.07E+12	2.53E+12	2.17E+12	2.15E+12	1.69E+12
ESO2/$	7.16E+09	7.95E+09	9.01E+09	8.96E+09	1.03E+10	1.02E+10	7.72E+09	1.11E+10	7.73E+09	7.55E+09	6.99E+09	7.61E+09	9.87E+09	7.38E+09	1.02E+10
ENO2/$	4.04E+07	4.06E+07	3.05E+07	3.08E+07	2.95E+07	3.01E+07	2.55E+07	3.38E+07	2.31E+07	2.50E+07	2.26E+07	2.34E+07	3.12E+07	2.24E+07	3.23E+07
EPM10/$	1.61E+07	1.53E+07	2.10E+07	2.11E+07	2.32E+07	2.40E+07	2.02E+07	2.72E+07	1.86E+07	2.89E+07	1.88E+07	1.94E+07	2.88E+07	1.81E+07	2.90E+07
ECO2/$	1.16E+10	1.16E+10	1.33E+10	1.34E+10	1.40E+10	1.56E+10	1.16E+10	1.40E+10	1.12E+10	1.15E+10	1.14E+10	1.16E+10	1.33E+10	1.07E+10	1.70E+10
EMETH/$	9.44E+04	2.25E+05	1.04E+05	1.14E+05	1.13E+05	8.96E+04	9.71E+04	1.08E+05	5.59E+04	6.19E+04	5.43E+04	4.21E+04	4.50E+04	5.55E+04	5.35E+04
EAMM/$	3.93E+07	2.66E+07	2.79E+07	2.62E+07	2.82E+07	2.91E+07	2.35E+07	3.38E+07	1.84E+07	1.95E+07	1.94E+07	1.89E+07	2.32E+07	2.01E+07	3.86E+07
ETOL/$	3.32E+05	2.85E+05	2.63E+05	3.44E+05	1.84E+05	1.84E+05	1.42E+05	1.99E+05	1.76E+05	1.32E+05	1.18E+05	8.89E+04	8.52E+04	1.28E+05	1.60E+05
ETCE/$	9.13E+06	7.88E+06	6.89E+06	1.02E+07	4.54E+06	4.81E+06	3.52E+06	5.00E+06	5.19E+06	3.00E+06	2.80E+06	2.13E+06	2.06E+06	3.09E+06	5.00E+06
ESTY-A/$	3.22E+03	3.48E+03	2.27E+03	4.11E+03	7.01E+02	6.62E+02	8.95E+02	1.40E+03	2.20E+03	6.58E+02	5.26E+02	4.05E+02	3.99E+02	6.46E+02	5.55E+02
ESTY-W/$	1.04E+01	1.20E+01	7.65E+00	1.01E+01	3.80E+00	3.48E+00	3.90E+00	5.49E+00	5.10E+00	3.26E+00	2.57E+00	1.89E+00	2.03E+00	2.66E+00	2.14E+00
ESTY-S/$	1.74E+01	2.82E+01	1.50E+01	1.76E+01	9.45E+00	9.19E+00	8.25E+00	1.23E+01	8.77E+00	7.40E+00	6.29E+00	4.87E+00	5.21E+00	6.63E+00	5.26E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	6.82E+11	6.59E+11	1.24E+12	1.23E+12	1.42E+12	1.29E+12	1.08E+12	1.45E+12	8.72E+11	1.08E+12	9.35E+11	9.53E+11	1.37E+12	8.28E+11	1.17E+12
REN/$	3.04E+09	2.65E+09	3.90E+09	3.96E+09	3.82E+09	3.82E+09	3.25E+09	3.35E+09	3.42E+09	2.73E+09	3.49E+09	3.73E+09	3.59E+09	3.62E+09	3.51E+09
Impact/$	1.89E+10	1.96E+10	2.24E+10	2.25E+10	2.44E+10	2.59E+10	1.94E+10	2.52E+10	1.90E+10	1.91E+10	1.85E+10	1.93E+10	2.33E+10	1.81E+10	2.73E+10
HR/$	2.06E+12	1.61E+12	2.10E+12	1.98E+12	1.95E+12	1.96E+12	1.69E+12	1.96E+12	2.55E+12	2.06E+12	2.07E+12	2.53E+12	2.17E+12	2.15E+12	1.69E+12
Total/$	2.76E+12	2.29E+12	3.37E+12	3.23E+12	3.39E+12	3.29E+12	2.79E+12	3.44E+12	3.44E+12	3.16E+12	3.03E+12	3.50E+12	3.57E+12	3.00E+12	2.89E+12
ICEC to money ratio (J/$)															
ICEC/$	1.29E+09	2.22E+09	1.70E+09	1.84E+09	1.83E+09	1.61E+09	1.58E+09	2.08E+09	9.58E+08	2.10E+09	1.90E+09	9.43E+08	1.02E+09	1.26E+09	1.08E+09

Continued

Table B.3 continued

NAICS	333618	33361A	333911	333912	333913	333921	333922	333923	333924	333991	333992	333993	333994	333995	333996
Econ.	18234	5499.7	6480.2	5185.5	1274	1570	5865.9	3084.2	5096.7	3368.7	4358.4	4549.8	2779.6	3444.4	2530.2
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.37E+12	1.23E+12	1.16E+12	8.91E+11	9.83E+11	2.00E+12	1.36E+12	1.20E+12	1.77E+12	1.04E+12	1.57E+12	7.64E+11	9.24E+11	1.27E+12	1.08E+12
BS/$	2.57E+10	1.69E+10	2.20E+10	2.13E+10	2.41E+10	1.78E+10	1.75E+10	1.62E+10	3.00E+10	2.82E+10	2.85E+10	1.50E+10	2.60E+10	1.49E+10	1.91E+10
HS/$	2.85E+09	3.67E+09	2.34E+09	3.34E+09	3.68E+09	4.61E+09	4.21E+09	3.73E+09	5.05E+09	3.44E+09	4.14E+09	3.17E+09	3.50E+09	3.94E+09	3.63E+09
AS/$	5.48E+08	3.13E+08	4.51E+08	4.26E+08	5.01E+08	4.60E+08	5.14E+08	4.06E+08	5.32E+08	4.50E+08	5.84E+08	4.53E+08	3.61E+08	3.67E+08	4.23E+08
sltot/$	1.96E+09	1.05E+09	1.62E+09	1.49E+09	1.77E+09	1.38E+09	1.47E+09	1.58E+09	2.40E+09	1.66E+09	1.70E+09	1.07E+09	1.61E+09	1.06E+09	1.31E+09
hydrotot/$	3.43E+09	3.41E+09	3.29E+09	2.69E+09	2.86E+09	3.68E+09	2.86E+09	2.86E+09	3.62E+09	2.83E+09	3.53E+09	2.21E+09	2.49E+09	3.24E+09	3.33E+09
geotot/$	3.11E+07	3.08E+07	2.98E+07	2.43E+07	2.59E+07	3.33E+07	2.59E+07	2.58E+07	3.27E+07	2.56E+07	3.19E+07	2.00E+07	2.26E+07	2.93E+07	3.01E+07
windtot/$	1.71E+06	1.70E+06	1.64E+06	1.34E+06	1.43E+06	1.83E+06	1.43E+06	1.42E+06	1.80E+06	1.41E+06	1.76E+06	1.10E+06	1.24E+06	1.62E+06	1.66E+06
erotot/$	1.41E+09	8.04E+08	1.16E+09	1.10E+09	1.29E+09	1.18E+09	1.32E+09	1.04E+09	1.37E+09	1.16E+09	1.50E+09	1.16E+09	9.29E+08	9.43E+08	1.09E+09
HR/$	1.76E+12	1.97E+12	1.95E+12	1.79E+12	2.04E+12	2.13E+12	2.13E+12	1.91E+12	2.18E+12	1.69E+12	2.01E+12	2.12E+12	1.93E+12	1.99E+12	2.03E+12
ESO2/$	1.16E+10	9.70E+09	9.79E+09	7.77E+09	9.49E+09	1.24E+10	9.05E+09	8.67E+09	1.19E+10	8.44E+09	1.19E+10	6.54E+09	7.55E+09	9.39E+09	9.23E+09
ENO2/$	3.73E+07	3.16E+07	2.92E+07	2.45E+07	2.66E+07	3.90E+07	2.97E+07	2.85E+07	3.94E+07	2.56E+07	3.42E+07	1.93E+07	2.19E+07	2.96E+07	2.81E+07
EPM10/$	2.86E+07	2.51E+07	2.33E+07	1.86E+07	2.11E+07	3.28E+07	2.45E+07	2.23E+07	3.26E+07	1.76E+07	2.74E+07	1.53E+07	1.80E+07	2.41E+07	2.15E+07
ECO2/$	1.74E+10	1.58E+10	1.41E+10	1.16E+10	1.16E+10	2.11E+10	1.56E+10	1.43E+10	2.07E+10	1.08E+10	1.69E+10	9.30E+09	1.11E+10	1.64E+10	1.43E+10
EMETH/$	7.47E+04	5.62E+04	8.60E+04	9.28E+04	9.64E+04	7.20E+04	6.54E+04	6.65E+04	8.23E+04	1.12E+05	1.09E+05	5.86E+04	1.06E+05	4.74E+04	5.71E+04
EAMM/$	3.95E+07	3.03E+07	3.05E+07	2.38E+07	2.92E+07	4.42E+07	3.07E+07	2.86E+07	4.25E+07	2.23E+07	3.86E+07	1.53E+07	2.00E+07	2.88E+07	2.62E+07
ETOL/$	1.97E+05	1.13E+05	2.13E+05	2.25E+05	2.07E+05	2.07E+05	1.92E+05	2.51E+05	2.33E+05	2.22E+05	1.45E+05	9.42E+04	1.06E+05	9.46E+04	9.97E+04
ETCE/$	5.71E+06	3.26E+06	6.19E+06	6.18E+06	5.70E+06	6.21E+06	5.56E+06	7.18E+06	6.87E+06	6.54E+06	3.86E+06	2.09E+06	2.44E+06	2.60E+06	2.51E+06
ESTY-A/$	1.54E+03	4.26E+02	1.78E+03	1.54E+03	1.91E+03	1.15E+03	1.31E+03	1.23E+03	1.60E+03	2.84E+03	8.05E+02	5.96E+02	5.33E+02	4.22E+02	5.29E+02
ESTY-W/$	4.43E+00	2.01E+00	4.76E+00	4.23E+00	5.36E+00	3.65E+00	3.97E+00	3.40E+00	4.69E+00	7.21E+00	4.61E+00	2.66E+00	2.91E+00	2.05E+00	2.42E+00
ESTY-S/$	9.15E+00	4.71E+00	8.98E+00	8.00E+00	1.06E+01	8.77E+00	9.34E+00	8.04E+00	9.95E+00	1.18E+01	1.54E+01	6.57E+00	5.46E+00	5.15E+00	5.47E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.40E+12	1.25E+12	1.18E+12	9.13E+11	1.01E+12	2.02E+12	1.38E+12	1.22E+12	1.80E+12	1.07E+12	1.60E+12	7.79E+11	9.50E+11	1.29E+12	1.10E+12
REN/$	3.43E+09	3.67E+09	3.29E+09	3.34E+09	3.68E+09	4.61E+09	4.21E+09	3.73E+09	5.05E+09	3.44E+09	4.14E+09	3.17E+09	3.50E+09	3.94E+09	3.63E+09
Impact/$	2.91E+10	2.56E+10	2.39E+10	1.94E+10	2.11E+10	3.35E+10	2.47E+10	2.30E+10	3.27E+10	1.93E+10	2.89E+10	1.59E+10	1.87E+10	2.59E+10	2.36E+10
HR/$	1.76E+12	1.97E+12	1.95E+12	1.79E+12	2.04E+12	2.13E+12	2.13E+12	1.91E+12	2.18E+12	1.69E+12	2.01E+12	2.12E+12	1.93E+12	1.99E+12	2.03E+12
Total/$	3.19E+12	3.25E+12	3.15E+12	2.73E+12	3.07E+12	4.19E+12	3.54E+12	3.15E+12	4.02E+12	2.78E+12	3.65E+12	2.92E+12	2.91E+12	3.31E+12	3.16E+12
ICEC to money ratio (J/$)															
ICEC/$	1.97E+09	1.06E+09	1.62E+09	1.50E+09	1.78E+09	1.39E+09	1.48E+09	1.58E+09	2.41E+09	1.67E+09	1.71E+09	1.07E+09	1.62E+09	1.07E+09	1.32E+09

Continued

Table B.3 continued

NAICS	33399A	334111	334112	334113	334119	334210	334220	334290	334300	334411	334413	33441A	334510	334511	334512
Econ.	9156.2	60511.3	13019.3	1369.5	23926.3	37540.7	38861.1	3982.1	8154.4	3834.6	77366.9	54749.3	10924.3	31989.5	2729.1
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.03E+12	3.96E+11	3.12E+11	7.01E+11	5.26E+11	4.31E+11	4.68E+11	4.86E+11	7.55E+11	1.25E+12	4.35E+11	8.02E+11	5.86E+11	3.83E+11	6.58E+11
BS/$	3.20E+10	2.10E+10	1.60E+10	2.27E+10	2.52E+10	1.70E+10	1.59E+10	1.94E+10	5.88E+10	3.20E+10	1.03E+10	1.81E+10	2.06E+10	1.48E+10	2.00E+10
HS/$	3.51E+09	2.34E+09	3.16E+09	1.90E+09	2.21E+09	1.51E+09	1.67E+09	3.14E+09	2.36E+09	2.42E+09	1.55E+09	2.31E+09	3.19E+09	1.60E+09	3.36E+09
AS/$	6.22E+08	4.69E+08	3.61E+08	4.89E+08	4.27E+08	3.52E+08	3.43E+08	3.89E+08	6.56E+08	5.10E+08	3.08E+08	4.86E+08	6.22E+08	3.28E+08	4.15E+08
sltot/$	1.74E+09	1.21E+09	9.76E+08	1.30E+09	1.44E+09	1.00E+09	1.00E+09	1.16E+09	3.92E+09	2.01E+09	6.59E+08	1.16E+09	1.40E+09	9.74E+08	1.21E+09
hydrotot/$	2.93E+09	2.06E+09	1.93E+09	2.66E+09	2.28E+09	1.69E+09	2.05E+09	2.12E+09	3.15E+09	5.03E+09	2.19E+09	2.98E+09	2.21E+09	2.14E+09	2.66E+09
geotot/$	2.65E+07	1.86E+07	1.75E+07	2.41E+07	2.07E+07	1.53E+07	1.85E+07	1.92E+07	2.85E+07	4.55E+07	1.98E+07	2.69E+07	2.00E+07	1.94E+07	2.40E+07
windtot/$	1.46E+06	1.03E+06	9.64E+05	1.33E+06	1.14E+06	8.41E+05	1.02E+06	1.06E+06	1.57E+06	2.51E+06	1.09E+06	1.49E+06	1.10E+06	1.07E+06	1.33E+06
erotot/$	1.60E+09	1.21E+09	9.29E+08	1.26E+09	1.10E+09	9.06E+08	8.81E+08	1.00E+09	1.69E+09	1.31E+09	7.92E+08	1.25E+09	1.60E+09	8.43E+08	1.07E+09
HR/$	2.07E+12	1.74E+12	1.77E+12	2.05E+12	2.00E+12	1.43E+12	1.69E+12	1.92E+12	2.02E+12	2.04E+12	1.12E+12	1.76E+12	2.11E+12	2.05E+12	1.97E+12
ESO2/$	8.50E+09	4.79E+09	4.05E+09	6.21E+09	5.63E+09	4.34E+09	4.93E+09	5.33E+09	7.82E+09	1.22E+10	4.95E+09	7.67E+09	7.04E+09	5.87E+09	8.38E+09
ENO2/$	2.78E+07	1.70E+07	1.44E+07	2.12E+07	1.89E+07	1.47E+07	1.55E+07	1.71E+07	2.91E+07	4.76E+07	1.49E+07	2.30E+07	2.01E+07	1.43E+07	2.25E+07
EPM10/$	1.94E+07	1.04E+07	9.26E+06	1.33E+07	1.33E+07	1.11E+07	1.05E+07	1.19E+07	1.72E+07	2.64E+07	1.00E+07	1.52E+07	1.32E+07	9.59E+06	1.51E+07
ECO2/$	1.32E+10	5.86E+09	5.11E+09	7.20E+09	6.63E+09	5.06E+09	5.53E+09	6.42E+09	9.74E+09	1.45E+10	5.36E+09	8.55E+09	7.65E+09	5.76E+09	9.49E+09
EMETH/$	1.45E+05	1.11E+05	8.06E+04	1.20E+05	1.13E+05	7.63E+04	5.95E+04	8.28E+04	1.86E+05	1.59E+05	4.88E+04	7.82E+04	8.83E+04	4.94E+04	1.62E+05
EAMM/$	2.43E+07	2.13E+07	1.84E+07	2.94E+07	2.23E+07	1.04E+07	1.06E+07	1.25E+07	3.16E+07	1.13E+08	8.01E+06	1.68E+07	1.43E+07	9.07E+06	1.94E+07
ETOL/$	1.94E+05	6.35E+05	4.11E+05	5.76E+05	4.06E+05	1.34E+05	1.22E+05	2.01E+05	5.07E+05	6.28E+05	7.89E+04	1.66E+05	2.10E+05	1.10E+05	1.81E+05
ETCE/$	5.17E+06	5.82E+06	4.94E+06	8.25E+06	6.56E+06	3.11E+06	2.48E+06	5.06E+06	1.03E+07	1.84E+07	1.25E+06	3.89E+06	4.55E+06	2.26E+06	4.37E+06
ESTY-A/$	1.97E+03	9.89E+02	7.02E+02	2.03E+03	1.65E+03	1.15E+03	6.63E+02	1.93E+03	4.15E+03	5.16E+03	3.91E+02	1.41E+03	1.59E+03	6.94E+02	1.38E+03
ESTY-W/$	6.21E+00	4.04E+00	2.86E+00	6.30E+00	5.19E+00	4.39E+00	3.04E+00	5.50E+00	1.29E+01	1.92E+01	3.65E+00	6.03E+00	5.90E+00	2.76E+00	6.22E+00
ESTY-S/$	1.22E+01	1.09E+01	7.79E+00	1.27E+01	1.11E+01	1.19E+01	8.54E+00	1.06E+01	2.11E+01	3.55E+01	2.01E+01	1.89E+01	1.82E+01	7.01E+00	1.08E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.06E+12	4.17E+11	3.28E+11	7.24E+11	5.51E+11	4.48E+11	4.84E+11	5.05E+11	8.14E+11	1.28E+12	4.45E+11	8.20E+11	6.07E+11	3.98E+11	6.78E+11
REN/$	3.51E+09	2.34E+09	3.16E+09	2.66E+09	2.28E+09	1.69E+09	2.05E+09	3.14E+09	3.92E+09	5.03E+09	2.19E+09	2.98E+09	3.19E+09	2.14E+09	3.36E+09
Impact/$	2.17E+10	1.07E+10	9.20E+09	1.35E+10	1.23E+10	9.44E+09	1.05E+10	1.18E+10	1.76E+10	2.68E+10	1.03E+10	1.63E+10	1.47E+10	1.17E+10	1.79E+10
HR/$	2.07E+12	1.74E+12	1.77E+12	2.05E+12	2.00E+12	1.43E+12	1.69E+12	1.92E+12	2.02E+12	2.04E+12	1.12E+12	1.76E+12	2.11E+12	2.05E+12	1.97E+12
Total/$	3.16E+12	2.17E+12	2.11E+12	2.79E+12	2.57E+12	1.89E+12	2.19E+12	2.44E+12	2.86E+12	3.36E+12	1.58E+12	2.60E+12	2.73E+12	2.46E+12	2.67E+12
ICEC to money ratio (J/$)															
ICEC/$	1.75E+09	1.22E+09	9.81E+08	1.30E+09	1.45E+09	1.01E+09	1.01E+09	1.17E+09	3.93E+09	2.02E+09	6.64E+08	1.16E+09	1.41E+09	9.79E+08	1.22E+09

Continued

Table B.3 continued

NAICS	334513	334514	334515	334516	334517	33451A	334611	334612	334613	335110	335120	335211	335212	335221	335222
Econ.	7536.4	3716.6	13529.5	6642.7	3657.1	5589.7	1241.6	3741.1	4600.4	3183.4	8930	3005.2	2233	3464.1	4837.1
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	5.07E+11	8.52E+11	3.21E+11	5.16E+11	6.02E+11	6.66E+11	3.53E+11	4.37E+11	1.18E+12	1.31E+12	1.10E+12	1.18E+12	1.01E+12	1.42E+12	1.30E+12
BS/$	1.57E+10	2.18E+10	1.44E+10	1.80E+10	1.90E+10	6.78E+10	4.66E+10	4.89E+10	3.94E+10	4.28E+10	3.56E+10	3.82E+10	3.93E+10	3.43E+10	4.38E+10
HS/$	3.20E+09	2.78E+09	1.45E+09	3.41E+09	3.35E+09	3.34E+09	1.12E+09	2.68E+09	3.05E+09	2.16E+09	3.87E+09	3.90E+09	2.51E+09	3.07E+09	2.93E+09
AS/$	3.64E+08	7.05E+08	3.18E+08	4.65E+08	4.10E+08	4.88E+08	4.69E+08	5.49E+08	7.60E+08	4.84E+08	5.34E+08	6.85E+08	7.68E+08	6.65E+08	7.63E+08
sltot/$	1.11E+09	2.20E+09	8.96E+08	1.14E+09	1.18E+09	4.09E+09	1.97E+09	2.15E+09	2.36E+09	2.18E+09	1.80E+09	2.03E+09	2.18E+09	1.94E+09	2.62E+09
hydrotot/$	2.15E+09	2.85E+09	1.85E+09	2.23E+09	2.43E+09	2.62E+09	1.34E+09	2.91E+09	4.71E+09	3.66E+09	3.18E+09	3.69E+09	3.04E+09	3.43E+09	3.92E+09
geotot/$	1.94E+07	2.57E+07	1.67E+07	2.02E+07	2.19E+07	2.37E+07	1.22E+07	2.64E+07	4.26E+07	3.31E+07	2.88E+07	3.33E+07	2.75E+07	3.10E+07	3.54E+07
windtot/$	1.07E+06	1.42E+06	9.20E+05	1.11E+06	1.21E+06	1.31E+06	6.71E+05	1.45E+06	2.35E+06	1.83E+06	1.59E+06	1.84E+06	1.51E+06	1.71E+06	1.95E+06
erotot/$	9.37E+08	1.81E+09	8.18E+08	1.20E+09	1.05E+09	1.25E+09	1.21E+09	1.41E+09	1.96E+09	1.24E+09	1.37E+09	1.76E+09	1.97E+09	1.71E+09	1.96E+09
HR/$	2.09E+12	1.90E+12	1.70E+12	2.28E+12	2.01E+12	2.05E+12	1.60E+12	1.56E+12	2.00E+12	1.66E+12	1.95E+12	1.80E+12	1.74E+12	1.84E+12	2.01E+12
ESO2/$	6.40E+09	9.51E+09	5.34E+09	6.58E+09	7.77E+09	7.61E+09	4.60E+09	6.83E+09	1.27E+10	9.86E+09	1.03E+10	1.15E+10	9.38E+09	1.19E+10	1.24E+10
ENO2/$	1.66E+07	2.91E+07	1.29E+07	1.89E+07	1.98E+07	2.17E+07	1.68E+07	2.33E+07	3.94E+07	3.34E+07	3.08E+07	3.55E+07	3.09E+07	3.63E+07	3.95E+07
EPM10/$	1.22E+07	1.65E+07	9.88E+06	1.26E+07	1.39E+07	1.48E+07	8.17E+06	1.13E+07	2.36E+07	2.13E+07	2.13E+07	2.87E+07	1.79E+07	2.65E+07	2.50E+07
ECO2/$	7.30E+09	1.21E+10	5.29E+09	7.64E+09	7.98E+09	8.96E+09	5.48E+09	7.94E+09	1.49E+10	1.05E+10	1.27E+10	1.38E+10	1.21E+10	1.59E+10	1.59E+10
EMETH/$	6.07E+04	1.05E+05	5.05E+04	8.27E+04	7.74E+04	9.56E+04	2.89E+05	2.83E+05	2.11E+05	1.91E+05	1.55E+05	1.95E+05	2.10E+05	1.69E+05	1.89E+05
EAMM/$	1.22E+07	2.11E+07	7.87E+06	1.69E+07	1.95E+07	1.53E+07	1.39E+07	1.35E+07	3.04E+07	6.06E+07	3.25E+07	3.32E+07	2.42E+07	4.16E+07	3.40E+07
ETOL/$	1.47E+05	2.36E+05	1.17E+05	2.37E+05	1.96E+05	1.80E+05	1.63E+05	2.50E+05	4.85E+05	2.84E+05	2.24E+05	3.40E+05	4.18E+05	3.57E+05	4.07E+05
ETCE/$	3.36E+06	5.64E+06	2.40E+06	5.81E+06	3.42E+06	3.83E+06	3.83E+06	6.58E+06	1.42E+07	7.83E+06	5.99E+06	9.51E+06	1.05E+07	1.06E+07	1.15E+07
ESTY-A/$	1.17E+03	2.15E+03	7.18E+02	2.01E+03	9.44E+02	1.24E+03	1.73E+03	3.20E+03	6.56E+03	2.22E+03	2.09E+03	3.98E+03	4.77E+03	4.15E+03	4.96E+03
ESTY-W/$	3.65E+00	1.27E+01	2.73E+00	6.37E+00	3.60E+00	6.52E+00	9.95E+00	1.28E+01	1.88E+01	1.05E+01	7.13E+00	1.31E+01	1.62E+01	1.09E+01	1.64E+01
ESTY-S/$	8.02E+00	4.56E+01	6.91E+00	1.45E+01	8.17E+00	1.03E+01	1.84E+01	2.04E+01	3.77E+01	1.89E+01	1.18E+01	2.08E+01	2.54E+01	1.87E+01	3.57E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	5.23E+11	8.74E+11	3.35E+11	5.34E+11	6.20E+11	7.34E+11	3.99E+11	4.86E+11	1.22E+12	1.35E+12	1.14E+12	1.22E+12	1.05E+12	1.45E+12	1.35E+12
REN/$	3.20E+09	2.85E+09	1.85E+09	3.41E+09	3.35E+09	4.09E+09	1.97E+09	2.91E+09	4.71E+09	3.66E+09	3.87E+09	3.90E+09	3.04E+09	3.43E+09	3.92E+09
Impact/$	1.37E+10	2.17E+10	1.07E+10	1.43E+10	1.58E+10	1.66E+10	1.01E+10	1.48E+10	2.77E+10	2.05E+10	2.31E+10	2.54E+10	2.15E+10	2.80E+10	2.84E+10
HR/$	2.09E+12	1.90E+12	1.70E+12	2.28E+12	2.01E+12	2.05E+12	1.60E+12	1.56E+12	2.00E+12	1.66E+12	1.95E+12	1.80E+12	1.74E+12	1.84E+12	2.01E+12
Total/$	2.63E+12	2.80E+12	2.05E+12	2.84E+12	2.65E+12	2.81E+12	2.02E+12	2.07E+12	3.25E+12	3.04E+12	3.12E+12	3.05E+12	2.81E+12	3.33E+12	3.39E+12
ICEC to money ratio (J/$)															
ICEC/$	1.11E+09	2.21E+09	9.01E+08	1.15E+09	1.19E+09	4.10E+09	1.98E+09	2.17E+09	2.38E+09	2.19E+09	1.81E+09	2.04E+09	2.19E+09	1.95E+09	2.63E+09

Continued

Table B.3 continued

NAICS	335224	335228	335311	335312	335313	335314	335911	335912	335921	335929	335930	335991	335999	336110	336120
Econ.	3557	3258.8	4649.5	11815.1	7309	10760.2	4395.1	2350.6	2741.1	12243.1	10079.1	2261.7	6713.6	205815.8	14389.2
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.68E+12	1.19E+12	2.24E+12	1.72E+12	1.18E+12	9.64E+11	3.63E+12	1.23E+12	1.75E+12	3.06E+12	1.29E+12	1.50E+12	1.06E+12	1.14E+12	1.10E+12
BS/$	3.38E+10	3.09E+10	4.02E+10	2.35E+10	1.65E+10	2.09E+10	2.22E+10	3.79E+10	5.49E+10	6.23E+10	1.93E+10	1.46E+10	5.54E+10	2.73E+10	2.74E+10
HS/$	3.44E+09	4.21E+09	4.48E+09	2.78E+09	2.09E+09	2.31E+09	3.59E+09	3.50E+09	2.07E+09	2.40E+09	2.92E+09	3.28E+09	4.05E+09	2.93E+09	2.65E+09
AS/$	7.27E+08	6.85E+08	5.87E+08	4.76E+08	4.31E+08	7.73E+08	5.03E+08	6.24E+08	9.37E+08	9.09E+08	4.76E+08	5.11E+08	1.16E+09	1.12E+09	9.63E+08
sltot/$	2.29E+09	1.75E+09	2.19E+09	1.49E+09	1.19E+09	1.86E+09	1.42E+09	2.71E+09	5.81E+09	5.29E+09	1.37E+09	1.06E+09	2.88E+09	3.23E+09	3.12E+09
hydrotot/$	3.72E+09	3.15E+09	3.61E+09	3.44E+09	2.66E+09	2.60E+09	6.08E+09	2.97E+09	3.41E+09	4.22E+09	3.38E+09	5.62E+09	3.70E+09	3.18E+09	3.06E+09
geotot/$	3.36E+07	2.85E+07	3.26E+07	3.11E+07	2.40E+07	2.35E+07	5.50E+07	2.69E+07	3.08E+07	3.82E+07	3.05E+07	5.08E+07	3.34E+07	2.87E+07	2.76E+07
windtot/$	1.85E+06	1.57E+06	1.80E+06	1.72E+06	1.33E+06	1.29E+06	3.03E+06	1.48E+06	1.70E+06	2.10E+06	1.68E+06	2.80E+06	1.84E+06	1.58E+06	1.52E+06
erotot/$	1.87E+09	1.76E+09	1.51E+09	1.22E+09	1.11E+09	1.99E+09	1.29E+09	1.60E+09	2.41E+09	2.34E+09	1.22E+09	1.31E+09	2.97E+09	2.87E+09	2.47E+09
HR/$	1.95E+12	1.81E+12	1.90E+12	1.83E+12	1.72E+12	2.12E+12	1.87E+12	1.46E+12	1.60E+12	1.65E+12	1.73E+12	1.50E+12	2.14E+12	1.74E+12	1.86E+12
ESO2/$	1.27E+10	9.73E+09	1.30E+10	1.19E+10	8.49E+09	7.50E+09	1.77E+10	1.03E+10	1.18E+10	1.85E+10	1.01E+10	1.27E+10	1.06E+10	9.19E+09	9.05E+09
ENO2/$	3.90E+07	3.32E+07	3.96E+07	3.41E+07	2.45E+07	2.50E+07	4.56E+07	3.04E+07	4.84E+07	4.53E+07	3.00E+07	4.70E+07	3.48E+07	3.37E+07	3.29E+07
EPM10/$	2.77E+07	2.49E+07	3.42E+07	2.74E+07	2.00E+07	1.78E+07	3.46E+07	2.35E+07	3.00E+07	3.34E+07	2.04E+07	2.42E+07	2.02E+07	2.08E+07	2.12E+07
ECO2/$	1.81E+10	1.44E+10	1.80E+10	1.56E+10	1.03E+10	9.58E+09	1.46E+10	1.15E+10	1.42E+10	1.46E+10	1.32E+10	1.84E+10	1.21E+10	1.37E+10	1.36E+10
EMETH/$	1.64E+05	1.64E+05	1.40E+05	9.00E+04	5.72E+04	8.37E+04	1.01E+05	1.63E+05	1.47E+05	1.14E+05	9.00E+04	5.24E+04	2.62E+05	1.64E+05	1.64E+05
EAMM/$	4.02E+07	2.92E+07	4.01E+07	3.59E+07	2.20E+07	1.69E+07	3.55E+07	2.98E+07	1.32E+08	5.51E+07	2.78E+07	1.15E+07	2.46E+07	3.22E+07	2.97E+07
ETOL/$	3.60E+05	3.44E+05	1.83E+05	1.80E+05	1.43E+05	2.37E+05	2.67E+05	2.30E+05	6.31E+05	2.70E+05	1.80E+05	1.75E+05	1.87E+05	8.20E+05	8.36E+05
ETCE/$	1.07E+07	9.97E+06	4.17E+06	4.90E+06	3.73E+06	6.15E+06	7.76E+06	6.00E+06	1.85E+07	5.09E+06	4.59E+06	1.75E+06	2.95E+06	2.17E+07	2.24E+07
ESTY-A/$	4.08E+03	4.09E+03	7.86E+02	1.29E+03	1.06E+03	2.47E+03	3.56E+03	2.40E+03	4.90E+03	1.37E+03	1.34E+03	6.86E+02	1.02E+03	6.96E+03	7.45E+03
ESTY-W/$	1.19E+01	1.23E+01	4.76E+00	5.28E+00	4.17E+00	7.59E+00	9.92E+00	9.65E+00	2.02E+01	1.40E+01	7.58E+00	6.23E+00	1.18E+01	8.66E+00	8.92E+00
ESTY-S/$	2.02E+01	2.13E+01	1.01E+01	1.09E+01	8.84E+00	1.71E+01	2.45E+01	3.24E+01	2.26E+01	3.03E+01	1.37E+01	2.03E+01	5.35E+01	9.45E+01	9.49E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.71E+12	1.22E+12	2.28E+12	1.75E+12	1.20E+12	9.85E+11	3.65E+12	1.27E+12	1.80E+12	3.13E+12	1.31E+12	1.52E+12	1.11E+12	1.17E+12	1.13E+12
REN/$	3.72E+09	4.21E+09	4.48E+09	3.44E+09	2.66E+09	2.60E+09	6.08E+09	3.50E+09	5.81E+09	5.29E+09	3.38E+09	5.62E+09	4.05E+09	3.23E+09	3.12E+09
Impact/$	3.09E+10	2.42E+10	3.12E+10	2.76E+10	1.88E+10	1.71E+10	3.24E+10	2.19E+10	2.62E+10	3.33E+10	2.34E+10	3.12E+10	2.28E+10	2.30E+10	2.27E+10
HR/$	1.95E+12	1.81E+12	1.90E+12	1.83E+12	1.72E+12	2.12E+12	1.87E+12	1.46E+12	1.60E+12	1.65E+12	1.73E+12	1.50E+12	2.14E+12	1.74E+12	1.86E+12
Total/$	3.69E+12	3.06E+12	4.21E+12	3.61E+12	2.93E+12	3.12E+12	5.56E+12	2.75E+12	3.43E+12	4.81E+12	3.07E+12	3.05E+12	3.28E+12	2.94E+12	3.02E+12
ICEC to money ratio (J/$)															
ICEC/$	2.30E+09	1.76E+09	2.21E+09	1.50E+09	1.19E+09	1.87E+09	1.44E+09	2.72E+09	5.83E+09	5.31E+09	1.38E+09	1.09E+09	2.89E+09	3.24E+09	3.13E+09

Continued

Table B.3 continued

NAICS	336211	336212	336213	336214	336300	336411	336412	336413	336414	33641A	336500	336611	336612	336991	336992
Econ.	8598.8	5328.3	3921.2	4420.9	173522.7	54867	22098.7	20121.6	15122	3975.6	8260.4	10543.3	5403.9	3176	1023.1
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.95E+12	1.52E+12	1.04E+12	1.21E+12	1.74E+12	6.87E+11	6.76E+11	7.71E+11	5.38E+11	4.39E+11	2.19E+12	9.95E+11	8.71E+11	1.89E+12	1.29E+12
BS/$	5.05E+10	2.81E+11	2.14E+11	3.26E+10	2.90E+10	1.83E+10	1.59E+10	2.13E+10	1.51E+10	1.63E+10	1.97E+10	2.31E+10	1.17E+11	2.95E+10	1.89E+10
HS/$	3.56E+09	4.31E+09	4.11E+09	3.88E+09	3.33E+09	2.17E+09	1.72E+09	2.11E+09	1.76E+09	2.91E+09	4.79E+09	2.46E+09	3.34E+09	5.15E+09	2.84E+09
AS/$	1.03E+09	1.23E+09	1.39E+09	1.03E+09	1.42E+09	6.75E+08	3.43E+08	4.58E+08	4.98E+08	4.59E+08	5.52E+08	7.99E+08	9.29E+08	5.79E+08	3.85E+08
sltot/$	4.18E+09	2.18E+10	1.27E+10	4.47E+09	2.53E+09	1.36E+09	1.43E+09	1.43E+09	1.28E+09	1.18E+09	1.55E+09	1.71E+09	6.59E+09	3.67E+09	1.23E+09
hydrotot/$	3.94E+09	4.10E+09	3.17E+09	3.27E+09	4.02E+09	2.60E+09	2.63E+09	3.24E+09	2.20E+09	2.96E+09	3.59E+09	3.10E+09	2.79E+09	3.88E+09	3.86E+09
geotot/$	3.56E+07	3.71E+07	2.86E+07	2.96E+07	3.63E+07	2.35E+07	2.38E+07	2.93E+07	1.99E+07	2.68E+07	3.24E+07	2.81E+07	2.52E+07	3.51E+07	3.49E+07
windtot/$	1.97E+06	2.04E+06	1.58E+06	1.63E+06	2.00E+06	1.30E+06	1.31E+06	1.61E+06	1.10E+06	1.48E+06	1.79E+06	1.55E+06	1.39E+06	1.94E+06	1.93E+06
erotot/$	2.64E+09	3.15E+09	3.57E+09	2.64E+09	3.66E+09	1.73E+09	8.82E+08	1.18E+09	1.28E+09	1.18E+09	1.42E+09	2.05E+09	2.39E+09	1.49E+09	9.89E+08
HR/$	2.08E+12	2.08E+12	2.09E+12	2.07E+12	1.97E+12	3.70E+12	1.77E+12	2.15E+12	1.88E+12	2.33E+12	2.07E+12	2.20E+12	1.86E+12	2.17E+12	2.09E+12
ESO2/$	1.30E+10	1.39E+10	9.54E+09	1.06E+10	1.27E+10	7.08E+09	6.60E+09	8.20E+09	6.31E+09	6.78E+09	1.34E+10	9.22E+09	9.01E+09	1.33E+10	1.19E+10
ENO2/$	4.27E+07	4.56E+07	3.63E+07	3.86E+07	4.04E+07	2.30E+07	2.08E+07	2.63E+07	1.90E+07	1.91E+07	4.19E+07	3.05E+07	3.07E+07	4.35E+07	3.09E+07
EPM10/$	2.91E+07	2.95E+07	2.18E+07	2.34E+07	2.94E+07	1.53E+07	1.60E+07	1.70E+07	1.28E+07	1.44E+07	3.44E+07	2.20E+07	1.94E+07	3.23E+07	2.49E+07
ECO2/$	1.90E+10	1.68E+10	1.29E+10	1.42E+10	1.88E+10	9.00E+09	9.51E+09	1.02E+10	7.56E+09	7.35E+09	2.23E+10	1.31E+10	1.11E+10	2.08E+10	1.33E+10
EMETH/$	1.87E+05	1.57E+05	1.82E+05	1.16E+05	1.10E+05	7.30E+04	4.79E+04	7.29E+04	5.10E+04	4.36E+04	7.51E+04	7.36E+04	1.13E+05	1.13E+05	5.68E+04
EAMM/$	4.42E+07	4.28E+07	3.19E+07	3.86E+07	3.90E+07	1.65E+07	1.60E+07	1.87E+07	1.16E+07	8.89E+06	4.40E+07	2.10E+07	3.14E+07	4.21E+07	3.00E+07
ETOL/$	9.18E+05	4.08E+05	5.53E+05	4.51E+05	2.86E+05	1.85E+05	1.26E+05	2.31E+05	1.20E+05	8.09E+04	2.48E+05	1.64E+05	2.97E+05	3.82E+05	1.09E+05
ETCE/$	2.42E+07	1.05E+07	1.28E+07	1.30E+07	7.80E+06	4.48E+06	3.40E+06	5.71E+06	2.56E+06	1.47E+06	6.94E+06	3.84E+06	7.31E+06	1.15E+07	2.61E+06
ESTY-A/$	7.68E+03	4.44E+03	4.24E+03	4.13E+03	2.40E+03	1.45E+03	1.00E+03	1.03E+03	7.25E+02	4.24E+02	1.29E+03	7.33E+02	1.95E+03	3.56E+03	5.57E+02
ESTY-W/$	9.69E+00	1.45E+01	1.32E+01	9.78E+00	7.67E+00	5.18E+00	2.75E+00	4.10E+00	3.58E+00	2.75E+00	4.34E+00	5.32E+00	1.09E+01	7.62E+00	2.81E+00
ESTY-S/$	1.03E+02	1.94E+01	3.74E+01	1.96E+01	1.74E+01	1.53E+01	5.56E+00	1.19E+01	1.23E+01	9.92E+00	9.45E+00	2.38E+01	1.68E+01	1.38E+01	8.11E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	2.00E+12	1.80E+12	1.25E+12	1.24E+12	1.77E+12	7.05E+11	6.92E+11	7.92E+11	5.54E+11	4.56E+11	2.21E+12	1.02E+12	9.89E+11	1.92E+12	1.31E+12
REN/$	4.18E+09	2.18E+10	1.27E+10	4.47E+09	4.02E+09	2.60E+09	2.63E+09	3.24E+09	2.20E+09	2.96E+09	4.79E+09	3.10E+09	6.59E+09	5.15E+09	3.86E+09
Impact/$	3.21E+10	3.08E+10	2.26E+10	2.50E+10	3.16E+10	1.61E+10	1.62E+10	1.85E+10	1.39E+10	1.42E+10	3.58E+10	2.24E+10	2.02E+10	3.42E+10	2.53E+10
HR/$	2.08E+12	2.08E+12	2.09E+12	2.07E+12	1.97E+12	3.70E+12	1.77E+12	2.15E+12	1.88E+12	2.33E+12	2.07E+12	2.20E+12	1.86E+12	2.17E+12	2.09E+12
Total/$	4.12E+12	3.93E+12	3.37E+12	3.34E+12	3.77E+12	4.43E+12	2.48E+12	2.96E+12	2.45E+12	2.81E+12	4.31E+12	3.25E+12	2.87E+12	4.13E+12	3.43E+12
ICEC to money ratio (J/$)															
ICEC/$	4.20E+09	2.18E+10	1.28E+10	4.48E+09	2.54E+09	1.37E+09	1.44E+09	1.44E+09	1.28E+09	1.19E+09	1.57E+09	1.72E+09	6.61E+09	3.69E+09	1.24E+09

Continued

Table B.3 continued

NAICS	336999	337110	337121	337122	337124	337127	33712A	337211	337212	337214	337215	337910	337920	339111	339112
Econ.	4436.5	9097.7	8385	10740.9	2306.2	4103.8	862.6	3093	2256	8027	7750.2	3879.1	2212.5	2215.7	17551.2
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.18E+12	4.32E+11	6.11E+11	5.22E+11	1.05E+12	9.14E+11	9.73E+11	5.97E+11	4.17E+11	9.96E+11	1.21E+12	7.25E+11	1.10E+12	7.27E+11	4.06E+11
BS/$	2.94E+10	9.50E+11	2.86E+11	8.85E+11	1.33E+11	3.48E+11	4.82E+11	5.73E+11	5.08E+11	1.36E+11	2.74E+11	9.22E+10	7.82E+10	1.05E+11	2.80E+10
HS/$	3.90E+09	2.80E+09	4.13E+09	2.12E+09	3.74E+09	3.38E+09	3.99E+09	3.20E+09	2.72E+09	2.42E+09	3.87E+09	4.09E+09	3.73E+09	3.44E+09	3.02E+09
AS/$	6.73E+08	1.68E+09	9.75E+09	1.95E+09	9.38E+08	1.22E+09	1.99E+09	1.64E+09	1.10E+09	1.72E+09	1.23E+09	5.35E+09	1.68E+09	6.46E+08	9.91E+08
sltot/$	3.52E+09	5.14E+10	2.14E+10	4.95E+10	7.46E+09	1.94E+10	4.41E+10	2.86E+10	2.66E+10	7.51E+09	1.49E+10	7.75E+09	6.72E+09	5.54E+09	1.86E+09
hydrotot/$	2.93E+09	3.19E+09	3.63E+09	3.82E+09	3.37E+09	3.29E+09	4.57E+09	3.53E+09	2.49E+09	3.12E+09	3.60E+09	3.03E+09	3.56E+09	3.00E+09	2.23E+09
geotot/$	2.65E+07	2.88E+07	3.28E+07	3.45E+07	3.05E+07	2.97E+07	4.13E+07	3.19E+07	2.25E+07	2.82E+07	3.26E+07	2.74E+07	3.22E+07	2.71E+07	2.02E+07
windtot/$	1.46E+06	1.59E+06	1.81E+06	1.90E+06	1.68E+06	1.64E+06	2.28E+06	1.76E+06	1.24E+06	1.56E+06	1.80E+06	1.51E+06	1.78E+06	1.50E+06	1.11E+06
erotot/$	1.73E+09	4.32E+09	2.51E+10	5.01E+09	2.41E+09	3.12E+09	5.12E+09	4.22E+09	2.83E+09	4.41E+09	3.16E+09	1.37E+10	4.33E+09	1.66E+09	2.55E+09
HR/$	1.65E+12	2.05E+12	2.32E+12	2.04E+12	1.89E+12	2.02E+12	4.40E+12	2.06E+12	2.08E+12	1.79E+12	2.01E+12	1.88E+12	1.91E+12	2.40E+12	1.83E+12
ESO2/$	9.71E+09	7.12E+09	9.05E+09	8.11E+09	9.99E+09	8.72E+09	1.15E+10	7.86E+09	5.60E+09	8.91E+09	9.78E+09	8.21E+09	1.09E+10	7.22E+09	5.17E+09
ENO2/$	3.32E+07	3.76E+07	3.86E+07	3.96E+07	3.29E+07	3.24E+07	4.81E+07	3.53E+07	2.60E+07	3.14E+07	3.49E+07	3.29E+07	3.30E+07	2.70E+07	2.00E+07
EPM10/$	2.29E+07	2.22E+07	1.82E+07	2.31E+07	2.13E+07	2.17E+07	2.26E+07	2.18E+07	1.77E+07	2.14E+07	2.53E+07	1.73E+07	1.98E+07	1.81E+07	1.08E+07
ECO2/$	1.47E+10	9.84E+09	1.19E+10	1.07E+10	1.31E+10	1.26E+10	1.69E+10	1.08E+10	7.59E+09	1.30E+10	1.54E+10	1.16E+10	1.20E+10	1.01E+10	6.73E+09
EMETH/$	1.07E+05	8.29E+05	6.43E+05	7.84E+05	5.91E+05	5.84E+05	7.18E+05	7.05E+05	6.06E+05	5.69E+05	5.62E+05	2.01E+05	1.89E+05	1.07E+05	1.32E+05
EAMM/$	2.77E+07	1.70E+07	2.63E+07	2.12E+07	3.11E+07	2.37E+07	2.10E+07	1.77E+07	1.41E+07	2.70E+07	2.95E+07	2.30E+07	2.98E+07	2.09E+07	1.09E+07
ETOL/$	4.08E+05	3.04E+06	3.50E+06	3.02E+06	2.94E+06	2.97E+06	3.01E+06	2.99E+06	2.88E+06	3.01E+06	2.88E+06	6.74E+05	5.49E+05	2.71E+05	2.62E+05
ETCE/$	1.24E+07	1.24E+07	2.06E+07	1.29E+07	1.65E+07	1.67E+07	1.42E+07	1.38E+07	1.19E+07	1.76E+07	1.33E+07	1.32E+07	1.35E+07	6.61E+06	5.86E+06
ESTY-A/$	4.65E+03	2.69E+03	4.95E+03	2.75E+03	4.20E+03	4.49E+03	2.92E+03	3.27E+03	2.31E+03	4.45E+03	2.00E+03	5.49E+03	6.38E+03	2.07E+03	2.64E+03
ESTY-W/$	1.03E+01	3.21E+01	1.80E+01	3.02E+01	1.29E+01	1.79E+01	3.38E+01	2.52E+01	1.99E+01	1.42E+01	1.27E+01	1.44E+01	1.48E+01	9.19E+00	8.39E+00
ESTY-S/$	1.81E+01	1.40E+01	3.85E+01	1.49E+01	1.63E+01	1.71E+01	3.88E+01	1.60E+01	1.11E+01	1.98E+01	1.22E+01	3.16E+01	2.56E+01	1.55E+01	1.57E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.21E+12	1.38E+12	8.98E+11	1.41E+12	1.19E+12	1.26E+12	1.46E+12	1.17E+12	9.26E+11	1.13E+12	1.49E+12	8.18E+11	1.18E+12	8.32E+11	4.34E+11
REN/$	3.90E+09	5.14E+10	2.51E+10	4.95E+10	7.46E+09	1.94E+10	4.41E+10	2.86E+10	2.66E+10	7.51E+09	1.49E+10	1.37E+10	6.72E+09	5.54E+09	3.02E+09
Impact/$	2.45E+10	1.71E+10	2.10E+10	1.90E+10	2.32E+10	2.14E+10	2.85E+10	1.88E+10	1.33E+10	2.20E+10	2.53E+10	2.00E+10	2.31E+10	1.74E+10	1.20E+10
HR/$	1.65E+12	2.05E+12	2.32E+12	2.04E+12	1.89E+12	2.02E+12	4.40E+12	2.06E+12	2.08E+12	1.79E+12	2.01E+12	1.88E+12	1.91E+12	2.40E+12	1.83E+12
Total/$	2.89E+12	3.50E+12	3.26E+12	3.51E+12	3.11E+12	3.32E+12	5.93E+12	3.27E+12	3.04E+12	2.95E+12	3.54E+12	2.73E+12	3.12E+12	3.26E+12	2.28E+12
ICEC to money ratio (J/$)															
ICEC/$	3.53E+09	5.15E+10	2.14E+10	4.95E+10	7.47E+09	1.94E+10	4.42E+10	2.87E+10	2.66E+10	7.53E+09	1.49E+10	7.76E+09	6.73E+09	5.55E+09	1.87E+09

Continued

Table B.3 continued

NAICS	339113	339114	339115	339116	339910	339920	339930	339940	339950	339991	339992	339994	339995	33999A	420000
Econ.	14029.1	2399.8	3386.5	3005.8	11693	10888.9	4361.9	4214.1	8958.5	5037.5	1320.5	1974.1	1271.3	9492.5	752854
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	5.11E+11	2.00E+12	3.91E+11	1.54E+12	3.63E+12	9.85E+11	7.08E+11	9.53E+11	7.57E+11	1.03E+12	3.46E+11	6.42E+11	9.57E+11	8.39E+11	2.09E+11
BS/$	3.52E+10	3.32E+10	2.55E+10	1.84E+10	1.91E+10	1.57E+11	1.32E+11	1.44E+11	1.32E+11	9.39E+10	3.25E+11	1.25E+11	1.85E+11	1.82E+11	2.30E+10
HS/$	2.08E+09	3.37E+09	2.49E+09	1.68E+09	3.33E+09	2.97E+09	3.54E+09	2.95E+09	3.53E+09	2.48E+09	3.25E+09	3.82E+09	3.37E+09	3.47E+09	2.55E+09
AS/$	3.26E+09	6.36E+08	7.04E+08	5.66E+08	4.55E+08	2.51E+09	1.81E+09	1.05E+09	1.31E+09	2.61E+09	8.98E+08	9.96E+09	2.17E+09	3.15E+09	5.10E+08
sltot/$	2.94E+09	1.77E+09	1.51E+09	1.16E+09	1.25E+09	1.22E+10	6.92E+09	8.19E+09	5.88E+09	1.73E+10	2.06E+10	1.69E+10	1.23E+10	1.18E+10	1.38E+09
hydrotot/$	2.42E+09	2.88E+09	2.52E+09	3.83E+09	3.44E+09	3.51E+09	3.48E+09	2.78E+09	3.36E+09	4.00E+09	2.47E+09	3.28E+09	2.53E+09	3.31E+09	1.63E+09
geotot/$	2.19E+07	2.60E+07	2.28E+07	3.46E+07	3.11E+07	3.17E+07	3.15E+07	2.51E+07	3.04E+07	3.62E+07	2.23E+07	2.96E+07	2.28E+07	2.99E+07	1.48E+07
windtot/$	1.21E+06	1.44E+06	1.26E+06	1.91E+06	1.71E+06	1.75E+06	1.74E+06	1.39E+06	1.68E+06	2.00E+06	1.23E+06	1.63E+06	1.26E+06	1.65E+06	8.13E+05
erotot/$	8.38E+09	1.64E+09	1.81E+09	1.46E+09	1.17E+09	6.46E+09	4.65E+09	2.70E+09	3.38E+09	6.71E+09	2.31E+09	2.56E+10	5.58E+09	8.10E+09	1.31E+09
HR/$	1.72E+12	2.02E+12	1.80E+12	2.16E+12	1.75E+12	1.89E+12	1.82E+12	1.62E+12	2.22E+12	1.88E+12	2.26E+12	1.88E+12	1.42E+12	1.82E+12	1.69E+12
ESO2/$	6.08E+09	9.42E+09	5.67E+09	9.86E+09	1.42E+10	1.05E+10	9.95E+09	7.72E+09	9.77E+09	1.13E+10	5.38E+09	8.75E+09	7.36E+09	9.57E+09	3.10E+09
ENO2/$	2.39E+07	3.07E+07	2.15E+07	2.79E+07	3.67E+07	3.79E+07	3.65E+07	3.03E+07	3.45E+07	4.12E+07	2.23E+07	3.47E+07	2.55E+07	3.55E+07	1.98E+07
EPM10/$	1.34E+07	2.45E+07	1.06E+07	1.74E+07	3.25E+07	3.61E+07	1.74E+07	2.70E+07	1.88E+07	2.40E+07	1.37E+07	1.61E+07	1.82E+07	1.90E+07	7.48E+06
ECO2/$	7.76E+09	9.42E+09	7.22E+09	8.23E+09	1.09E+10	1.36E+10	1.26E+10	9.57E+09	1.15E+10	1.52E+10	7.01E+09	1.15E+10	1.14E+10	1.20E+10	4.79E+09
EMETH/$	1.62E+05	1.48E+05	1.33E+05	9.26E+04	6.45E+04	2.16E+05	4.53E+05	2.54E+05	4.74E+05	1.98E+05	1.86E+05	2.34E+05	9.73E+04	3.59E+05	6.50E+04
EAMM/$	1.43E+07	2.30E+07	9.75E+06	1.79E+07	3.51E+07	2.65E+07	2.33E+07	1.46E+07	2.69E+07	2.23E+07	7.77E+06	2.01E+07	2.12E+07	2.47E+07	3.59E+06
ETOL/$	2.51E+05	1.71E+05	3.02E+05	1.26E+05	1.18E+05	4.49E+05	3.97E+05	2.74E+05	4.83E+05	3.54E+05	3.13E+05	4.71E+05	1.83E+05	3.69E+05	9.20E+04
ETCE/$	4.49E+06	3.62E+06	7.32E+06	2.40E+06	2.48E+06	9.94E+06	6.83E+06	5.62E+06	1.21E+07	8.44E+06	2.35E+06	7.81E+06	2.55E+06	7.40E+06	1.19E+06
ESTY-A/$	1.70E+03	1.44E+03	3.61E+03	8.27E+02	6.20E+02	4.13E+03	2.71E+03	2.55E+03	5.86E+03	3.86E+03	8.39E+02	2.65E+03	3.96E+02	2.63E+03	5.14E+02
ESTY-W/$	7.58E+00	7.30E+00	1.17E+01	4.35E+00	3.02E+00	1.65E+01	1.88E+01	1.24E+01	2.06E+01	1.72E+01	1.02E+01	1.36E+01	6.07E+00	1.40E+01	2.28E+00
ESTY-S/$	1.82E+01	2.25E+01	2.49E+01	1.21E+01	7.69E+00	3.59E+01	2.99E+01	3.00E+01	2.75E+01	4.88E+01	7.89E+00	3.10E+01	9.09E+00	2.31E+01	4.12E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	5.46E+11	2.03E+12	4.16E+11	1.56E+12	3.65E+12	1.14E+12	8.40E+11	1.10E+12	8.89E+11	1.12E+12	6.71E+11	7.68E+11	1.14E+12	1.02E+12	2.31E+11
REN/$	8.38E+09	3.37E+09	2.52E+09	3.83E+09	3.44E+09	1.22E+10	6.92E+09	8.19E+09	5.88E+09	1.73E+10	2.06E+10	2.56E+10	1.23E+10	1.18E+10	2.55E+09
Impact/$	1.39E+10	1.89E+10	1.29E+10	1.82E+10	2.51E+10	2.42E+10	2.27E+10	1.74E+10	2.14E+10	2.66E+10	1.24E+10	2.04E+10	1.89E+10	2.17E+10	7.92E+09
HR/$	1.72E+12	2.02E+12	1.80E+12	2.16E+12	1.75E+12	1.89E+12	1.82E+12	1.62E+12	2.22E+12	1.88E+12	2.26E+12	1.88E+12	1.42E+12	1.82E+12	1.69E+12
Total/$	2.29E+12	4.08E+12	2.23E+12	3.74E+12	5.43E+12	3.07E+12	2.69E+12	2.74E+12	3.14E+12	3.05E+12	2.96E+12	2.69E+12	2.59E+12	2.87E+12	1.93E+12
ICEC to money ratio (J/$)															
ICEC/$	2.95E+09	1.78E+09	1.52E+09	1.17E+09	1.26E+09	1.22E+10	6.94E+09	8.21E+09	5.90E+09	1.73E+10	2.06E+10	1.69E+10	1.23E+10	1.18E+10	1.38E+09

Continued

Table B.3 continued

NAICS	481000	482000	483000	484000	485000	486000	48A000	491000	492000	493000	4A0000	511110	511120	511130	5111A0
Econ.	119445	37967	24396.5	169396.7	24625.8	27284.1	44337.9	58861	41786.3	29222.7	729824	41042.6	29522.4	22305.6	20672.1
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.32E+12	1.17E+12	5.01E+11	8.24E+11	5.94E+11	2.99E+12	4.88E+11	2.46E+11	7.12E+11	5.33E+11	2.85E+11	3.30E+11	3.09E+11	2.96E+11	1.91E+11
BS/$	1.46E+10	8.53E+10	1.71E+10	1.47E+10	1.06E+10	1.55E+10	1.90E+10	9.45E+09	1.02E+10	1.79E+10	2.14E+10	1.34E+11	8.55E+10	9.29E+10	4.40E+10
HS/$	4.27E+09	2.69E+09	4.83E+09	2.60E+09	3.87E+09	2.31E+09	4.48E+09	6.19E+09	2.89E+09	5.20E+09	4.16E+09	2.04E+09	3.14E+09	3.19E+09	2.52E+09
AS/$	1.61E+09	3.90E+08	7.64E+08	3.53E+08	2.82E+08	6.31E+08	5.51E+08	2.92E+08	9.55E+08	3.82E+08	4.90E+08	6.18E+08	7.76E+08	6.01E+08	3.69E+08
sltot/$	1.36E+09	4.77E+09	1.21E+09	1.65E+09	1.53E+09	1.06E+09	1.17E+09	6.14E+08	1.21E+09	1.25E+09	1.28E+09	5.08E+09	3.49E+09	3.67E+09	1.83E+09
hydrotot/$	2.22E+09	1.24E+09	1.73E+09	1.46E+09	1.22E+09	3.80E+09	2.37E+09	5.22E+08	1.09E+09	5.48E+09	3.19E+09	2.00E+09	1.46E+09	1.71E+09	1.16E+09
geotot/$	2.01E+07	1.12E+07	1.57E+07	1.32E+07	1.10E+07	3.44E+07	2.14E+07	4.72E+06	9.85E+06	4.96E+07	2.88E+07	1.81E+07	1.32E+07	1.55E+07	1.05E+07
windtot/$	1.11E+06	6.20E+05	8.65E+05	7.27E+05	6.08E+05	1.90E+06	1.18E+06	2.60E+05	5.43E+05	2.73E+06	1.59E+06	9.98E+05	7.30E+05	8.55E+05	5.77E+05
erotot/$	4.14E+09	1.00E+09	1.96E+09	9.07E+08	7.26E+08	1.62E+09	1.42E+09	7.50E+08	2.46E+09	9.82E+08	1.26E+09	1.59E+09	2.00E+09	1.55E+09	9.48E+08
HR/$	1.23E+12	1.20E+12	2.21E+12	1.86E+12	1.62E+12	1.42E+12	2.09E+12	3.85E+11	1.93E+12	8.85E+11	2.28E+12	1.72E+12	1.50E+12	1.59E+12	1.57E+12
ESO2/$	6.60E+09	9.01E+09	3.92E+10	6.15E+09	8.36E+09	1.06E+10	9.99E+09	1.66E+09	3.38E+09	1.03E+10	5.28E+09	5.95E+09	4.69E+09	4.93E+09	3.06E+09
ENO2/$	5.09E+07	2.11E+08	1.89E+08	1.71E+08	2.02E+08	4.56E+07	2.10E+08	1.31E+07	2.22E+07	1.50E+08	2.14E+07	2.21E+07	1.85E+07	1.88E+07	1.15E+07
EPM10/$	3.44E+07	5.51E+07	9.81E+07	1.07E+07	4.56E+07	3.51E+07	5.31E+07	8.19E+06	6.98E+06	1.33E+07	1.06E+07	1.12E+07	9.03E+06	9.62E+06	5.94E+06
ECO2/$	3.31E+10	1.65E+10	1.91E+10	2.38E+10	1.62E+10	3.34E+10	1.62E+10	4.26E+09	9.31E+09	2.20E+10	6.27E+09	5.96E+09	5.27E+09	5.41E+09	3.51E+09
EMETH/$	5.82E+04	7.49E+04	6.20E+04	4.61E+04	3.66E+04	6.96E+04	6.30E+04	3.36E+04	3.77E+04	4.74E+04	7.21E+04	5.83E+05	4.05E+05	4.19E+05	2.24E+05
EAMM/$	9.26E+06	9.24E+06	6.03E+06	7.28E+06	5.91E+06	1.47E+07	5.95E+06	3.11E+06	5.43E+06	3.54E+06	3.70E+06	1.87E+07	1.49E+07	1.46E+07	8.17E+06
ETOL/$	1.65E+05	1.17E+05	1.46E+05	1.46E+05	1.19E+05	2.53E+05	1.10E+05	3.82E+04	1.11E+05	7.34E+04	1.10E+05	3.37E+06	3.57E+06	3.53E+06	3.60E+06
ETCE/$	1.01E+06	1.46E+06	1.28E+06	2.21E+06	2.19E+06	2.34E+06	1.12E+06	4.59E+05	1.33E+06	7.59E+05	1.13E+06	5.30E+06	5.88E+06	5.73E+06	5.70E+06
ESTY-A/$	3.32E+02	4.24E+02	4.34E+02	9.89E+02	1.02E+03	4.55E+02	3.82E+02	1.61E+02	5.93E+02	3.04E+02	4.67E+02	3.33E+02	4.40E+02	3.98E+02	3.63E+02
ESTY-W/$	3.65E+00	5.21E+00	2.55E+00	3.72E+00	3.12E+00	5.26E+00	2.41E+00	1.30E+00	2.79E+00	1.81E+00	2.22E+00	7.85E+00	6.93E+00	6.44E+00	3.75E+00
ESTY-S/$	4.75E+00	4.15E+00	5.48E+00	6.01E+00	5.07E+00	6.45E+00	4.74E+00	3.11E+00	4.17E+00	2.93E+00	3.36E+00	9.53E+00	1.62E+01	1.13E+01	7.05E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.33E+12	1.25E+12	5.18E+11	8.38E+11	6.05E+11	3.01E+12	5.07E+11	2.56E+11	7.22E+11	5.51E+11	3.07E+11	4.63E+11	3.94E+11	3.89E+11	2.35E+11
REN/$	4.27E+09	4.77E+09	4.83E+09	2.60E+09	3.87E+09	3.80E+09	4.48E+09	6.19E+09	2.89E+09	5.48E+09	4.16E+09	5.08E+09	3.49E+09	3.67E+09	2.52E+09
Impact/$	3.98E+10	2.58E+10	5.86E+10	3.02E+10	2.48E+10	4.41E+10	2.65E+10	5.94E+09	1.27E+10	3.24E+10	1.16E+10	1.20E+10	1.00E+10	1.04E+10	6.61E+09
HR/$	1.23E+12	1.20E+12	2.21E+12	1.86E+12	1.62E+12	1.42E+12	2.09E+12	3.85E+11	1.93E+12	8.85E+11	2.28E+12	1.72E+12	1.50E+12	1.59E+12	1.57E+12
Total/$	2.60E+12	2.48E+12	2.79E+12	2.73E+12	2.25E+12	4.48E+12	2.63E+12	6.53E+11	2.67E+12	1.47E+12	2.60E+12	2.20E+12	1.91E+12	2.00E+12	1.81E+12
ICEC to money ratio (J/$)															
ICEC/$	1.41E+09	4.79E+09	1.22E+09	1.67E+09	1.55E+09	1.17E+09	1.18E+09	6.21E+08	1.23E+09	1.27E+09	1.29E+09	5.09E+09	3.50E+09	3.68E+09	1.83E+09

Continued

Table B.3 continued

NAICS	511200	512100	512200	513100	513200	513300	514100	514200	522A00	523000	524100	524200	525000	52A000	531000
Econ.	61376.9	49744.1	11427.5	41272	45174.5	277604.5	11703.8	35811.6	124793.6	198074.5	249661	90354.3	64300	343510.2	607472.4
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.24E+11	2.26E+11	1.54E+11	1.93E+11	1.76E+11	2.25E+11	1.96E+11	1.41E+11	1.57E+11	1.56E+11	6.69E+10	5.47E+10	1.68E+11	8.65E+10	3.54E+11
BS/$	1.34E+10	2.72E+10	1.73E+10	2.07E+10	1.57E+10	1.93E+10	1.72E+10	1.42E+10	1.07E+10	8.43E+09	6.05E+09	4.42E+09	1.13E+10	6.95E+09	1.72E+10
HS/$	1.25E+09	3.60E+09	2.45E+09	3.82E+09	4.43E+09	4.27E+09	1.91E+09	1.80E+09	6.28E+09	2.85E+09	1.59E+09	2.31E+09	2.98E+09	1.74E+09	7.96E+09
AS/$	4.57E+08	9.26E+08	4.38E+08	5.34E+08	3.72E+08	2.49E+08	6.18E+08	4.68E+08	3.66E+08	3.91E+08	1.95E+08	2.01E+08	4.64E+08	3.95E+08	9.53E+08
sltot/$	7.90E+08	1.71E+09	9.28E+08	1.23E+09	9.08E+08	1.09E+09	1.04E+09	8.92E+08	6.59E+08	5.68E+08	3.84E+08	3.31E+08	7.51E+08	4.91E+08	1.33E+09
hydrotot/$	8.70E+08	2.20E+09	1.24E+09	1.92E+09	1.60E+09	1.21E+09	1.36E+09	1.14E+09	1.76E+09	2.01E+09	5.29E+08	3.87E+08	2.01E+09	6.11E+08	4.44E+09
geotot/$	7.86E+06	1.99E+07	1.12E+07	1.73E+07	1.44E+07	1.09E+07	1.23E+07	1.03E+07	1.59E+07	1.81E+07	4.79E+06	3.50E+06	1.82E+07	5.52E+06	4.01E+07
windtot/$	4.34E+05	1.10E+06	6.19E+05	9.56E+05	7.97E+05	6.03E+05	6.76E+05	5.67E+05	8.77E+05	1.00E+06	2.64E+05	1.93E+05	1.00E+06	3.05E+05	2.21E+06
erotot/$	1.18E+09	2.38E+09	1.13E+09	1.37E+09	9.57E+08	6.39E+08	1.59E+09	1.20E+09	9.41E+08	1.00E+09	5.02E+08	5.18E+08	1.19E+09	1.02E+09	2.45E+09
HR/$	1.72E+12	1.75E+12	9.89E+11	2.14E+12	1.32E+12	1.30E+12	1.86E+12	1.64E+12	1.97E+12	2.51E+12	2.07E+12	1.53E+12	2.20E+12	1.33E+12	6.99E+11
ESO2/$	1.84E+09	4.14E+09	2.52E+09	3.46E+09	3.00E+09	2.58E+09	2.76E+09	2.28E+09	3.03E+09	3.30E+09	1.02E+09	7.91E+08	3.42E+09	1.23E+09	6.78E+09
ENO2/$	6.75E+06	1.34E+07	9.43E+06	1.09E+07	9.32E+06	9.01E+06	1.00E+07	7.96E+06	9.86E+06	9.90E+06	3.78E+06	3.14E+06	1.05E+07	5.05E+06	1.89E+07
EPM10/$	4.94E+06	1.01E+07	6.19E+06	9.46E+06	6.37E+06	8.69E+06	6.38E+06	7.25E+06	1.09E+07	7.39E+06	3.32E+06	2.55E+06	9.04E+06	6.19E+06	2.03E+07
ECO2/$	2.24E+09	4.71E+09	3.21E+09	3.79E+09	3.42E+09	3.11E+09	3.58E+09	2.61E+09	3.41E+09	3.60E+09	1.37E+09	1.09E+09	3.83E+09	1.70E+09	6.93E+09
EMETH/$	6.72E+04	1.00E+05	7.56E+04	6.58E+04	5.87E+04	5.26E+04	7.37E+04	5.00E+04	4.55E+04	3.67E+04	2.45E+04	1.97E+04	4.54E+04	2.63E+04	3.05E+04
EAMM/$	3.55E+06	5.12E+06	3.72E+06	4.06E+06	4.31E+06	4.16E+06	4.67E+06	3.31E+06	2.48E+06	1.96E+06	1.23E+06	1.08E+06	2.42E+06	1.44E+06	2.01E+06
ETOL/$	3.40E+06	1.55E+05	1.41E+05	1.15E+05	9.43E+04	8.09E+04	1.65E+05	7.13E+04	4.75E+04	4.32E+04	3.34E+04	1.91E+04	5.58E+04	3.30E+04	4.46E+04
ETCE/$	5.22E+06	1.31E+06	1.81E+06	9.34E+05	1.04E+06	1.09E+06	1.16E+06	7.92E+05	4.97E+05	3.68E+05	2.69E+05	2.41E+05	4.96E+05	2.79E+05	5.65E+05
ESTY-A/$	2.19E+02	4.94E+02	8.43E+02	3.17E+02	3.86E+02	4.10E+02	3.64E+02	2.53E+02	1.77E+02	1.35E+02	1.01E+02	9.60E+01	1.84E+02	9.87E+01	1.97E+02
ESTY-W/$	1.51E+00	2.97E+00	2.84E+00	2.05E+00	1.95E+00	2.06E+00	2.13E+00	1.45E+00	1.13E+00	9.51E-01	6.33E-01	5.45E-01	1.22E+00	7.08E-01	1.28E+00
ESTY-S/$	3.51E+00	6.17E+00	4.73E+00	4.48E+00	4.18E+00	4.04E+00	4.44E+00	2.82E+00	2.00E+00	1.95E+00	1.28E+00	1.19E+00	2.57E+00	1.46E+00	2.31E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.37E+11	2.53E+11	1.71E+11	2.14E+11	1.92E+11	2.44E+11	2.13E+11	1.55E+11	1.67E+11	1.64E+11	7.30E+10	5.92E+10	1.80E+11	9.35E+10	3.71E+11
REN/$	1.25E+09	3.60E+09	2.45E+09	3.82E+09	4.43E+09	4.27E+09	1.91E+09	1.80E+09	6.28E+09	2.85E+09	1.59E+09	2.31E+09	2.98E+09	1.74E+09	7.96E+09
Impact/$	4.11E+09	8.88E+09	5.76E+09	7.27E+09	6.45E+09	5.71E+09	6.35E+09	4.91E+09	6.46E+09	6.92E+09	2.40E+09	1.89E+09	7.27E+09	2.95E+09	1.38E+10
HR/$	1.72E+12	1.75E+12	9.89E+11	2.14E+12	1.32E+12	1.30E+12	1.86E+12	1.64E+12	1.97E+12	2.51E+12	2.07E+12	1.53E+12	2.20E+12	1.33E+12	6.99E+11
Total/$	1.86E+12	2.01E+12	1.17E+12	2.36E+12	1.52E+12	1.55E+12	2.08E+12	1.80E+12	2.15E+12	2.69E+12	2.15E+12	1.59E+12	2.39E+12	1.42E+12	1.09E+12
ICEC to money ratio (J/$)															
ICEC/$	7.93E+08	1.71E+09	9.32E+08	1.23E+09	9.11E+08	1.10E+09	1.04E+09	8.95E+08	6.62E+08	5.72E+08	3.86E+08	3.33E+08	7.55E+08	4.93E+08	1.33E+09

Continued

Table B.3 continued

NAICS	532100	532230	532400	532A00	533000	541100	541200	541300	541400	541511	541512	54151A	541610	5416A0	541700
Econ.	42162	8323.6	41084.7	17142.6	102007.4	152040.8	71432.5	131136	17739.1	86326.8	29507.8	23429.4	69148	15914.6	63340.1
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	3.06E+11	2.35E+11	1.18E+11	1.60E+11	6.20E+09	1.08E+11	1.22E+11	1.12E+11	1.75E+11	1.27E+11	1.21E+11	1.38E+11	1.46E+11	1.49E+11	3.59E+11
BS/$	1.28E+10	1.67E+10	8.89E+09	8.81E+09	1.13E+09	1.13E+10	1.22E+10	1.06E+10	1.32E+10	1.06E+10	1.02E+10	1.17E+10	1.48E+10	1.11E+10	2.13E+10
HS/$	3.89E+09	4.43E+09	2.47E+09	3.03E+09	5.55E+07	2.02E+09	1.77E+09	1.86E+09	3.32E+09	1.43E+09	1.62E+09	1.45E+09	1.73E+09	2.10E+09	4.45E+09
AS/$	3.77E+08	3.73E+08	4.03E+08	5.23E+08	2.84E+07	3.38E+08	4.75E+08	4.95E+08	5.91E+08	7.37E+08	5.55E+08	5.57E+08	8.07E+08	4.49E+08	7.71E+08
sltot/$	1.24E+09	1.02E+09	6.15E+08	7.06E+08	5.56E+07	6.99E+08	7.51E+08	7.31E+08	9.34E+08	7.84E+08	7.26E+08	7.98E+08	9.96E+08	7.49E+08	1.56E+09
hydrotot/$	1.25E+09	3.62E+09	1.02E+09	1.33E+09	2.85E+07	9.16E+08	9.20E+08	1.02E+09	1.29E+09	9.11E+08	1.20E+09	1.01E+09	8.81E+08	9.98E+08	2.26E+09
geotot/$	1.13E+07	3.28E+07	9.19E+06	1.20E+07	2.57E+05	8.28E+06	8.32E+06	9.26E+06	1.17E+07	8.23E+06	1.09E+07	9.12E+06	7.97E+06	9.02E+06	2.04E+07
windtot/$	6.23E+05	1.81E+06	5.07E+05	6.61E+05	1.42E+04	4.56E+05	4.59E+05	5.10E+05	6.44E+05	4.54E+05	6.00E+05	5.03E+05	4.39E+05	4.97E+05	1.13E+06
erotot/$	9.70E+08	9.60E+08	1.04E+09	1.34E+09	7.29E+07	8.68E+08	1.22E+09	1.27E+09	1.52E+09	1.89E+09	1.43E+09	1.43E+09	2.07E+09	1.15E+09	1.98E+09
HR/$	9.78E+11	1.15E+12	8.47E+11	6.01E+11	7.47E+10	4.26E+11	1.86E+12	1.91E+12	1.51E+12	1.45E+12	3.04E+12	1.56E+12	1.78E+12	1.52E+12	9.12E+11
ESO2/$	2.71E+09	5.58E+09	1.88E+09	2.47E+09	1.13E+08	1.77E+09	1.85E+09	1.90E+09	2.82E+09	1.84E+09	2.27E+09	2.01E+09	1.99E+09	1.95E+09	4.51E+09
ENO2/$	1.07E+07	1.50E+07	6.72E+06	8.50E+06	4.16E+05	6.29E+06	6.77E+06	6.48E+06	1.02E+07	6.91E+06	7.53E+06	6.99E+06	8.23E+06	7.17E+06	1.61E+07
EPM10/$	8.03E+06	1.29E+07	5.38E+06	6.63E+06	2.02E+05	5.44E+06	5.23E+06	5.26E+06	6.83E+06	5.22E+06	5.36E+06	5.85E+06	5.31E+06	5.97E+06	1.33E+07
ECO2/$	4.42E+09	5.47E+09	2.57E+09	3.27E+09	2.89E+08	2.19E+09	2.31E+09	2.34E+09	3.37E+09	2.56E+09	2.50E+09	2.50E+09	3.00E+09	2.73E+09	5.60E+09
EMETH/$	3.82E+04	3.78E+04	3.09E+04	3.35E+04	6.42E+03	4.34E+04	5.20E+04	3.75E+04	6.25E+04	4.76E+04	3.77E+04	4.47E+04	6.24E+04	3.82E+04	8.62E+04
EAMM/$	4.96E+06	2.09E+06	1.81E+06	2.61E+06	2.37E+05	2.03E+06	2.47E+06	2.08E+06	5.34E+06	2.69E+06	2.26E+06	3.27E+06	3.82E+06	5.34E+06	1.71E+07
ETOL/$	9.32E+04	5.65E+04	5.18E+04	5.27E+04	2.40E+03	5.54E+04	4.74E+04	3.65E+04	8.16E+04	4.62E+04	5.32E+04	6.10E+04	8.79E+04	5.85E+04	1.50E+05
ETCE/$	1.38E+06	6.25E+05	4.27E+05	6.00E+05	3.69E+04	4.20E+05	4.87E+05	4.79E+05	1.43E+06	5.46E+05	5.24E+05	7.23E+05	7.18E+05	9.16E+05	2.95E+06
ESTY-A/$	5.51E+02	2.30E+02	1.57E+02	2.16E+02	1.77E+01	1.53E+02	1.90E+02	1.87E+02	6.30E+02	2.00E+02	1.83E+02	2.24E+02	2.62E+02	2.86E+02	9.43E+02
ESTY-W/$	2.02E+00	1.34E+00	9.21E-01	1.21E+00	1.23E-01	1.09E+00	1.24E+00	1.06E+00	3.55E+00	1.25E+00	1.08E+00	1.32E+00	1.89E+00	1.45E+00	4.59E+00
ESTY-S/$	3.53E+00	2.06E+00	1.88E+00	3.32E+00	2.00E-01	2.25E+00	2.21E+00	2.02E+00	1.52E+01	2.64E+00	2.16E+00	2.92E+00	5.31E+00	2.43E+00	1.12E+01
Aggregate ECEC to money ratios (sej/$)															
NR/$	3.18E+11	2.52E+11	1.27E+11	1.68E+11	7.33E+09	1.20E+11	1.34E+11	1.23E+11	1.88E+11	1.38E+11	1.31E+11	1.50E+11	1.61E+11	1.60E+11	3.80E+11
REN/$	3.89E+09	4.43E+09	2.47E+09	3.03E+09	7.29E+07	2.02E+09	1.77E+09	1.86E+09	3.32E+09	1.89E+09	1.62E+09	1.45E+09	2.07E+09	2.10E+09	4.45E+09
Impact/$	7.16E+09	1.11E+10	4.46E+09	5.76E+09	4.03E+08	3.97E+09	4.18E+09	4.26E+09	6.21E+09	4.41E+09	4.79E+09	4.52E+09	5.01E+09	4.70E+09	1.02E+10
HR/$	9.78E+11	1.15E+12	8.47E+11	6.01E+11	7.47E+10	4.26E+11	1.86E+12	1.91E+12	1.51E+12	1.45E+12	3.04E+12	1.56E+12	1.78E+12	1.52E+12	9.12E+11
Total/$	1.31E+12	1.41E+12	9.81E+11	7.78E+11	8.25E+10	5.52E+11	2.00E+12	2.04E+12	1.71E+12	1.60E+12	3.18E+12	1.72E+12	1.95E+12	1.68E+12	1.31E+12
ICEC to money ratio (J/$)															
ICEC/$	1.25E+09	1.03E+09	6.17E+08	7.09E+08	5.58E+07	7.01E+08	7.53E+08	7.33E+08	9.38E+08	7.87E+08	7.28E+08	8.00E+08	1.00E+09	7.52E+08	1.57E+09

Continued

Table B.3 continued

NAICS	541800	541920	541940	5419A0	550000	561100	561200	561300	561400	561500	561600	561700	561900	562000	611100
Econ.	57713	8873.6	10398	41431.5	315497.2	29642.1	8043.5	88652.8	40561.9	25096.6	21833.5	61124.6	28717.3	41689.9	22039
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	1.45E+11	1.93E+11	3.29E+11	9.85E+10	2.11E+11	1.25E+11	1.31E+11	2.98E+10	2.65E+11	3.57E+11	1.58E+11	3.02E+11	2.58E+11	9.55E+11	3.62E+11
BS/$	1.82E+10	1.84E+10	3.24E+10	1.06E+10	2.23E+10	1.04E+10	1.01E+10	2.92E+09	1.22E+10	2.41E+10	6.84E+09	2.17E+10	2.42E+10	6.86E+10	3.60E+10
HS/$	1.94E+09	3.18E+09	3.73E+09	3.17E+09	5.53E+09	1.81E+09	2.70E+09	4.71E+08	3.01E+09	1.48E+10	1.18E+09	3.20E+09	4.21E+09	1.71E+10	5.40E+09
AS/$	1.41E+09	5.49E+08	4.74E+09	2.89E+08	2.42E+08	5.20E+08	4.18E+08	1.57E+08	4.64E+08	5.47E+08	3.70E+08	2.42E+10	5.31E+08	5.40E+08	4.65E+08
sltot/$	1.41E+09	1.10E+09	3.73E+09	6.04E+08	1.23E+09	7.40E+08	7.01E+08	1.99E+08	8.15E+08	1.30E+09	5.30E+08	1.16E+10	1.31E+09	4.64E+09	2.13E+09
hydrotot/$	1.19E+09	1.64E+09	2.43E+09	9.58E+08	2.42E+09	8.50E+08	1.10E+09	2.20E+08	1.22E+09	3.80E+09	6.36E+08	1.42E+09	1.41E+09	4.22E+09	2.69E+09
geotot/$	1.08E+07	1.48E+07	2.19E+07	8.67E+06	2.19E+07	7.69E+06	9.94E+06	1.99E+06	1.10E+07	3.43E+07	5.75E+06	1.28E+07	1.27E+07	3.82E+07	2.43E+07
windtot/$	5.93E+05	8.18E+05	1.21E+06	4.78E+05	1.21E+06	4.24E+05	5.48E+05	1.10E+05	6.08E+05	1.89E+06	3.17E+05	7.07E+05	7.01E+05	2.10E+06	1.34E+06
erotot/$	3.63E+09	1.41E+09	1.22E+10	7.43E+08	6.23E+08	1.34E+09	1.07E+09	4.04E+08	1.19E+09	1.41E+09	9.51E+08	6.23E+10	1.37E+09	1.39E+09	1.20E+09
HR/$	1.68E+12	1.26E+12	1.03E+12	4.17E+11	2.39E+12	2.11E+12	2.01E+12	2.95E+12	1.66E+12	2.03E+12	2.29E+12	1.56E+12	1.55E+12	1.64E+12	7.04E+11
ESO2/$	2.39E+09	3.80E+09	5.30E+09	1.77E+09	4.08E+09	1.77E+09	2.06E+09	4.79E+08	2.58E+09	6.45E+09	1.41E+09	3.41E+09	3.17E+09	8.25E+09	5.07E+09
ENO2/$	8.77E+06	1.31E+07	2.09E+07	5.73E+06	1.20E+07	6.50E+06	7.09E+06	2.11E+06	9.45E+06	2.01E+07	5.65E+06	2.12E+07	1.18E+07	3.00E+07	2.23E+07
EPM10/$	6.40E+06	8.50E+06	1.42E+07	4.52E+06	1.24E+07	5.14E+06	6.24E+06	1.27E+06	6.40E+06	1.10E+07	4.08E+06	7.29E+06	7.04E+06	1.00E+07	9.18E+07
ECO2/$	2.90E+09	4.37E+09	6.68E+09	2.39E+09	4.55E+09	2.63E+09	2.87E+09	1.03E+09	4.42E+09	7.86E+09	2.69E+09	6.03E+09	4.76E+09	1.48E+10	6.39E+09
EMETH/$	7.16E+04	1.16E+05	1.82E+05	4.03E+04	5.91E+04	4.14E+04	3.04E+04	1.24E+04	5.24E+04	9.65E+04	2.39E+04	7.79E+04	1.23E+05	5.57E+04	6.75E+04
EAMM/$	3.48E+06	7.55E+06	1.26E+07	1.81E+06	3.23E+06	2.70E+06	2.16E+06	5.98E+05	3.50E+06	4.55E+06	1.92E+06	5.10E+06	5.84E+06	7.38E+06	4.33E+06
ETOL/$	8.06E+04	9.46E+04	2.26E+05	5.57E+04	1.31E+05	4.87E+04	3.56E+04	1.34E+04	6.83E+04	1.08E+05	3.88E+04	1.07E+05	9.14E+04	1.27E+05	1.14E+05
ETCE/$	7.55E+05	9.96E+05	3.29E+06	3.55E+05	9.77E+05	6.05E+05	4.70E+05	1.23E+05	6.59E+05	7.23E+05	3.98E+05	1.72E+06	1.18E+06	1.29E+06	1.29E+06
ESTY-A/$	2.95E+02	3.71E+02	1.22E+03	1.22E+02	3.44E+02	2.43E+02	1.82E+02	4.87E+01	2.60E+02	2.41E+02	1.51E+02	8.05E+02	5.18E+02	5.26E+02	4.18E+02
ESTY-W/$	1.88E+00	4.26E+00	5.72E+00	9.28E-01	1.82E+00	1.50E+00	1.27E+00	3.05E-01	1.79E+00	2.16E+00	9.46E-01	3.36E+00	3.07E+00	4.55E+00	2.53E+00
ESTY-S/$	4.18E+00	2.04E+01	1.57E+01	1.73E+00	3.19E+00	4.32E+00	3.87E+00	5.51E-01	4.11E+00	3.73E+00	1.92E+00	7.99E+00	5.92E+00	8.83E+00	4.27E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	1.63E+11	2.12E+11	3.61E+11	1.09E+11	2.34E+11	1.35E+11	1.41E+11	3.27E+10	2.77E+11	3.81E+11	1.65E+11	3.24E+11	2.82E+11	1.02E+12	3.98E+11
REN/$	3.63E+09	3.18E+09	1.22E+10	3.17E+09	5.53E+09	1.81E+09	2.70E+09	4.71E+08	3.01E+09	1.48E+10	1.18E+09	6.23E+10	4.21E+09	1.71E+10	5.40E+09
Impact/$	5.32E+09	8.21E+09	1.20E+10	4.17E+09	8.66E+09	4.41E+09	4.94E+09	1.51E+09	7.02E+09	1.43E+10	4.11E+09	9.47E+09	7.96E+09	2.31E+10	1.16E+10
HR/$	1.68E+12	1.26E+12	1.03E+12	4.17E+11	2.39E+12	2.11E+12	2.01E+12	2.95E+12	1.66E+12	2.03E+12	2.29E+12	1.56E+12	1.55E+12	1.64E+12	7.04E+11
Total/$	1.85E+12	1.48E+12	1.41E+12	5.34E+11	2.64E+12	2.25E+12	2.15E+12	2.98E+12	1.95E+12	2.44E+12	2.46E+12	1.95E+12	1.84E+12	2.71E+12	1.12E+12
ICEC to money ratio (J/$)															
ICEC/$	1.42E+09	1.11E+09	3.73E+09	6.06E+08	1.23E+09	7.43E+08	7.04E+08	1.99E+08	8.23E+08	1.31E+09	5.35E+08	1.16E+10	1.32E+09	4.68E+09	2.13E+09

Continued

Table B.3 continued

NAICS	611A00	611B00	621600	621A00	621B00	622000	623000	624400	624A00	711100	711200	711500	711A00	712000	713940
Econ.	55820.9	23831.9	36197.7	268711.2	75161.4	267335.2	93581.7	26765.7	39516.2	8933.7	15696	14263.5	10510.9	4514	11067.8
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	2.68E+11	2.12E+11	1.92E+11	1.62E+11	3.57E+11	3.23E+11	3.08E+11	3.79E+11	4.46E+11	1.62E+11	1.46E+11	2.00E+11	1.31E+11	3.92E+11	3.78E+11
BS/$	3.12E+10	2.06E+10	1.01E+10	1.07E+10	2.27E+10	2.15E+10	2.44E+10	4.87E+10	4.19E+10	2.46E+10	1.37E+10	3.26E+10	1.42E+10	4.09E+10	2.91E+10
HS/$	2.78E+09	3.05E+09	2.13E+09	2.16E+09	4.43E+09	6.07E+09	8.73E+09	7.60E+09	5.94E+09	3.70E+09	4.03E+09	3.09E+09	3.31E+09	1.25E+10	1.10E+10
AS/$	5.91E+08	5.71E+08	5.39E+08	4.81E+08	9.75E+08	2.52E+09	4.33E+09	6.55E+09	4.19E+09	9.61E+08	9.52E+08	8.48E+08	5.97E+08	2.04E+09	5.48E+08
sltot/$	1.84E+09	1.23E+09	8.22E+08	7.27E+08	1.57E+09	2.20E+09	3.07E+09	5.12E+09	3.74E+09	1.71E+09	1.09E+09	2.02E+09	9.52E+08	3.59E+09	1.79E+09
hydrotot/$	1.72E+09	1.91E+09	1.01E+09	1.09E+09	1.85E+09	2.40E+09	3.10E+09	2.94E+09	2.44E+09	1.49E+09	1.59E+09	1.37E+09	1.32E+09	4.56E+09	5.19E+09
geotot/$	1.56E+07	1.73E+07	9.15E+06	9.90E+06	1.67E+07	2.17E+07	2.80E+07	2.66E+07	2.21E+07	1.34E+07	1.44E+07	1.24E+07	1.19E+07	4.13E+07	4.69E+07
windtot/$	8.59E+05	9.52E+05	5.05E+05	5.46E+05	9.22E+05	1.20E+06	1.55E+06	1.47E+06	1.22E+06	7.41E+05	7.94E+05	6.85E+05	6.56E+05	2.28E+06	2.59E+06
erotot/$	1.52E+09	1.47E+09	1.38E+09	1.24E+09	2.51E+09	6.48E+09	1.11E+10	1.68E+10	1.08E+10	2.47E+09	2.45E+09	2.18E+09	1.54E+09	5.24E+09	1.41E+09
HR/$	6.42E+11	7.51E+11	2.20E+13	1.98E+12	1.75E+12	2.86E+12	1.43E+12	1.16E+12	2.34E+12	1.38E+12	2.14E+12	1.60E+12	7.49E+11	2.47E+12	1.05E+12
ESO2/$	3.75E+09	3.84E+09	2.31E+09	2.23E+09	4.27E+09	4.85E+09	5.61E+09	5.78E+09	5.42E+09	2.87E+09	2.72E+09	2.84E+09	2.37E+09	7.81E+09	8.15E+09
ENO2/$	1.31E+07	1.26E+07	8.73E+06	7.68E+06	1.57E+07	1.74E+07	1.97E+07	2.25E+07	2.07E+07	9.97E+06	8.83E+06	1.05E+07	8.03E+06	2.45E+07	2.26E+07
EPM10/$	1.17E+07	1.03E+07	6.05E+06	6.21E+06	1.05E+07	1.16E+07	1.29E+07	1.85E+07	1.35E+07	7.85E+06	7.96E+06	7.61E+06	6.94E+06	2.13E+07	2.29E+07
ECO2/$	4.48E+09	4.38E+09	3.10E+09	2.68E+09	5.83E+09	5.90E+09	6.28E+09	6.91E+09	7.55E+09	3.40E+09	3.06E+09	3.59E+09	2.82E+09	8.26E+09	8.16E+09
EMETH/$	8.46E+04	8.09E+04	5.02E+04	4.49E+04	1.08E+05	1.02E+05	1.09E+05	1.07E+05	1.50E+05	5.97E+04	3.51E+04	7.33E+04	4.32E+04	1.43E+05	6.01E+04
EAMM/$	6.30E+06	5.92E+06	6.26E+06	3.68E+06	9.70E+06	7.88E+06	5.69E+06	6.03E+06	7.62E+06	3.75E+06	2.07E+06	6.46E+06	2.54E+06	6.52E+06	3.74E+06
ETOL/$	1.29E+05	1.61E+05	1.11E+05	6.38E+04	2.02E+05	1.42E+05	1.06E+05	1.33E+05	1.92E+05	1.07E+05	5.29E+04	1.49E+05	6.95E+04	1.41E+05	1.03E+05
ETCE/$	1.91E+06	1.45E+06	2.79E+06	1.07E+06	3.64E+06	2.79E+06	2.32E+06	2.42E+06	2.26E+06	9.45E+05	5.16E+05	1.78E+06	6.18E+05	1.32E+06	1.16E+06
ESTY-A/$	5.98E+02	5.39E+02	1.31E+03	4.52E+02	1.55E+03	1.23E+03	1.09E+03	1.09E+03	9.90E+02	3.29E+02	1.78E+02	6.74E+02	2.31E+02	4.81E+02	4.22E+02
ESTY-W/$	3.05E+00	2.71E+00	4.03E+00	2.03E+00	6.10E+00	4.99E+00	3.84E+00	4.36E+00	4.72E+00	1.98E+00	1.11E+00	3.07E+00	1.29E+00	3.44E+00	2.28E+00
ESTY-S/$	6.16E+00	5.89E+00	1.11E+01	5.67E+00	1.85E+01	1.45E+01	6.84E+00	6.50E+00	7.07E+00	4.21E+00	1.90E+00	6.00E+00	2.40E+00	5.75E+00	3.83E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	3.00E+11	2.33E+11	2.02E+11	1.73E+11	3.79E+11	3.44E+11	3.32E+11	4.28E+11	4.88E+11	1.86E+11	1.60E+11	2.32E+11	1.46E+11	4.32E+11	4.07E+11
REN/$	2.78E+09	3.05E+09	2.13E+09	2.16E+09	4.43E+09	6.48E+09	1.11E+10	1.68E+10	1.08E+10	3.70E+09	4.03E+09	3.09E+09	3.31E+09	1.25E+10	1.10E+10
Impact/$	8.26E+09	8.26E+09	5.44E+09	4.93E+09	1.01E+10	1.08E+10	1.19E+10	1.27E+10	1.30E+10	6.30E+09	5.80E+09	6.46E+09	5.20E+09	1.61E+10	1.64E+10
HR/$	6.42E+11	7.51E+11	2.20E+13	1.98E+12	1.75E+12	2.86E+12	1.43E+12	1.16E+12	2.34E+12	1.38E+12	2.14E+12	1.60E+12	7.49E+11	2.47E+12	1.05E+12
Total/$	9.52E+11	9.95E+11	2.22E+13	2.16E+12	2.14E+12	3.22E+12	1.78E+12	1.62E+12	2.85E+12	1.58E+12	2.31E+12	1.84E+12	9.03E+11	2.93E+12	1.48E+12
ICEC to money ratio (J/$)															
ICEC/$	1.84E+09	1.24E+09	8.26E+08	7.30E+08	1.58E+09	2.21E+09	3.07E+09	5.13E+09	3.75E+09	1.72E+09	1.10E+09	2.03E+09	9.55E+08	3.59E+09	1.80E+09

Continued

Table B.3 continued

NAICS	713950	713A00	7211A0	721A00	722000	811192	8111A0	811200	811300	811400	812100	812200	812300	812900	813100
Econ.	2256	66163.9	70573.7	8381.7	344334	7236.6	138413.9	36963.6	32975.5	24649.4	28755.6	11407.8	20174.5	34924.3	40397.4
ECEC to money ratios for individual resource categories (sej/$)															
LS/$	5.04E+11	2.73E+11	2.79E+11	6.29E+11	4.29E+11	2.77E+11	5.69E+11	3.01E+11	4.15E+11	5.12E+11	2.38E+11	5.89E+11	4.92E+11	2.84E+11	1.74E+11
BS/$	3.80E+10	2.28E+10	2.38E+10	3.54E+10	3.78E+10	1.35E+10	1.78E+10	1.13E+10	1.39E+10	2.60E+10	1.84E+10	4.62E+10	1.56E+10	3.24E+10	1.30E+10
HS/$	1.89E+10	7.65E+09	1.16E+10	2.67E+10	6.58E+09	1.36E+10	4.35E+09	2.26E+09	2.59E+09	2.71E+09	3.92E+09	7.89E+09	1.62E+10	3.64E+09	6.68E+09
AS/$	5.76E+08	1.49E+09	4.55E+08	1.73E+09	1.95E+10	3.56E+08	5.97E+08	3.54E+08	4.47E+08	8.19E+08	6.02E+08	6.74E+08	8.82E+08	1.45E+09	3.87E+08
sltot/$	2.31E+09	1.86E+09	1.46E+09	2.65E+09	9.61E+09	9.22E+08	1.59E+09	7.57E+08	1.31E+09	1.96E+09	1.25E+09	2.93E+09	1.23E+09	4.04E+09	8.49E+08
hydrotot/$	7.81E+09	2.74E+09	3.52E+09	7.65E+09	3.96E+09	3.43E+09	2.70E+09	1.67E+09	1.92E+09	1.92E+09	2.88E+09	2.61E+09	4.71E+09	2.40E+09	1.79E+09
geotot/$	7.06E+07	2.47E+07	3.19E+07	6.92E+07	3.58E+07	3.10E+07	2.44E+07	1.51E+07	1.74E+07	1.74E+07	2.60E+07	2.36E+07	4.26E+07	2.17E+07	1.62E+07
windtot/$	3.89E+06	1.36E+06	1.76E+06	3.81E+06	1.98E+06	1.71E+06	1.34E+06	8.31E+05	9.59E+05	9.57E+05	1.43E+06	1.30E+06	2.35E+06	1.20E+06	8.93E+05
erotot/$	1.48E+09	3.84E+09	1.17E+09	4.44E+09	5.00E+10	9.15E+08	1.54E+09	9.10E+08	1.15E+09	2.10E+09	1.55E+09	1.73E+09	2.27E+09	3.72E+09	9.95E+08
HR/$	2.19E+12	5.33E+11	2.04E+12	1.17E+12	1.60E+12	1.29E+12	9.14E+11	1.13E+12	1.28E+12	1.23E+12	1.39E+12	1.90E+12	1.91E+12	1.02E+12	3.59E+11
ESO2/$	1.19E+10	4.73E+09	6.40E+09	1.31E+10	7.43E+09	6.05E+09	6.35E+09	3.62E+09	4.56E+09	4.75E+09	4.82E+09	5.53E+09	7.97E+09	4.62E+09	3.23E+09
ENO2/$	3.18E+07	1.46E+07	1.84E+07	3.84E+07	3.45E+07	1.60E+07	2.06E+07	1.11E+07	1.52E+07	1.61E+07	1.43E+07	2.02E+07	2.44E+07	1.56E+07	1.07E+07
EPM10/$	3.01E+07	1.35E+07	1.55E+07	3.47E+07	1.57E+07	1.08E+07	1.36E+07	8.40E+06	1.03E+07	1.06E+07	1.09E+07	2.48E+07	1.28E+07	1.10E+07	2.51E+07
ECO2/$	1.12E+10	5.07E+09	6.34E+09	1.37E+10	9.23E+09	9.49E+09	1.06E+10	4.26E+09	6.27E+09	6.23E+09	5.28E+09	6.69E+09	1.04E+10	5.64E+09	3.61E+09
EMETH/$	5.44E+04	5.05E+04	4.59E+04	8.48E+04	1.09E+05	3.22E+04	6.54E+04	4.76E+04	5.27E+04	6.17E+04	5.62E+04	5.81E+04	4.64E+04	1.02E+05	2.96E+04
EAMM/$	4.05E+06	3.76E+06	3.03E+06	1.14E+07	7.66E+06	2.46E+06	1.29E+07	6.31E+06	8.71E+06	1.00E+07	3.43E+06	5.77E+06	4.76E+06	5.53E+06	1.69E+06
ETOL/$	1.04E+05	8.33E+04	8.54E+04	2.08E+05	1.33E+05	5.88E+04	1.84E+05	9.29E+04	1.08E+05	1.36E+05	8.00E+04	1.01E+05	9.26E+04	2.29E+05	3.79E+04
ETCE/$	1.54E+06	8.43E+05	1.07E+06	4.63E+06	2.52E+06	6.99E+05	4.69E+06	1.94E+06	2.55E+06	3.00E+06	1.15E+06	1.26E+06	1.19E+06	1.23E+06	4.84E+05
ESTY-A/$	5.81E+02	2.95E+02	3.86E+02	1.98E+03	1.12E+03	2.67E+02	1.99E+03	7.94E+02	1.06E+03	1.20E+03	4.81E+02	3.67E+02	4.00E+02	4.20E+02	1.69E+02
ESTY-W/$	2.66E+00	1.98E+00	1.88E+00	5.70E+00	4.19E+00	1.44E+00	5.30E+00	2.72E+00	3.46E+00	4.16E+00	2.10E+00	2.96E+00	2.24E+00	3.15E+00	1.01E+00
ESTY-S/$	3.70E+00	4.96E+00	2.99E+00	8.60E+00	7.28E+00	3.47E+00	1.04E+01	6.61E+00	9.17E+00	9.33E+00	4.20E+00	7.70E+00	6.33E+00	9.73E+00	1.56E+00
Aggregate ECEC to money ratios (sej/$)															
NR/$	5.42E+11	2.96E+11	3.03E+11	6.64E+11	4.67E+11	2.91E+11	5.87E+11	3.12E+11	4.29E+11	5.38E+11	2.57E+11	6.36E+11	5.07E+11	3.17E+11	1.87E+11
REN/$	1.89E+10	7.65E+09	1.16E+10	2.67E+10	5.00E+10	1.36E+10	4.35E+09	2.26E+09	2.59E+09	2.71E+09	3.92E+09	7.89E+09	1.62E+10	4.04E+09	6.68E+09
Impact/$	2.32E+10	9.84E+09	1.28E+10	2.69E+10	1.67E+10	1.56E+10	1.70E+10	7.91E+09	1.09E+10	1.10E+10	1.01E+10	1.23E+10	1.84E+10	1.03E+10	6.89E+09
HR/$	2.19E+12	5.33E+11	2.04E+12	1.17E+12	1.60E+12	1.29E+12	9.14E+11	1.13E+12	1.28E+12	1.23E+12	1.39E+12	1.90E+12	1.91E+12	1.02E+12	3.59E+11
Total/$	2.77E+12	8.47E+11	2.37E+12	1.89E+12	2.13E+12	1.61E+12	1.52E+12	1.45E+12	1.72E+12	1.78E+12	1.66E+12	2.56E+12	2.45E+12	1.35E+12	5.59E+11
ICEC to money ratio (J/$)															
ICEC/$	2.32E+09	1.86E+09	1.47E+09	2.66E+09	9.62E+09	9.28E+08	1.60E+09	7.61E+08	1.32E+09	1.97E+09	1.26E+09	2.94E+09	1.25E+09	4.05E+09	8.53E+08

Continued

Table B.3 continued

NAICS	813A00	813B00	S00101	S00102	S00201	S00202	S00203	S00800
Econ.	13978.5	45080.9	8337	7424	7513	22167	94676	592861.7
ECEC to money ratios for individual resource categories (sej/$)								
LS/$	2.29E+11	3.42E+11	6.19E+11	1.62E+11	4.45E+12	4.52E+12	1.58E+12	2.25E+11
BS/$	2.56E+10	4.93E+10	9.92E+09	1.40E+10	3.08E+10	1.15E+10	5.21E+10	2.03E+10
HS/$	3.60E+09	6.50E+09	8.19E+08	2.85E+10	8.19E+09	5.82E+10	3.71E+10	5.68E+08
AS/$	4.88E+08	1.16E+09	2.18E+08	4.08E+09	7.53E+08	3.05E+08	7.45E+08	4.52E+08
sltot/$	1.37E+09	2.61E+09	5.88E+08	2.28E+09	2.42E+09	7.54E+08	3.18E+09	1.29E+09
hydrotot/$	1.71E+09	3.07E+09	4.58E+08	9.85E+08	1.37E+10	1.15E+09	5.99E+09	3.17E+08
geotot/$	1.54E+07	2.78E+07	4.14E+06	8.91E+06	1.24E+08	1.04E+07	5.42E+07	2.86E+06
windtot/$	8.51E+05	1.53E+06	2.28E+05	4.91E+05	6.83E+06	5.75E+05	2.99E+06	1.58E+05
erotot/$	1.25E+09	2.99E+09	5.59E+08	1.05E+10	1.94E+09	7.83E+08	1.92E+09	1.16E+09
HR/$	2.43E+12	1.85E+12	2.95E+11	6.47E+13	1.58E+13	1.36E+12	1.98E+13	2.29E+11
ESO2/$	3.78E+09	6.19E+09	2.11E+09	2.58E+09	2.82E+10	4.01E+09	1.13E+10	7.84E+08
ENO2/$	1.50E+07	2.06E+07	1.38E+07	1.31E+07	9.52E+07	2.64E+07	3.93E+07	4.05E+06
EPM10/$	9.45E+06	1.71E+07	5.53E+07	5.79E+06	3.53E+07	5.40E+07	6.34E+07	1.31E+07
ECO2/$	4.68E+09	6.93E+09	7.38E+09	4.86E+09	5.42E+10	3.07E+10	1.61E+10	1.07E+09
EMETH/$	1.14E+05	1.96E+05	3.05E+04	6.53E+04	1.06E+05	2.83E+04	7.63E+04	2.04E+04
EAMM/$	5.00E+06	8.11E+06	4.27E+06	3.67E+06	2.70E+07	3.66E+06	9.79E+06	1.38E+06
ETOL/$	1.22E+05	1.41E+05	6.02E+04	1.17E+05	4.55E+05	5.35E+04	1.96E+05	3.66E+04
ETCE/$	8.31E+05	1.15E+06	5.83E+05	7.86E+05	4.82E+06	8.05E+05	3.40E+06	4.88E+05
ESTY-A/$	3.04E+02	4.02E+02	1.81E+02	2.62E+02	1.85E+03	2.67E+02	9.97E+02	1.57E+02
ESTY-W/$	2.47E+00	4.01E+00	1.67E+00	1.56E+00	1.12E+01	1.60E+00	5.55E+00	1.09E+00
ESTY-S/$	4.78E+00	7.59E+00	2.35E+00	3.02E+00	1.42E+01	3.24E+00	1.46E+01	1.34E+00
Aggregate ECEC to money ratios (sej/$)								
NR/$	2.55E+11	3.91E+11	6.28E+11	1.76E+11	4.48E+12	4.53E+12	1.63E+12	2.46E+11
REN/$	3.60E+09	6.50E+09	8.19E+08	2.85E+10	1.37E+10	5.82E+10	3.71E+10	1.29E+09
Impact/$	8.49E+09	1.32E+10	9.56E+09	7.46E+09	8.25E+10	3.48E+10	2.75E+10	1.87E+09
HR/$	2.43E+12	1.85E+12	2.95E+11	6.47E+13	1.58E+13	1.36E+12	1.98E+13	2.29E+11
Total/$	2.70E+12	2.26E+12	9.34E+11	6.49E+13	2.04E+13	5.98E+12	2.15E+13	4.78E+11
ICEC to money ratio (J/$)								
ICEC/$	1.37E+09	2.62E+09	6.05E+08	2.28E+09	2.56E+09	8.07E+08	3.22E+09	1.30E+09

APPENDIX C

CALCULATIONS FOR TABLE 4.1

(a) (5.953×10^6 barrels on-shore production/day)×(30 days/month)×(12 months/yr)×(6.12×10^9 J/barrel) =1.31×10^{19} J/yr

(b) Iron Ore Mining: Mass Flow Rate (F) = 181MMT/yr; exergy of Fe_2O_3 (b) = 103J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 1.88×10^{16}J/yr

(c) Non-Ferrous Metal Mining: Mass Flow Rate (F) = 576MMT/yr; exergy of CuO (b) = 82J/g (Cu is the largest component of non-ferrous metals mined) (Szargut et al., 1988); ICEC flow = $F \times b$ = 4.71×10^{16}J/yr

(d) Crushed Stone: Mass Flow Rate (F) = 1118MMT/yr; exergy of SiO_2 (b) = 132J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 1.48×10^{17}J/yr

(e) Sand: Mass Flow Rate (F) = 894MMT/yr; exergy of SiO_2 (b) = 132J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 1.18×10^{17}J/yr

(f) Raw Coal Excluding Overburden: Mass Flow Rate (F) = 878MMT/yr; exergy of coal (b) = 29000J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 2.56×10^{19}J/yr

(g) Nitrogen from Mineralization: Mass Flow Rate (F) = 3MMT/yr; exergy of $Mg(NO_3)_2$ (b) = 387J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 1.16×10^{15}J/yr

(h) Phosphorous from Mineralization: Mass Flow Rate (F) = 2MMT/yr; exergy of $Mg_3(PO_4)_2$ (b) = 495J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 9.88×10^{14}J/yr

(i) (4.6×10^8 sej/g of P_2O_5) × (1g of P_2O_5/0.23g of P) = 2×10^8 sej/g of P

(j) N-deposition from Atmosphere is considered is an input from lithosphere since Nitrogenous salts enter plants through soil

(k) Nitrogen from Atmospheric Deposition: Mass Flow Rate (*F*) = 2MMT/yr; exergy of $Mg(NO_3)_2$ (*b*) = 387J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 7.76×10^{14}J/yr

(l) Negative sign indicates flow from industry sector to Lithosphere

(m) Return of Decomposing detritus to agricultural soil: 440MMT/yr of returned detritus residue × 0.44g C/g of residue × 11Kcal/g C × 4186J/Kcal = 8.91×10^{18}J/yr (Odum, 1996)

(n) (0.44g C/g of residue) × (11Kcal/g C) × (4186J/Kcal) × (11068 sej/J Transformity of Detritus Production) = 2.24×10^{8} sej/g residue

(o) Wood Production: 520MMT/yr roundwood × 3.8Kcal/g roundwood × 4186 J/Kcal = 8.27×10^{18}J/yr (Odum, 1996)

(p) (3.8Kcal/g roundwood) × (4186 J/Kcal) × (34900 sej/J) = 5.55×10^{8} sej/g of roundwood

(q) Pasture Grazing: 440MMT/yr of wet grass × 0.5 MMT of dry grass/MMT of wet grass × 10^{12} g/MMT × 1.86×10^{11}J/ha/yr of pasture evapotranspiration × 9×10^{-4} m^2/g × 10^{-4} ha/m^2 = 5.83×10^{19} sej/MMT of wet grass (Odum, 1996)

(r) (0.5 MMT of dry grass/MMT of wet grass) × (10^{12} g/MMT) × (1.86×10^{11} J/ha/yr of pasture evapotranspiration) × (6962 sej/J) × (9×10^{-4} m^2/g) × (10^{-4} ha/m^2) = 5.83×10^{19} sej/MMT of wet grass

(s) Water Consumption: 1.47×10^{14}gallons/yr × 3785 cm^3/gallon of water × 1g of water/cm^3 of water × 4.94J/g of water = 2.73×10^{18} J/yr (Brown and Bardi, 2001)

(t) (3785 cm^3/gallon of water) × (1g of water/cm^3 of water) × (4.94J/g of water) × (4.1×10^{4} sej/J) = 7.67×10^{8} sej/gallon of water

(u) Atmospheric Gases being at reference state are ignored in ICEC analysis

(v) $(12g\ C/44g\ CO_2) \times (8Kcal/g\ C) \times (4186J/Kcal) \times (6780sej/J) = 6.19\times10^7\ sej/g\ CO_2$

APPENDIX D

CALCULATIONS FOR TABLE 5.1

(a) List of industry sectors and their NAICS codes are given in Appendix A.2 of the Supplementary Material

(b) (4.803×10^6 barrels on-shore production/day) × (30 days/month) × (12 months/yr) × (6.12×10^9 J/barrel) = 1.06×10^{19} J/yr

(c) Iron Ore Mining: Mass Flow Rate (F) = 202MMT/yr; exergy of Fe_2O_3 (b) = 103J/g (Szargut et al., 1988); ICEC Flow = $F \times b = 2.08\times10^{16}$J/yr

(d) Copper Mining: (2.07MMT/yr 1997 mine production) × (297MMT/yr 1993 domestic ores input) / (1.79MMT/yr 1993 mine production) = (342MMT/yr 1997 domestic ores input); assuming flotation, concentration, smelting and refining technologies and ratio of domestic to imported concentrates unchanged between 1993 and 1997

(e) Copper Mining: 342MMT/yr domestic ores input (F); exergy of CuO (b) = 82J/g (Szargut et al., 1988); ICEC flow = $F \times b = 2.80\times10^{16}$J/yr

(f) Gold Mining: (325tons/yr 1997 gold production) × (221MMT/yr 1993 domestic gangue) / (331tons/yr 1993 gold production) = (217MMT/yr 1997 domestic gangue); assuming flotation, concentration, smelting and refining technologies and ratio of domestic to imported concentrates unchanged between 1993 and 1997

(g) Gold Mining: 217MMT/yr domestic ores input (F); exergy of Au_2O_3 (b) = (114.7KJ/mol)/(441.93g/mol of Au_2O_3) (Szargut et al., 1988); ICEC flow = $F \times b$ = 5.63×10^{16}J/yr

(h) Crushed Stone: Mass Flow Rate (F) = 1390MMT/yr; exergy of SiO_2 (b) = 132J/g (Szargut et al., 1988); ICEC Flow = $F \times b = 1.83\times10^{17}$J/yr

(i) Sand: Mass Flow Rate (F) = 961MMT/yr; exergy of SiO_2 (b) = 132J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 1.27×10^{17}J/yr

(j) Raw Coal Excluding Overburden: Mass Flow Rate (F) = 878MMT/yr; exergy of coal (b) = 29000J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 2.56×10^{19}J/yr

(k) Nitrogen from mineralization: (3MMT/yr 1993 Nitrogen flux from mineralization) × (1.91×10^6 farms in 1997) × (487acres average size of farm in 1997) / (1.93×10^6 farms in 1993) / (491acres average size of farm in 1993) = 2.96MMT/yr 1997 Nitrogen flux from mineralization

(l) Nitrogen from mineralization: Mass Flow Rate (F) = 2.96MMT/yr; exergy of $Mg(NO_3)_2$ (b) = 387J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 1.15×10^{15}J/yr

(m) Phosphorous from mineralization: (2MMT/yr 1993 Phosphorous flux from mineralization) × (1.91×10^6 farms in 1997) × (487acres average size of farm in 1997) / (1.93×10^6 farms in 1993) / (491acres average size of farm in 1993) = 1.97MMT/yr 1997 Phosphorous flux from mineralization

(n) Phosphorous from mineralization: Mass Flow Rate (F) = 1.97MMT/yr; exergy of $Mg_3(PO_4)_2$ (b) = 495J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 9.75×10^{14}J/yr

(o) (4.6×10^8 sej/g of P_2O_5) × (1g of P_2O_5/0.23g of P) = 2×10^9 sej/g of P

(p) N-deposition from Atmosphere is considered is an input from lithosphere since Nitrogenous salts enter plants through soil

(q) N-deposition from atmosphere: (2MMT/yr 1993 N-deposition flux) × (1.91×10^6 farms in 1997) × (487acres average size of farm in 1997) / (1.93×10^6 farms in 1993) / (491acres average size of farm in 1993) = 1.97MMT/yr 1997 N-deposition flux

(r) N-deposition from atmosphere: Mass Flow Rate (F) = 1.97MMT/yr; exergy of $Mg(NO_3)_2$ (b) = 387J/g (Szargut et al., 1988); ICEC Flow = $F \times b$ = 7.62×10^{14}J/yr

(s) Return of detrital matter: (440MMT/yr 1993 flux) × (1.91×10^6 farms in 1997) × (487acres average size of farm in 1997) / (1.93×10^6 farms in 1993) / (491acres average size of farm in 1993) = 433.4MMT/yr 1997 flux, Negative sign indicates flow from industry sector to Lithosphere

(t) Return of detrital matter: (433MMT/yr of returned detritus residue) × (0.44g C/g of residue) × (11Kcal/g C) × (4186J/Kcal) = 8.77×10^{18}J/yr (Odum, 1996)

(u) (0.44g C/g of residue) × (11Kcal/g C) × (4186J/Kcal) × (11068 sej/J Transformity of Detritus Production) = 2.24×10^8 sej/g residue

(v) Wood Production: 520MMT/yr roundwood × 3.8Kcal/g roundwood × 4186 J/Kcal = 8.27×10^{18}J/yr (Odum, 1996)

(w) (3.8Kcal/g roundwood) × (4186 J/Kcal) × (34900 sej/J) = 5.55×10^8 sej/g of roundwood

(y) (0.5 MMT of dry grass/MMT of wet grass) × (10^{12} g/MMT) × (1.86×10^{11} J/ha/yr of pasture evapotranspiration) × (6962 sej/J) × (9×10^{-4} m^2/g) × (10^{-4} ha/m^2) = 5.83×1019 sej/MMT of wet grass

(z) Water Consumption: 1.47×10^{14}gallons/yr × 3785 cm^3/gallon of water × 1g of water/cm3 of water × 4.94J/g of water = 2.73×10^{18} J/yr (Odum, 1996)

(α) (3785 cm^3/gallon of water) × (1g of water/cm^3 of water) × (4.94J/g of water) × (4.1×10^4 sej/J) = 7.67×10^8 sej/gallon of water

(β) CO_2 in 24-hour photosynthesis: (880MMT/yr 1993 CO_2 flux) × (1.91×10^6 farms in 1997) × (487acres average size of farm in 1997) / (1.93×10^6 farms in 1993) / (491acres average size of farm in 1993) = 866.8MMT/yr 1997 CO_2 flux

(γ) Atmospheric Gases being at reference state are ignored in ICEC analysis

(δ) (12g C/44g CO_2) × (8Kcal/g C) × (4186J/Kcal) × (6780sej/J) = 6.19×10^7 sej/g CO_2

APPENDIX E

CALCULATIONS FOR GEOTHERMAL AND COAL-FIRED THERMOELECTRIC SYSTEMS USING 91-SECTOR 1992 RESULTS

This appendix provides detailed calculations for the case study comparing geothermal and coal-fired thermoelectric facilities using 91-sector 1992 results presented in Chapter 6. Summary results for the case study have been presented in Table 6.1.

Items	Unit	Amount	Exergy ‡ (J/unit)	Total Exergy	Price § ($/unit)	SIC	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
OUTPUTS										
Electricity Poduction	J	3.28E+14	1	3.28E+14	2.06E-08	68A				
INPUTS										
PLANT CONSTRUCTION PHASE										
1 Extraction wells, cement	g	5.71E+08	6.35E+02	3.63E+11	5.46E-05	36	1.54E+13	4.82E+17	1.58E+09	4.93E+13
2 Reinjection wells, cement	g	2.85E+08	6.35E+02	1.81E+11	5.46E-05	36	1.54E+13	2.40E+17	1.58E+09	2.46E+13
3 Steam lines										
Steel	g	2.79E+07	7.04E+03	1.96E+11	3.80E-04	46	5.42E+12	5.75E+16	1.01E+09	1.07E+13
Aluminum Cover	g	1.40E+06	3.29E+04	4.61E+10	1.27E-03	46	5.42E+12	9.64E+15	1.01E+09	1.79E+12
4 Building and assets of plant										
(a) Misc										
concrete	g	1.57E+08	6.35E+02	9.97E+10	5.46E-05	36	1.54E+13	1.32E+17	1.58E+09	1.35E+13
(b) Construction of main building										
Carbon and Inox steel	g	4.14E+06	7.10E+03	2.94E+10	3.80E-04	37	7.24E+12	1.14E+16	1.13E+09	1.77E+12
Aluminum	g	1.14E+05	3.29E+04	3.75E+09	1.27E-03	38	7.29E+12	1.06E+15	1.70E+09	2.45E+11
5 Steel Components of the plant system										
carbon steel	g	3.51E+06	7.10E+03	2.49E+10	3.80E-04	49	2.79E+12	3.73E+15	1.09E+09	1.46E+12
inox steel	g	4.76E+06	7.10E+03	3.38E+10	3.80E-04	49	2.79E+12	5.05E+15	1.09E+09	1.97E+12
6 Electric wires										
copper	g	7.53E+05	2111.856	1.59E+09	2.35E-03	55	2.90E+12	5.13E+15	1.13E+09	2.00E+12
7 Electricity	J	1.64E+10	1	1.64E+10	2.06E-08	68A	4.52E+12	1.53E+15	9.98E+08	3.37E+11
8 Diesel Fuel	J	1.94E+11	1	1.94E+11	4.25E-09	31	1.58E+13	2.73E+16	2.21E+09	1.82E+12
9 Major components of the plant										
Iron and steel	g	1.54E+07	7.10E+03	1.09E+11	3.80E-04	49	2.79E+12	1.63E+16	1.09E+09	6.38E+12
copper	g	3.59E+05	2111.856	7.58E+08	2.35E-03	49	2.79E+12	2.36E+15	1.09E+09	9.20E+11
pig-iron	g	1.36E+06	8.75E+03	1.19E+10	3.80E-04	49	2.79E+12	1.44E+15	1.09E+09	5.64E+11
chromium	g	1.36E+05	999.88461	1.36E+08	8.50E-05	49	2.79E+12	3.23E+13	1.09E+09	1.26E+10
molybdenum	g	8.98E+03	1000	8.98E+06	4.85E-03	49	2.79E+12	1.22E+14	1.09E+09	4.75E+10
nickel	g	1.22E+05	1000.3408	1.22E+08	7.00E-03	49	2.79E+12	2.39E+15	1.09E+09	9.32E+11
10 Transport of plant Material										
Diesel Fuel	J	3.00E+11	1	3.00E+11	4.25E-09	31	1.58E+13	4.23E+16	2.21E+09	2.82E+12
11 Labor for construction										
Non-specialized Labor	yrs	7.13E+00	__	__	__	D	__	1.78E+17	__	__
Graduated Labor	yrs	4.55E-01	__	__	__	D	__	2.27E+16	__	__
PLANT OPERATING PHASE										
12 Annual electricity inputs	J	2.53E+13	1	2.53E+13	2.06E-08	68A	4.518E+12	2.35E+18	9.98E+08	5.20E+14
13 Labor										
Graduated	yrs	2.60E-01	__	__	__	D	__	1.29E+16	__	__
Tech and Admin	yrs	1.20E+00	__	__	__	D	__	2.99E+16	__	__
Non-specialized Labor	yrs	4.17E+00	__	__	__	D	__	1.04E+17	__	__
Other	yrs	5.21E+01	__	__	__	D	__	1.30E+18	__	__
14 Maintainance Material										
Steel	g	8.00E+05	7.10E+03	5.68E+09	3.80E-04	49	2.79E+12	8.49E+14	1.09E+09	3.32E+11
Aluminum	g	3.00E+05	3.29E+04	9.88E+09	1.27E-03	49	2.79E+12	1.06E+15	1.09E+09	4.16E+11
DIRECT ENVIRONMENTAL INPUTS										
15 Geothermal Heat	J	2.25E+15	1	2.25E+15	__	D *	__	3.35E+19	__	2.25E+15
IMPACT OF EMISSIONS										
16 CO2	g	1.18E+09	0	0	__	D	__	8.46E+15	__	__

‡ Exergy values obtained from (Szargut et al., 1997)

§ Prices of metals and cement obtained from Mineral Commodity Summaries (); prices of diesel fuel () and electricity () obtained from DOE's Energy Information Administration

* Direct Inputs

Table E.1: Exergy, ECEC and ICEC Calculations for purchased and direct inputs for Geothermal Electricity Generation facility (based on 1992 results)

Items	Unit	Amount (units/yr)	Exergy‡ (J/unit)	Tot. Exergy (J/yr)	Price § ($/unit)	SIC	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
OUTPUTS										
Annual net electricity production	J	2.44E+16	1	2.44E+16	1.75E-08	68A				
INPUTS										
PLANT BUILDING PHASE			(J/unit)							
1 Concrete	g	1.67E+10	635	1.06E+13	5.46E-05	36	1.54E+13	1.41E+19	1.58E+09	1.44E+15
2 Iron and Steel for Structure	g	1.07E+09	7040	7.53E+12	3.80E-04	37	7.24E+12	2.95E+18	1.13E+09	4.58E+14
3 Copper Electric wires	g	4.00E+07	2111.856	8.45E+10	2.35E-03	55	2.90E+12	2.73E+17	1.13E+09	1.06E+14
4 Diesel Transport of materials by truck	J	4.76E+11	1	4.76E+11	4.25E-09	31	1.58E+13	3.19E+16	2.21E+09	4.46E+12
5 Steam Generators (Steel)	g	1.71E+09	7100	1.21E+13	3.80E-04	49	2.79E+12	1.81E+18	1.09E+09	7.09E+14
6 Steam Condesers (Steel)	g	6.67E+07	7100	4.74E+11	3.80E-04	49	2.79E+12	7.08E+16	1.09E+09	2.77E+13
7 Pre-heaters for input water (Steel)	g	4.12E+07	7100	2.93E+11	3.80E-04	49	2.79E+12	4.37E+16	1.09E+09	1.71E+13
8 Pre-heaters for combustion air (Steel)	g	3.20E+07	7100	2.27E+11	3.80E-04	49	2.79E+12	3.40E+16	1.09E+09	1.33E+13
9 Pumps and valves (steel)	g	1.67E+07	7100	1.19E+11	3.80E-04	46	5.42E+12	3.44E+16	1.01E+09	6.39E+12
10 Pipes (Steel)	g	3.33E+07	7100	2.36E+11	3.80E-04	46	5.42E+12	6.86E+16	1.01E+09	1.28E+13
11 Chimneys (Concrete)	g	9.33E+08	635	5.92E+11	5.46E-05	36	1.54E+13	7.87E+17	1.58E+09	8.05E+13
12 Electro. Precipitators (steel)	g	1.04E+09	7100	7.38E+12	3.80E-04	53	2.83E+12	1.12E+18	1.06E+09	4.21E+14
13 Turbines (Steel)	g	7.33E+07	7100	5.20E+11	3.80E-04	43	3.88E+12	1.08E+17	8.29E+08	2.31E+13
14 Electric Generators (Steel)	g	3.80E+07	7100	2.70E+11	3.80E-04	53	2.83E+12	4.08E+16	1.06E+09	1.54E+13
15 Electric Motors										
Steel	g	1.60E+07	7100	1.14E+11	3.80E-04	53	2.83E+12	1.72E+16	1.06E+09	6.47E+12
Copper	g	4.00E+06	2111.856	8.45E+09	2.35E-03	53	2.83E+12	2.66E+16	1.06E+09	1.00E+13
16 Transformers										
Steel	g	3.93E+07	7100	2.79E+11	3.80E-04	53	2.83E+12	4.22E+16	1.06E+09	1.59E+13
Copper	g	1.23E+07	2111.856	2.60E+10	2.35E-03	53	2.83E+12	8.18E+16	1.06E+09	3.08E+13
17 Travelling bridge crane (Steel)	g	5.00E+06	7100	3.55E+10	3.80E-04	46	5.42E+12	1.03E+16	1.01E+09	1.91E+12
18 Labor										
Engineering	yrs	7.38E+00	__	__	__	D	__	3.68E+17	__	__
Admin	yrs	1.74E+00	__	__	__	D	__	4.33E+16	__	__
Construction	yrs	1.82E+02	__	__	__	D	__	4.53E+18	__	__
19 Electricity	J	2.40E+12	1	2.40E+12	2.06E-08	68A	4.52E+12	2.23E+17	9.98E+08	4.94E+13
20 Diesel for yard machinery	J	2.13E+12	1	2.13E+12	4.25E-09	31	1.58E+13	1.43E+17	2.21E+09	2.00E+13
21 Diesel transport major components	J	5.99E+11	1	5.99E+11	4.25E-09	31	1.58E+13	4.02E+16	2.21E+09	5.61E+12
22 Coal Transport machinery (steel)	g	8.33E+07	7100	5.91E+11	3.80E-04	46	5.42E+12	1.72E+17	1.01E+09	3.19E+13
23 Coal grinding machinery (Steel)	g	8.00E+07	7100	5.68E+11	3.80E-04	44,45	3.17E+12	9.62E+16	1.33E+09	4.04E+13
24 Ash treatment/stor. Machinery (Steel)	g	3.33E+07	7100	2.36E+11	3.80E-04	44,45	3.17E+12	4.01E+16	1.33E+09	1.68E+13
PLANT OPERATING PHASE										
Direct renewable inputs										
25 Solar radiation	J	1.11E+15	1	1.11E+15	__	D	__	1.11E+15	__	1.11E+15

Continued

Table E.2: Exergy, ECEC and ICEC Calculations for purchased and direct inputs for Coal-Fired Thermoelectric facility (based on 1992 results)

Table E.2 continued

Items	Unit	Amount (units/yr)	Exergy (J/unit)	Tot. Exergy (J/yr)	Price ($/unit)	SIC	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
PLANT OPERATING PHASE										
Goods and services										
26 Labor										
Graduated	yrs	2.00E+00	__	__	__	D	__	1.49E+17	__	__
Technical and admin	yrs	1.80E+02	__	__	__	D	__	8.96E+18	__	__
Other tech services	yrs	3.00E+02	__	__	__	D	__	7.47E+18	__	__
27 Fuels										
Combustion Oil	J	2.31E+16	1	2.31E+16	2.31E-09	31	1.58E+13	8.42E+20	2.21E+09	1.18E+17
Coal	J	4.42E+16	1	4.42E+16	1.19E-09	7	3.86E+13	2.03E+21	1.11E+09	5.85E+16
Diesel for coal operating machinery	J	6.40E+13	1	6.40E+13	4.25E-09	31	1.58E+13	4.29E+18	2.21E+09	6.02E+14
IMPACT OF EMISSIONS ON HUMAN HEALTH										
28 CO2	g	7.35E+12	__	__	__	D	__	5.27E+19	__	__
29 SO2	g	5.30E+10	__	__	__	D	__	9.86E+19	__	__
30 NO2	g	2.12E+10	__	__	__	D	__	6.42E+19	__	__
31 PM10	g	2.19E+09	__	__	__	D	__	2.80E+19	__	__

APPENDIX F

SUPPLY CHAIN STAGES AND CORRESPONDING ECEC/MONEY RATIOS FOR DIFFERENT RESOURCE CATEGORIES

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	3,470	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Petroleum Refineries	9,230	1.28E+13	5.25E+09	1.65E+11	1.05E+12	1.40E+13
Other basic organic chemical manufacturing	72,820	2.83E+12	1.69E+10	7.59E+10	1.58E+12	4.51E+12
Noncellulosic organic fiber manufacturing	329,763	1.48E+12	7.56E+09	6.16E+10	1.66E+12	3.20E+12
Fiber yarn and thread mills	1,041,754	9.53E+11	1.85E+11	4.54E+10	1.88E+12	3.06E+12

Table F.1: Fiber Yarn and Thread Mills (NAICS 313100) (Figure 6.15(**a**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	11,194	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Petroleum Refineries	29,776	1.28E+13	5.25E+09	1.65E+11	1.05E+12	1.40E+13
Other basic organic chemical manufacturing	234,917	2.83E+12	1.69E+10	7.59E+10	1.58E+12	4.51E+12
Plastic Material and Resin Manufacturing	1,067,640	2.90E+12	7.99E+09	6.92E+10	1.43E+12	4.41E+12

Table F.2: Plastic Material and Resin Manufacturing (NAICS 325211) (Figure 6.15(**b**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	15	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Power Generation and Supply	154	5.82E+12	1.68E+11	4.20E+11	1.09E+12	7.50E+12
Real Estate	5,738	3.71E+11	7.96E+09	1.38E+10	6.99E+11	1.09E+12
Management of companies and enterprises	110,243	2.34E+11	5.53E+09	8.66E+09	2.39E+12	2.64E+12
Pharmaceutical and Medical Manufacturing	1,226,325	3.80E+11	8.01E+09	1.23E+10	1.31E+12	1.72E+12

Table F.3: Pharmaceutical and Medical Manufacturing (NAICS 325400) (Figure 6.15(**c**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Copper, Nickel, lead and zinc mining	28,066	8.62E+13	1.17E+10	9.94E+10	1.51E+12	8.78E+13
Primary smelting and refining of copper	175,664	2.64E+13	8.15E+09	9.44E+10	1.80E+12	2.83E+13
Copper rolling, drawing and extruding	285,359	1.02E+13	6.11E+09	6.92E+10	1.67E+12	1.20E+13
Copper wire, except mechanical, drawing	1,033,073	4.44E+12	7.25E+09	5.79E+10	1.90E+12	6.41E+12

Table F.4: Copper wire, except mechanical, drawing (NAICS 331422) (Figure 6.15(**d**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of Emissions	Human Resources	Total
Oil and Gas Extraction	0.32	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Power Generation and Supply	3	5.82E+12	1.68E+11	4.20E+11	1.09E+12	7.50E+12
Real Estate	123	3.71E+11	7.96E+09	1.38E+10	6.99E+11	1.09E+12
Management of companies and enterprises	2,369	2.34E+11	5.53E+09	8.66E+09	2.39E+12	2.64E+12
Wholesale Trade	54,521	2.31E+11	2.55E+09	7.92E+09	1.69E+12	1.93E+12
Semiconductor and related devices manufacturing	1,052,491	4.45E+11	2.19E+09	1.03E+10	1.12E+12	1.58E+12

Table F.5: Semiconductor and Related Device Manufacturing (NAICS 334413) (Figure 6.15(**e**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	6	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Power Generation and Supply	63	5.82E+12	1.68E+11	4.20E+11	1.09E+12	7.50E+12
Real Estate	2,346	3.71E+11	7.96E+09	1.38E+10	6.99E+11	1.09E+12
Management of companies and enterprises	45,075	2.34E+11	5.53E+09	8.66E+09	2.39E+12	2.64E+12
Wholesale Trade	1,037,250	2.31E+11	2.55E+09	7.92E+09	1.69E+12	1.93E+12

Table F.6: Wholesale trade (NAICS 420000) (Figure 6.15(**f**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	17	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Power Generation and Supply	177	5.82E+12	1.68E+11	4.20E+11	1.09E+12	7.50E+12
Real Estate	6,594	3.71E+11	7.96E+09	1.38E+10	6.99E+11	1.09E+12
Travel Arrangement and Reservation Services	103,667	3.81E+11	1.48E+10	1.43E+10	2.03E+12	2.44E+12
Air Transportation	1,005,823	1.33E+12	4.27E+09	3.98E+10	1.23E+12	2.60E+12

Table F.7: Air transportation (NAICS 481000) (Figure 6.15(**g**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	80	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Power Generation and Supply	873	5.82E+12	1.68E+11	4.20E+11	1.09E+12	7.50E+12
Real Estate	32,683	3.71E+11	7.96E+09	1.38E+10	6.99E+11	1.09E+12
Machinery & Equipment rental and leasing	1,012,465	1.27E+11	2.47E+09	4.46E+09	8.47E+11	9.81E+11

Table F.8: Machinery and equipment rental and leasing (NAICS 532400) (Figure 6.15(**h**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	188	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Power Generation and Supply	1,974	5.82E+12	1.68E+11	4.20E+11	1.09E+12	7.50E+12
Real Estate	73,526	3.71E+11	7.96E+09	1.38E+10	6.99E+11	1.09E+12
Legal Services	1,036,628	1.20E+11	2.02E+09	3.97E+09	4.26E+11	5.52E+11

Table F.9: Legal Services (NAICS 541100) (Figure 6.15(**i**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	36,040	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Petroleum Refineries	55,812	1.28E+13	5.25E+09	1.65E+11	1.05E+12	1.40E+13
Waste Management and Remediation services	1,148,343	1.02E+12	1.71E+10	2.31E+10	1.64E+12	2.71E+12

Table F.10: Waste Management and remediation services (NAICS 562000) (Figure 6.15(**j**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and gas extraction	476	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Power Generation and Supply	5,175	5.82E+12	1.68E+11	4.20E+11	1.09E+12	7.50E+12
Real Estate	193,800	3.71E+11	7.96E+09	1.38E+10	6.99E+11	1.09E+12
Colleges, Universities and Junior Colleges	1,000,280	3.00E+11	2.78E+09	8.26E+09	6.42E+11	9.52E+11

Table F.11: Colleges, universities, and junior colleges (NAICS 611A00) (Figure 6.15(**k**))

Supply Chain Stages	Economic ($/yr)	ECEC/$ Ratio (sej/$)				
		Non Renewable	Renewable	Impact of emissions	Human Resources	Total
Oil and Gas Extraction	5	1.96E+13	4.05E+09	2.08E+11	8.23E+11	2.07E+13
Power Generation and Supply	53	5.82E+12	1.68E+11	4.20E+11	1.09E+12	7.50E+12
Real Estate	2,000	3.71E+11	7.96E+09	1.38E+10	6.99E+11	1.09E+12
Promoters of performing arts and sports and agents for public figures	42,340	1.46E+11	3.31E+09	5.20E+09	7.49E+11	9.03E+11
Spectator Sports	1,125,700	1.60E+11	4.03E+09	5.80E+09	2.14E+12	2.31E+12

Table F.12: Spectator sports (NAICS 711200) (Figure 6.15(**l**))

APPENDIX G

CALCULATIONS FOR GEOTHERMAL, COAL-FIRED, OIL-FIRED, NG-FIRED, HYDROELECTRIC AND WIND-BASED ELECTRICITY GENERATION SYSTEMS USING 488-SECTOR 1997 RESULTS

This appendix provides detailed calculations for the case study comparing geothermal, coal-fired thermoelectric, oil-fired thermoelectric, NG-fired thermoelectric, hydroelectric and wind based electricity generation facilities using ECEC/$ and ICEC/$ ratios for 488-sector 1997 US economy presented in Chapter 5. Summary results for the case study have been presented in Figures 6.8 and 6.9.

Items	Unit	Amount (units/yr)	Exergy (J/unit)	Tot. Exergy (J/yr)	Price § ($/unit)	NAICS	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
OUTPUTS										
Annual net electricity production	J	2.44E+16	1.00E+00	2.44E+16	2.20E-08	221100	7.50E+12	4.03E+21	1.28E+09	6.86E+17
INPUTS										
PLANT BUILDING PHASE			(J/unit)							
1 Concrete	g	1.67E+10	6.35E+02	1.06E+13	5.84E-05	327320	2.40E+13	2.34E+19	1.29E+09	1.26E+15
2 Iron and Steel for Structure	g	1.07E+09	7.04E+03	7.53E+12	4.07E-04	331111	1.11E+13	4.82E+18	1.36E+09	5.91E+14
3 Copper Electric wires	g	4.00E+07	2.11E+03	8.45E+10	2.51E-03	331422	6.41E+12	6.44E+17	7.27E+09	7.31E+14
4 Diesel Transport of materials by truck	J	4.76E+11	1.00E+00	4.76E+11	4.55E-09	324110	1.40E+13	6.38E+16	3.96E+09	8.57E+12
5 Steam Generators (Steel)	g	1.71E+09	7.10E+03	1.21E+13	4.07E-04	333611	2.89E+12	2.01E+18	1.08E+09	7.48E+14
6 Steam Condesers (Steel)	g	6.67E+07	7.10E+03	4.74E+11	4.07E-04	332410	3.53E+12	9.56E+16	1.03E+09	2.80E+13
7 Pre-heaters for input water (Steel)	g	4.12E+07	7.10E+03	2.93E+11	4.07E-04	332410	3.53E+12	5.91E+16	1.03E+09	1.73E+13
8 Pre-heaters for combustion air (Steel)	g	3.20E+07	7.10E+03	2.27E+11	4.07E-04	332410	3.53E+12	4.59E+16	1.03E+09	1.34E+13
9 Pumps and valves (steel)	g	1.67E+07	7.10E+03	1.19E+11	4.07E-04	333911	3.15E+12	2.14E+16	1.62E+09	1.10E+13
10 Pipes (Steel)	g	3.33E+07	7.10E+03	2.36E+11	4.07E-04	332996	3.99E+12	5.40E+16	9.54E+08	1.29E+13
11 Chimneys (Concrete)	g	9.33E+08	6.35E+02	5.92E+11	5.84E-05	327320	2.40E+13	1.31E+18	1.29E+09	7.03E+13
12 Electro. Precipitators (steel)	g	1.04E+09	7.10E+03	7.38E+12	4.07E-04	333298	3.28E+12	1.39E+18	1.64E+09	6.91E+14
13 Turbines (Steel)	g	7.33E+07	7.10E+03	5.20E+11	4.07E-04	333611	2.89E+12	8.62E+16	1.08E+09	3.21E+13
14 Electric Generators (Steel)	g	3.80E+07	7.10E+03	2.70E+11	4.07E-04	335312	3.61E+12	5.58E+16	1.50E+09	2.32E+13
15 Electric Motors										
Steel	g	1.60E+07	7.10E+03	1.14E+11	4.07E-04	335312	3.61E+12	2.35E+16	1.50E+09	9.78E+12
Copper	g	4.00E+06	2.11E+03	8.45E+09	2.51E-03	335312	3.61E+12	3.63E+16	1.50E+09	1.51E+13
16 Transformers										
Steel	g	3.93E+07	7.10E+03	2.79E+11	4.07E-04	335311	4.21E+12	6.73E+16	2.21E+09	3.53E+13
Copper	g	1.23E+07	2.11E+03	2.60E+10	2.51E-03	335311	4.21E+12	1.30E+17	2.21E+09	6.83E+13
17 Travelling bridge crane (Steel)	g	5.00E+06	7.10E+03	3.55E+10	4.07E-04	333923	3.15E+12	6.41E+15	1.58E+09	3.22E+12
18 Labor										
Engineering	yrs	7.38	__	__	__	D	__	3.68E+17	__	__
Admin	yrs	1.74	__	__	__	D	__	4.33E+16	__	__
Construction	yrs	182	__	__	__	D	__	4.53E+18	__	__
19 Electricity	J	2.40E+12	1.00E+00	2.40E+12	2.20E-08	221100	7.50E+12	3.97E+17	1.28E+09	6.75E+13
20 Diesel for yard machinery	J	2.13E+12	1.00E+00	2.13E+12	4.55E-09	324110	1.40E+13	2.85E+17	3.96E+09	3.83E+13
21 Diesel transport major components	J	5.99E+11	1.00E+00	5.99E+11	4.55E-09	324110	1.40E+13	8.02E+16	3.96E+09	1.08E+13
22 Coal Transport machinery (steel)	g	8.33E+07	7.10E+03	5.91E+11	4.07E-04	333298	3.28E+12	1.11E+17	1.64E+09	5.54E+13
23 Coal grinding machinery (Steel)	g	8.00E+07	7.10E+03	5.68E+11	4.07E-04	333131	3.41E+12	1.11E+17	2.69E+09	8.75E+13
24 Ash treatment/stor. Machinery (Steel)	g	3.33E+07	7.10E+03	2.36E+11	4.07E-04	333298	3.28E+12	4.44E+16	1.64E+09	2.21E+13
PLANT OPERATING PHASE										
Direct renewable inputs										
25 Solar radiation	J	1.11E+15	1.00E+00	1.11E+15	__	D	__	1.11E+15	__	1.11E+15
Goods and services										
26 Labor										
Graduated	yrs	2	__	__	__	D	__	9.96E+16	__	__
Technical and admin	yrs	180	__	__	__	D	__	4.48E+18	__	__
Other tech services	yrs	300	__	__	__	D	__	7.47E+18	__	__
27 Fuels										
Combustion Oil	J	2.31E+16	1	2.31E+16	2.47E-09	324110	1.4E+13	8.01E+20	3.96E+09	2.26E+17
Coal	J	4.42E+16	1	4.42E+16	1.27E-09	212100	5.8E+13	3.26E+21	2.13E+09	1.2E+17
Diesel for coal operating machinery	J	6.4E+13	1	6.4E+13	4.55E-09	324110	1.4E+13	8.57E+18	3.96E+09	1.15E+15
IMPACT OF EMISSIONS ON HUMAN HEALTH										
28 CO2	g	7.35E+12	__	__	__	D	__	5.27E+19	__	__
29 SO2	g	5.3E+10	__	__	__	D	__	9.86E+19	__	__
30 NO2	g	2.12E+10	__	__	__	D	__	6.42E+19	__	__
31 PM10	g	2.19E+09	__	__	__	D	__	2.8E+19	__	__

Table G.1: Exergy, ECEC and ICEC Calculations for purchased and direct inputs for Coal-Fired Thermoelectric facility (based on 488-sector 1997 US economic model)

	Unit	Amount (units/yr)	Exergy (J/unit)	Tot. Exergy (J/yr)	Price § ($/unit)	NAICS	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
OUTPUTS										
Electricity Production	J	3.28E+14	1.00E+00	3.28E+14	2.20E-08	221100	7.50E+12	5.42E+19	1.28E+09	9.22E+15
INPUTS										
PLANT CONSTRUCTION PHASE										
1 Extraction wells, cement	g	5.71E+08	6.35E+02	3.63E+11	5.84E-05	327310	6.37E+12	2.13E+17	1.78E+09	5.93E+13
2 Reinjection wells, cement	g	2.85E+08	6.35E+02	1.81E+11	5.84E-05	327310	6.37E+12	1.06E+17	1.78E+09	2.96E+13
3 Steam lines										
Steel	g	2.79E+07	7.04E+03	1.96E+11	4.07E-04	331210	5.52E+12	6.27E+16	1.05E+09	1.19E+13
Aluminum Cover	g	1.40E+06	3.29E+04	4.61E+10	1.36E-03	331312	1.20E+13	2.28E+16	1.60E+09	3.03E+12
6 Building and assets of plant										
(a) Misc										
concrete	g	1.57E+08	6.35E+02	9.97E+10	5.84E-05	327320	2.40E+13	2.20E+17	1.29E+09	1.18E+13
(b) Construction of main building										
Carbon and Inox steel	g	4.14E+06	7.10E+03	2.94E+10	4.07E-04	331111	1.11E+13	1.87E+16	1.36E+09	2.29E+12
Aluminum	g	1.14E+05	3.29E+04	3.75E+09	1.36E-03	331312	1.20E+13	1.86E+15	1.60E+09	2.47E+11
7 Steel Components of the plant system										
carbon steel	g	3.51E+06	7.10E+03	2.49E+10	4.07E-04	331111	1.11E+13	1.58E+16	1.36E+09	1.94E+12
inox steel	g	4.76E+06	7.10E+03	3.38E+10	4.07E-04	331111	1.11E+13	2.14E+16	1.36E+09	2.63E+12
8 Electric wires										
copper	g	7.53E+05	2.11E+03	1.59E+09	2.51E-03	331422	6.41E+12	1.21E+16	7.27E+09	1.38E+13
10 Electricity	J	1.64E+10	1.00E+00	1.64E+10	2.20E-08	221100	7.50E+12	2.71E+15	1.28E+09	4.61E+11
11 Diesel Fuel	J	1.94E+11	1.00E+00	1.94E+11	4.55E-09	324110	1.40E+13	2.60E+16	3.96E+09	3.49E+12
12 Major components of the plant										
Iron and steel	g	1.54E+07	7.10E+03	1.09E+11	4.07E-04	331111	1.11E+13	6.94E+16	1.36E+09	8.51E+12
copper	g	3.59E+05	2.11E+03	7.58E+08	2.51E-03	331411	2.83E+13	2.55E+16	2.23E+09	2.01E+12
pig-iron	g	1.36E+06	8.75E+03	1.19E+10	4.07E-04	331111	1.11E+13	6.13E+15	1.36E+09	7.51E+11
chromium	g	1.36E+05	1.00E+03	1.36E+08	9.10E-05	331491	1.40E+13	1.73E+14	4.42E+09	5.47E+10
molybdenum	g	8.98E+03	1.00E+03	8.98E+06	5.19E-03	331491	1.40E+13	6.52E+14	4.42E+09	2.06E+11
nickel	g	1.22E+05	1.00E+03	1.22E+08	7.49E-03	331491	1.40E+13	1.28E+16	4.42E+09	4.04E+12
Lube & Insulating Oil	J	5.41E+10	1.00E+00	5.41E+10	1.08E-08	324191	5.74E+12	3.36E+15	4.66E+09	5.41E+10
13 Transport of plant Mat										
Diesel Fuel	J	3.00E+11	1.00E+00	3.00E+11	4.55E-09	324110	1.40E+13	4.02E+16	3.96E+09	5.40E+12
14 Labor for construction										
Not specialized work force	yrs	7.13E+00	__	__	__	D	__	1.78E+17	__	__
Graduated Labor	yrs	4.55E-01	__	__	__	D	__	2.27E+16	__	__
PLANT OPERATING PHASE										
15 Annual electricity input	J	2.53E+13	1.00E+00	2.53E+13	2.20E-08	221100	7.50E+12	4.18E+18	1.28E+09	7.12E+14
16 Labor										
Graduated	J	2.60E-01	1.00E+00	__	__	D	__	1.29E+16	__	__
Tech and Admin	J	1.20E+00	1.00E+00	__	__	D	__	2.99E+16	__	__
Not specialized work force	J	4.17E+00	1.00E+00	__	__	D	__	1.04E+17	__	__
Other	J	5.21E+01	1.00E+00	__	__	D	__	1.30E+18	__	__
17 Maintainance Material										
Lube Oil	J	4.61E+10	1.00E+00	4.61E+10	1.08E-08	324191	5.74E+12	2.86E+15	4.66E+09	4.61E+10
Steel	g	8.00E+05	7.10E+03	5.68E+09	4.07E-04	331111	1.11E+13	3.60E+15	1.36E+09	4.42E+11
Aluminum	g	3.00E+05	3.29E+04	9.88E+09	1.36E-03	331312	1.20E+13	4.89E+15	1.60E+09	6.50E+11
DIRECT ENVIRONMENTAL INPUTS										
18 Geothermal Heat	J	2.25E+15	1.00E+00	2.25E+15	__	D	__	3.35E+19	__	2.25E+15
EMISSIONS										
CO2	g	1.18E+09	__	__	__	D	D	8.46E+15	__	__

Table G.2: Exergy, ECEC and ICEC calculations for purchased and direct inputs to geothermal facility (based on 488-sector 1997 US economic model)

Items	Unit	Amount (units/yr)	Exergy‡ (J/unit)	Tot. Exergy (J/yr)	Price § ($/unit)	NAICS	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
OUTPUTS										
Annual net electricity production	J	3.94E+14	1.00E+00	3.94E+14	1.88E-08	221100	7.50E+12	5.54E+19	1.28E+09	9.44E+15
PLANT CONSTRUCTION PHASE										
Goods, energy and labor, divided by plant lifetime, 50 years)										
1 Cement	g	9.00E+08	6.35E+02	5.72E+11	5.84E-05	327310	6.37E+12	3.35E+17	1.78E+09	9.35E+13
2 Iron and steel	g	9.00E+07	7.10E+03	6.39E+11	4.07E-04	331111	1.11E+13	4.05E+17	1.36E+09	4.97E+13
3 Pelton turbines (steel)	g	1.08E+07	7.10E+03	7.64E+10	4.07E-04	333611	2.89E+12	1.27E+16	1.08E+09	4.71E+12
4 Alternators										
Steel	g	3.41E+06	7.10E+03	2.42E+10	4.07E-04	334515	2.05E+12	2.84E+15	9.01E+08	1.25E+12
Copper	g	3.20E+05	2.51E-03	8.05E+02	2.51E-03	334515	2.05E+12	1.65E+15	9.01E+08	7.25E+11
5 Transformers										
Iron and steel	g	2.16E+06	7.10E+03	1.53E+10	4.07E-04	335311	4.21E+12	3.70E+15	2.21E+09	1.94E+12
Copper	g	4.00E+05	2.51E-03	1.01E+03	2.51E-03	335311	4.21E+12	4.23E+15	2.21E+09	2.22E+12
Cooling oil	J	4.24E+10	1.00E+00	4.24E+10	1.08E-08	324191	5.74E+12	2.63E+15	4.66E+09	2.13E+12
6 High pressure water piping (steel)	g	2.40E+07	7.10E+03	1.70E+11	4.07E-04	331210	5.52E+12	5.39E+16	1.05E+09	1.03E+13
7 Water gates & other machinery (steel)	g	2.57E+06	7.10E+03	1.82E+10	4.07E-04	332111	4.35E+12	4.54E+15	1.13E+09	1.18E+12
8 Copper wires	g	2.40E+06	2.51E-03	6.03E+03	2.51E-03	331422	6.41E+12	3.87E+16	7.27E+09	4.39E+13
9 Travelling bridge crane (steel)	g	6.55E+05	7.10E+03	4.65E+09	4.07E-04	333923	3.15E+12	8.40E+14	1.58E+09	4.22E+11
10 Labor and services	yrs	5.31E+01	__	__	__	D	__	1.32E+18	__	__
11 Electricity	J	2.02E+12	1.00E+00		1.88E-08	221100	7.50E+12	2.85E+17	1.28E+09	4.84E+13
12 Diesel for people transportation	J	5.64E+09	1.00E+00	5.64E+09	4.55E-09	324110	1.40E+13	3.60E+14	3.96E+09	1.01E+11
13 Diesel for cement transportation	J	4.42E+11	1.00E+00	4.42E+11	4.55E-09	324110	1.40E+13	2.82E+16	3.96E+09	7.95E+12
14 Miscellaneous electric materials	g	2.00E+06								
15 Miscellaneous mechanical components	g	1.74E+07								
16 Additional services for plant manufacture	$	6.22E+04	__	__	1.00E+00	5419A0	5.34E+11	3.32E+16	6.06E+08	3.77E+13
PLANT OPERATING PHASE										
Locally available environmental inputs										
17 Rain geopotential	J	7.61E+14	1.00E+00	7.61E+14	__	D	__	1.69E+19	__	7.61E+14
18 Geological structure used up	g	1.30E+09	1.00E+00	1.30E+09	__	D	__	4.45E+18	__	1.30E+09
Goods, labor and energy for plant operating										
19 Labor and services	yrs	1.00E+00	__	__	__	D	__	2.49E+16	__	__
20 Electricity	J	1.99E+12	1.00E+00	1.99E+12	1.88E-08	221100	7.50E+12	2.79E+17	1.28E+09	4.76E+13
Plant maintenance										
21 Labor and services	yrs	3.00E+00	__	__	__	D	__	7.47E+16	__	__
IMPACT OF EMISSIONS ON HUMAN HEALTH										
22 CO2	g	1.27E+09	__	__	__	D	__	9.14E+15	__	__

Table G.3: Exergy, ECEC and ICEC calculations for purchased and direct inputs to hydroelectric facility (based on 488-sector 1997 US economic model)

	Unit	Amount (units/yr)	Exergy (J/unit)	Tot. Exergy (J/yr)	Price ($/unit)	NAICS	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
OUTPUTS										
Electricity Production	J	1.86E+15	1.00E+00	1.86E+15	2.20E-08	221100	7.50E+12	3.07E+20	1.28E+09	5.23E+16
INPUTS										
A) Steam turbine group, 136 MWe										
Construction inputs for the steam turbine section										
(Goods, energy and labor imported from outside the system, have been divided by plant lifetime)										
1 Concrete	g	1.20E+08	6.35E+02	7.62E+10	5.84E-05	327320	2.40E+13	1.68E+17	1.29E+09	9.04E+12
2 Copper electric wires	g	1.47E+06	2.11E+03	3.11E+09	4.07E-04	331422	6.41E+12	3.84E+15	7.27E+09	4.36E+12
3 Diesel transport of materials by truck	J	3.24E+09	1.00E+00	3.24E+09	4.55E-09	324110	1.40E+13	4.34E+14	3.96E+09	5.83E+10
4 Steam gen. & support structure (steel)	g	1.00E+08	7.10E+03	7.10E+11	4.07E-04	333611	2.89E+12	2.47E+17	1.08E+09	4.38E+13
5 Steam condenser (steel)	g	6.47E+05	7.10E+03	4.74E+11	4.07E-04	332410	3.53E+12	9.28E+14	1.03E+09	2.72E+11
6 Chimney										
7 Concrete and refractory material	g	7.07E+07	6.35E+02	4.49E+10	5.84E-05	327320	2.40E+13	9.91E+16	1.29E+09	5.33E+12
8 Iron	g	1.08E+06	7.10E+03	7.69E+09	4.07E-04	331111	1.11E+13	4.88E+15	1.36E+09	5.98E+11
9 Turbine (steel)	g	9.07E+06	7.10E+03	6.44E+10	4.07E-04	333611	2.89E+12	1.07E+16	1.08E+09	3.97E+12
10 Alternator										
Steel	g	8.33E+06	7.10E+03	5.92E+10	4.07E-04	334515	2.05E+12	6.93E+15	9.01E+08	3.05E+12
Copper	g	5.00E+05	2.51E-03	1.26E+03	2.51E-03	334515	2.05E+12	2.57E+15	9.01E+08	1.13E+12
11 Transformer 170 MVA										
Steel	g	3.58E+06	7.10E+03	2.54E+10	4.07E-04	335311	4.21E+12	6.13E+15	2.21E+09	3.22E+12
Copper	g	5.05E+05	2.51E-03	1.27E+03	2.51E-03	335311	4.21E+12	5.35E+15	2.21E+09	2.81E+12
Cooling oil	J	4.38E+10	1.00E+00	4.38E+10	1.08E-08	324191	5.74E+12	2.71E+15	4.66E+09	2.20E+12
12 Lubricants	J	5.66E+10	1.00E+00	5.66E+10	1.08E-08	324191	5.74E+12	3.51E+15	4.66E+09	5.66E+10
13 Water and fuel reservoirs										
Steel	g	3.11E+07	7.10E+03	2.21E+11	4.07E-04	331111	1.11E+13	1.40E+17	1.36E+09	1.72E+13
14 Travelling bridge crane (steel)	g	5.00E+06	7.10E+03	3.55E+10	4.07E-04	333923	3.15E+12	6.41E+15	1.58E+09	3.22E+12
15 Labor	yrs	3.29E+01	__	__	__	D	__	8.19E+17	__	__
16 Electricity	J	2.77E+11	1.00E+00	2.77E+11	2.20E-08	221100	7.50E+12	4.57E+16	1.28E+09	7.78E+12
17 Diesel for yard machinery	J	2.46E+11	1.00E+00	2.46E+11	4.55E-09	324110	1.40E+13	3.29E+16	3.96E+09	4.43E+12
18 Diesel for transp. major components	J	3.31E+10	1.00E+00	3.31E+10	4.55E-09	324110	1.40E+13	4.43E+15	3.96E+09	5.96E+11
Operating inputs for the steam turbine section										
19 Labor										
Graduated	yrs	2.97E+00	__	__	__	D	__	1.48E+17	__	__
Technical and administrative	yrs	4.16E+01	__	__	__	D	__	1.04E+18	__	__
Other technical services	yrs	3.79E+01	__	__	__	D	__	9.43E+17	__	__
20 Fuels supplied to the steam turbine										
Methane	J	4.69E+15	1.00E+00	4.69E+15	2.79E-09	221200	1.02E+13	2.79E+20	1.09E+09	1.42E+16
Diesel	J	2.22E+12	1.00E+00	2.22E+12	4.55E-09	324110	1.40E+13	2.98E+17	3.96E+09	4.00E+13
B) Turbogas group, 35 MW										
21 Construction inputs for the turbogas section										
(Goods, energy and labor imported from outside the system, have been divided by plant lifetime)										
Total steel	g	4.09E+07	7.10E+03	2.90E+11	4.07E-04	331111	1.11E+13	1.84E+17	1.36E+09	2.26E+13
Total concrete and refractory materials	g	4.91E+07	6.35E+02	3.12E+10	5.84E-05	327320	2.40E+13	6.88E+16	1.29E+09	3.70E+12
Total copper	g	6.38E+05	2.11E+03	1.35E+09	2.51E-03	331411	2.83E+13	4.54E+16	2.23E+09	3.58E+12
Total diesel	J	6.41E+10	1.00E+00	6.41E+10	4.55E-09	324110	1.40E+13	8.59E+15	3.96E+09	1.15E+12
Total lube an cooling oil	J	2.58E+10	1.00E+00	2.58E+10	1.08E-08	324191	5.74E+12	1.60E+15	4.66E+09	2.58E+10
Total electricity	J	7.12E+10	1.00E+00	7.12E+10	2.20E-08	221100	7.50E+12	1.18E+16	1.28E+09	2.00E+12
Total labor	yrs	1.14E+01	__	__	__	D	__	2.84E+17	__	__

Continued

Table G.4: Exergy, ECEC and ICEC calculations for purchased and direct inputs to NG-based thermoelectric facility (based on 488-sector 1997 US economic model)

Table G.4 continued

		Unit	Amount (units/yr)	Exergy (J/unit)	Tot. Exergy (J/yr)	Price ($/unit)	NAICS	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
22	Operating inputs for the turbogas section										
	Labor										
	Graduated	yrs	1.03E+00	__	__	__	D	__	5.13E+16	__	__
	Technical and administrative	yrs	1.44E+01	__	__	__	D	__	3.59E+17	__	__
	Other technical services	yrs	1.31E+01	__	__	__	D	__	3.27E+17	__	__
23	Fuels supplied to the turbogas group										
	Methane	J	1.53E+15	1.00E+00	1.53E+15	2.79E-09	221200	1.02E+13	9.12E+19	1.09E+09	4.66E+15
C) Integration and reserve boilers											
24	Fuels supplied to the integration boilers										
	Methane	J	1.32E+15	1.00E+00	1.32E+15	2.79E-09	221200	1.02E+13	7.86E+19	1.09E+09	4.01E+15
25	Add. services & investments for fuel supply										
	Add. services for fuel supply to steam turbine	$	8.97E+06	__	__	1.00E+00	5419A0	5.34E+11	4.79E+18	6.06E+08	5.44E+15
	Add. services for fuel supply to gas turbine	$	2.93E+06	__	__	1.00E+00	5419A0	5.34E+11	1.56E+18	6.06E+08	1.78E+15
	Additional services for fuel supply to boilers	$	2.53E+06	__	__	1.00E+00	5419A0	5.34E+11	1.35E+18	6.06E+08	1.53E+15
Locally available renewable inputs											
26	Total solar radiation	J	7.38E+13	1.00E+00	7.38E+13	__	D	__	7.38E+13	__	7.38E+13
	Rain on land (chemical potential)	J	2.82E+10	1.00E+00	2.82E+10	__	D	__	6.26E+14	__	2.82E+10
IMPACT OF EMISSIONS ON HUMAN HEALTH											
27	CO_2	g	1.26E+08	__	__	__	D	__	9.06E+14	__	__

Items	Uni	Amount (units/yr)	Exergy (J/unit)	Tot. Exergy (J/yr)	Price ($/unit)	NAICS	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
OUTPUTS										
Annual net electricity production	J	2.35E+16	1.00E+00	2.35E+16	2.20E-08	221100	7.50E+12	3.88E+21	1.28E+09	6.61E+17
INPUTS										
PLANT CONSTRUCTION PHASE										
(Goods, energy and labor have been divided by plant lifetime, 30 years)										
1 Concrete	g	3.64E+10	6.35E+02	2.31E+13	5.84E-05	327320	2.40E+13	5.10E+19	1.29E+09	2.74E+15
2 Iron and steel for structure	g	6.17E+08	7.10E+03	4.38E+12	4.07E-04	331111	1.11E+13	2.78E+18	1.36E+09	3.41E+14
4 Copper electric wires	g	5.26E+06	2.11E+03	1.11E+10	4.07E-04	331422	6.41E+12	1.37E+16	7.27E+09	1.56E+13
5 Diesel transport of material by truck	J	9.87E+11	1.00E+00	9.87E+11	4.55E-09	324110	1.40E+13	1.32E+17	3.96E+09	1.78E+13
6 Steam generators (steel)	g	2.57E+08	7.10E+03	1.83E+12	4.07E-04	333611	2.89E+12	6.35E+17	1.08E+09	1.13E+14
7 Steam condensers (steel)	g	6.27E+07	7.10E+03	4.74E+11	4.07E-04	332410	3.53E+12	8.99E+16	1.03E+09	2.63E+13
8 Pre-heaters for input water (steel)	g	4.12E+07	7.10E+03	2.92E+11	4.07E-04	332410	3.53E+12	5.90E+16	1.03E+09	1.73E+13
9 Pre-heaters for combustion air (steel)	g	3.20E+07	7.10E+03	2.27E+11	4.07E-04	332410	3.53E+12	4.59E+16	1.03E+09	1.35E+13
10 Pumps and valves (steel)	g	1.67E+07	7.10E+03	1.18E+11	4.07E-04	333911	3.15E+12	2.14E+16	1.62E+09	1.10E+13
11 Pipes (steel)	g	3.33E+07	7.10E+03	2.37E+11	4.07E-04	332996	3.99E+12	5.40E+16	9.54E+08	1.29E+13
12 Chimneys (mostly concrete)	g	9.33E+08	6.35E+02	5.93E+11	5.84E-05	327320	2.40E+13	1.31E+18	1.29E+09	7.04E+13
13 Electrost. precipitators (steel)	g	2.93E+08	7.10E+03	2.08E+12	4.07E-04	333298	3.28E+12	3.91E+17	1.64E+09	1.95E+14
14 Turbines (steel)	g	6.86E+07	7.10E+03	4.87E+11	4.07E-04	333611	2.89E+12	8.07E+16	1.08E+09	3.00E+13
15 Electric generators (steel)	g	4.67E+07	7.10E+03	3.31E+11	4.07E-04	335312	3.61E+12	6.85E+16	1.50E+09	2.85E+13
16 Electric motors										
Steel	g	1.60E+07	7.10E+03	1.14E+11	4.07E-04	335312	3.61E+12	2.35E+16	1.50E+09	9.78E+12
Copper	g	4.00E+06	2.11E+03	8.45E+09	2.51E-03	335312	3.61E+12	3.63E+16	1.50E+09	1.51E+13
17 Electric boards and panels (iron)	g	3.33E+07	7.10E+03	2.37E+11	4.07E-04	332111	4.35E+12	5.89E+16	1.13E+09	1.53E+13
18 Transformers 370 MVA										
Steel	g	3.12E+07	7.10E+03	2.22E+11	4.07E-04	335311	4.21E+12	5.34E+16	2.21E+09	2.80E+13
Copper	g	4.40E+06	2.51E-03	1.11E+04	2.51E-03	335311	4.21E+12	4.66E+16	2.21E+09	2.44E+13
Cooling oil	J	3.81E+11	1.00E+00	3.81E+11	1.08E-08	324191	5.74E+12	2.36E+16	4.66E+09	1.92E+13
20 Travelling bridge crane (steel)	g	5.00E+06	7.10E+03	3.55E+10	4.07E-04	333923	3.15E+12	6.41E+15	1.58E+09	3.22E+12
21 Labor and services	yrs	3.47E+02	__	__	__	D	__	8.65E+18	__	__
22 Electricity	J	2.40E+12	1.00E+00	2.40E+12	2.20E-08	221100	7.50E+12	3.97E+17	1.28E+09	6.75E+13
23 Diesel for yard machinery	J	2.13E+12	1.00E+00	2.13E+12	4.55E-09	324110	1.40E+13	2.86E+17	3.96E+09	3.84E+13
24 Diesel for transp. major components	J	2.54E+11	1.00E+00	2.54E+11	4.55E-09	324110	1.40E+13	3.40E+16	3.96E+09	4.57E+12
25 Lubricants	J	4.91E+11	1.00E+00	4.91E+11	1.08E-08	324191	5.74E+12	3.05E+16	4.66E+09	2.47E+13
PLANT OPERATING PHASE										
LOCALLY AVAILABLE RENEWABLE INPUTS										
27 Solar radiation	J	1.06E+16	1.00E+00	1.06E+16	__	D	__	7.38E+13	__	7.38E+13
Goods and services										
30 Labor and services:										
Graduated	yrs	8.00E+00	__	__	__	D	__	3.98E+17	__	__
Technical and administrative	yrs	1.00E+02	__	__	__	D	__	2.49E+18	__	__
Other technical services	yrs	1.97E+02	__	__	__	D	__	4.91E+18	__	__
31 Labor plant maintenance & labor from outside	yrs	1.00E+02	__	__	__	D	__	2.49E+18	__	__
32 Currently replaced materials:										
Machinery and electric materials	$	3.12E+06	__	__	1.00E+00	5419A0	5.34E+11	1.66E+18	6.06E+08	1.89E+15
Lubricants	J	1.37E+12	1.00E+00	1.37E+12	1.08E-08	324191	5.74E+12	8.52E+16	4.66E+09	6.91E+13
34 Combustion oil	J	6.14E+16	1.00E+00	2.31E+16	2.47E-09	324110	1.40E+13	2.13E+21	3.96E+09	6.01E+17
35 Additional services for fuel supply	$	2.38E+08	__	__	1.00E+00	5419A0	5.34E+11	1.27E+20	6.06E+08	1.44E+17
IMPACT OF EMISSIONS ON HUMAN HEALTH										
30 CO2	g	6.03E+12	__	__	__	D	__	4.32E+19	__	__

Table G.5: Exergy, ECEC and ICEC calculations for purchased and direct inputs to Oil-based thermoelectric facility (based on 488-sector 1997 US economic model)

Items	Unit	Amount (units/yr)	Exergy (J/unit)	Tot. Exergy (J/yr)	Price § ($/unit)	NAICS	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
OUTPUTS										
Annual net electricity production	J	1.35E+12	1.00E+00	1.35E+12	2.20E-08	221100	7.50E+12	2.23E+17	1.28E+09	3.80E+13
INPUTS										
PLANT BUILDING PHASE										
1 Concrete in basement	g	5.62E+06	6.35E+02	3.57E+09	5.84E-05	327320	2.40E+13	7.88E+15	1.29E+09	4.23E+11
2 Iron in basement	g	2.65E+05	7.10E+03	1.88E+09	4.07E-04	331111	1.11E+13	1.19E+15	1.36E+09	1.46E+11
3 Tower (steel)	g	5.04E+05	7.10E+03	3.58E+09	4.07E-04	331111	1.11E+13	2.27E+15	1.36E+09	2.78E+11
4 Nacelle:										
Structure (steel)	g	8.00E+04	7.10E+03	5.68E+08	4.07E-04	331111	1.11E+13	3.60E+14	1.36E+09	4.42E+10
Top (steel)	g	2.00E+04	7.10E+03	1.42E+08	4.07E-04	331111	1.11E+13	9.01E+13	1.36E+09	1.10E+10
5 Step up gear:										
Casing (pig iron)	g	6.00E+04	8.75E+03	5.25E+08	4.07E-04	331111	1.11E+13	2.70E+14	1.36E+09	3.31E+10
Gears (steel)	g	2.00E+04	7.10E+03	1.42E+08	4.07E-04	331111	1.11E+13	9.01E+13	1.36E+09	1.10E+10
6 Drive line (steel)	g	8.00E+03	7.10E+03	5.68E+07	4.07E-04	331111	1.11E+13	3.60E+13	1.36E+09	4.42E+09
7 Gearmotor (steel)	g	1.20E+04	7.10E+03	8.52E+07	4.07E-04	331111	1.11E+13	5.41E+13	1.36E+09	6.63E+09
8 Nacelle electric switchboard:										
Steel	g	2.40E+03	7.10E+03	1.70E+07	4.07E-04	331111	1.11E+13	1.08E+13	1.36E+09	1.33E+09
Copper	g	1.20E+03	2.11E+03	2.53E+06	2.51E-03	331411	2.83E+13	8.53E+13	2.23E+09	6.72E+09
9 Nacelle electric wires:										
Copper	g	1.70E+03	2.11E+03	3.59E+06	4.07E-04	331422	6.41E+12	4.43E+12	7.27E+09	5.03E+09
10 Electricity generators:										
Steel	g	4.20E+04	7.10E+03	2.98E+08	4.07E-04	335312	3.61E+12	6.17E+13	1.50E+09	2.57E+10
Copper	g	1.80E+04	2.11E+03	3.80E+07	2.51E-03	335312	3.61E+12	1.63E+14	1.50E+09	6.81E+10
11 Oleodynamic box:										
Steel	g	5.60E+03	7.10E+03	3.98E+07	4.07E-04	331111	1.11E+13	2.52E+13	1.36E+09	3.09E+09
Copper	g	1.60E+03	2.11E+03	3.38E+06	2.51E-03	331411	2.83E+13	1.14E+14	2.23E+09	8.97E+09
12 Oleodynamic control board:										
Steel	g	2.88E+03	7.10E+03	2.04E+07	4.07E-04	331111	1.11E+13	1.30E+13	1.36E+09	1.59E+09
Copper	g	1.60E+02	2.11E+03	3.38E+05	2.51E-03	331411	2.83E+13	1.14E+13	2.23E+09	8.97E+08
13 Blade gear cylinder (steel)	g	4.80E+03	7.10E+03	3.41E+07	4.07E-04	331111	1.11E+13	2.16E+13	1.36E+09	2.65E+09
14 Bearings (steel)	g	1.20E+03	7.10E+03	8.52E+06	4.07E-04	331111	1.11E+13	5.41E+12	1.36E+09	6.63E+08
15 Rotor group:										
Steel	g	1.32E+04	7.10E+03	9.37E+07	4.07E-04	331111	1.11E+13	5.95E+13	1.36E+09	7.29E+09
Pig iron	g	8.00E+04	8.75E+03	7.00E+08	4.07E-04	331111	1.11E+13	3.60E+14	1.36E+09	4.42E+10
16 Blade:										
Steel	g	3.20E+03	7.10E+03	2.27E+07	4.07E-04	331111	1.11E+13	1.44E+13	1.36E+09	1.77E+09
17 Blade balance weight (pig iron)	g	1.60E+04	8.75E+03	1.40E+08	4.07E-04	331111	1.11E+13	7.21E+13	1.36E+09	8.84E+09
18 Electric wires:										
Copper	g	3.40E+04	2.11E+03	7.18E+07	2.51E-03	331422	6.41E+12	5.48E+14	7.27E+09	6.22E+11
19 General control board and computer:										
Steel	g	1.44E+04	7.10E+03	1.02E+08	4.07E-04	331111	1.11E+13	6.49E+13	1.36E+09	7.95E+09
Copper	g	7.20E+03	2.11E+03	1.52E+07	2.51E-03	331422	6.41E+12	1.16E+14	7.27E+09	1.32E+11
20 Transformer:										
Iron	g	1.27E+05	7.10E+03	9.02E+08	4.07E-04	335311	4.21E+12	2.17E+14	2.21E+09	1.14E+11
Copper	g	2.35E+04	2.11E+03	4.97E+07	2.51E-03	335311	4.21E+12	2.49E+14	2.21E+09	1.31E+11
21 Labor & services for design and construction	years	9.48E-02	__	__	__	D	__	2.36E+15	__	__
22 Machinery (steel)	g	0.00E+00	__	__	4.07E-04					
23 Additional services for plant manufacture	US $	2.94E+01	__	__	1.00E+00	5419A0	5.34E+11	1.57E+13	6.06E+08	1.78E+10
Maintenance										
24 Labor and services	years	4.17E-02	__	__	__	D	__	1.04E+15	__	__

Continued

Table G.6: Exergy, ECEC and ICEC calculations for purchased and direct inputs to Oil-based thermoelectric facility (based on 488-sector 1997 US economic model)

Table G.6 continued

Items	Unit	Amount (units/yr)	Exergy (J/unit)	Tot. Exergy (J/yr)	Price § ($/unit)	NAICS	ECEC/$ (sej/$)	ECEC (sej/yr)	ICEC/$ (J/$)	ICEC (J/yr)
25 Nitrogen gas	g	2.00E+04	2.57E+01	5.14E+05	3.93E-04	325120	2.44E+12	1.91E+13	1.04E+09	8.15E+09
26 Lube oil	J	3.10E+09	1.00E+00	3.10E+09	1.08E-08	324191	5.74E+12	1.92E+14	4.66E+09	1.56E+11
Operating phase										
27 Wind	J	4.85E+13	1.00E+00	4.85E+13	__	D	__	7.28E+16	__	4.85E+13
28 Labor	years	4.17E-02	__	__	__	D	__	1.57E+15	__	__
IMPACT OF EMISSIONS ON HUMAN HEALTH										
29 CO2	g	1.36E+07	__	__	__	D	__	9.72E+13	__	__

APPENDIX H

ALGORITHMS FOR THERMODYNAMIC INPUT-OUTPUT ANALYSIS OF INDUSTRIAL PROCESSES OR PRODUCTS

ECEC/money ratio is particularly useful in hybrid thermodynamic life cycle analysis of industrial systems. A hybrid analysis integrates process models or product systems with economy-scale input-output models, and in the process, combines relatively accurate, process-specific data with more uncertain economy-scale data (Suh et al., 2004). Consequently, a hybrid analysis is more powerful as it combines the two critical attributes of an environmental decision tool, namely specificity and a broad system boundary. ECEC/money and ICEC/money ratios can come in handy in this context as the interactions of a product system with the rest of the economy are routinely measured in monetary terms in normal accounting procedures. The algorithms for exergy, ICEC and ECEC analyses are presented here. Figure H.1 shows the analyses boundaries for the three types of analyses.

- *Exergy Analysis*: As shown in Figure H.1, exergy analysis focuses only on the process or product system under investigation. Consequently, to perform exergy analysis, only information about material or energy flows in and out of the process and corresponding standard exergy values are required. Material or energy flows are typically determined in the design phase of the process and can be obtained from Standard Operating Procedures (SOPs) and company logs. Alternatively they can be estimated from computer simulation packages such as ASPEN and HYSYS. Exergy values can be obtained from standard databases such as the one offered by Szargut et al. (1988), or can be estimated from temperature, pressure and composition data for input and output streams. The algorithm for performing exergy analysis is shown in Table H.1.

- *ICEC Analysis*: As shown in Figure H.1, ICEC analysis focuses on the process or product system under investigation as well as all the industrial stages of its supply chain. To perform ICEC analysis, not only material or energy flow information on input and output streams is required but also exergy flows in the rest of economy required to sustain the process system in question need to be estimated. This task can be accomplished through the use of ICEC/money ratios calculated in this dissertation. To expand the analysis boundary to include the rest of economy, monetary transactions of the process system with the rest of the economy must be estimated. This task is typically accomplished during the costing phase of the project where economic potential of the operation is determined. The monetary transaction of the process system are subsequently assigned to appropriate industry sectors from either 91-sector 1992 or 488-sector 1997 US economic models. This is followed by multiplying the monetary transaction by corresponding ICEC/money ratios to determine cumulative exergy consumption in the rest of the economy. In some cases prices of inputs may have to be adjusted to be in harmony with the economic model chosen. Inputs to the process system that do not come from the economy are considered separately. These are the direct environmental inputs. To determine exergy flows associated with direct environmental inputs, their mass or energy flows are multiplied by corresponding standard exergy values. The algorithm for ICEC analysis is presented in Table H.2.

- *ECEC Analysis*: As shown in Figure H.1, ECEC analysis expands the analysis boundary even further to include ecological stages of the production chain of a process or product system. To perform ECEC analysis, information about material and energy inputs to the process needs to be combined with an estimate of resulting cumulative exergy consumption in the economy and ecosystems. This can be done via ECEC/money ratios derived in this dissertation. Just like ICEC analysis, material or energy flows into the process or multiplied by corresponding prices to determine monetary interactions between the process and the economic system. These monetary interactions are assigned to appropriate industry sectors from the economic model of choice. Subsequently, the monetary transactions are multiplied by ECEC/money ratios to estimate ECEC throughput of the process. To comply with the allocation rules of ECEC analysis discussed in Chapter 2, ECEC/money ratios for non-renewable resources, renewable resources, human resources and human health impact of emissions are considered independently. Inputs from non-renewable resources, human resources and human health impact of emissions are added, whereas those from renewable resources are not to avoid double counting. The same procedure is applied for direct environmental inputs, but with transformity values in place of ECEC/money ratios. Distinction between non-renewable resources, renewable resources, human resources and human health impact of emissions, and that between direct environmental inputs and purchased inputs also enables ready calculation of performance metrics including yield ratio, loading ratio, yield-to-loading ratio and impact per value added. The algorithm for ECEC analysis is presented in Table H.3.

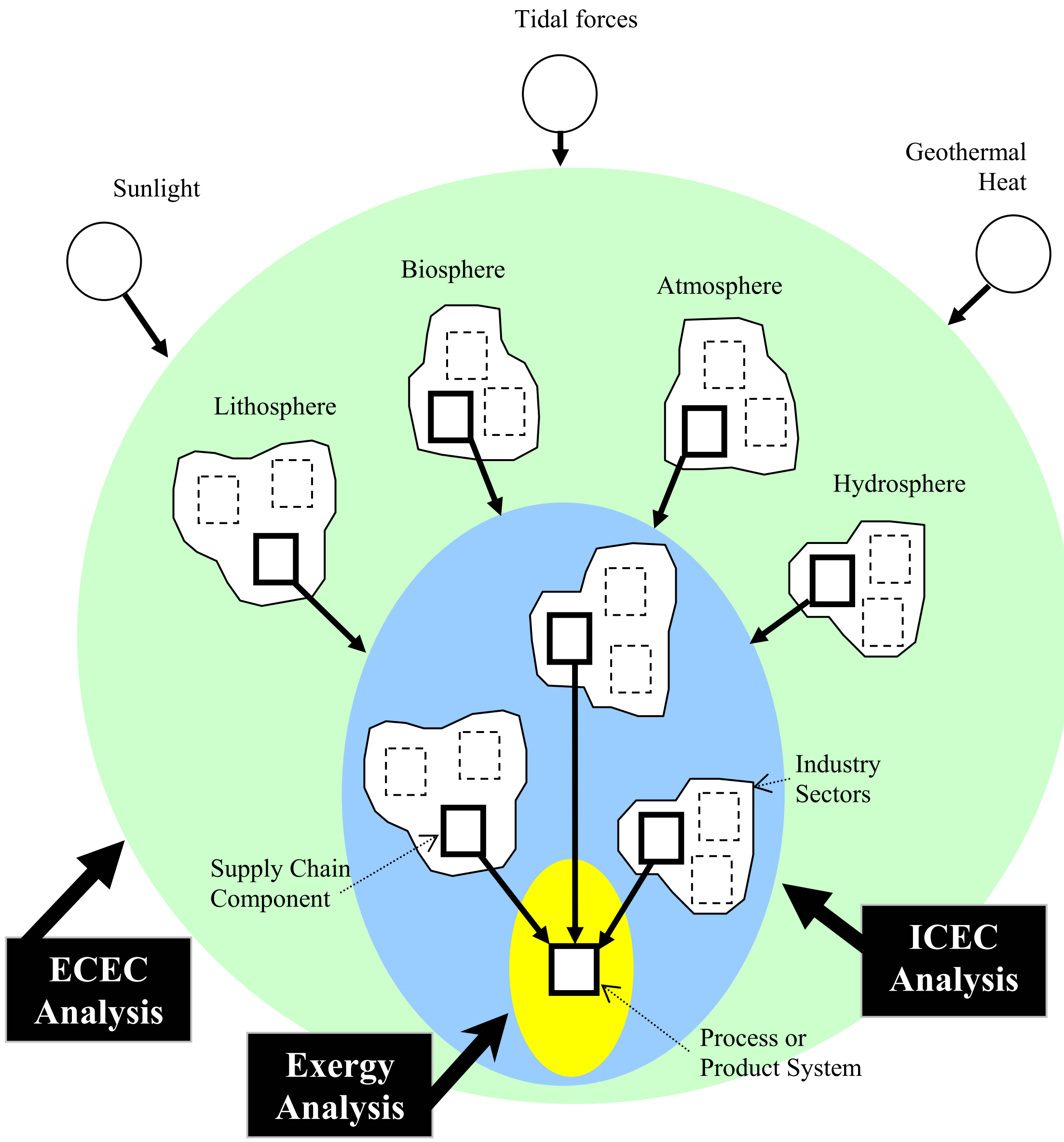


Figure H.1: Analysis Boundaries for exergy, ICEC and ECEC Analyses

Algorithm for Exergy Analysis

- Step 1: Identify Material and Energy Inputs ($\mathbf{m}_{input}$) and Outputs ($\mathbf{m}_{output}$)
- Step 2: Identify Standard Exergy Values ($\mathbf{b}_{input}$, $\mathbf{b}_{output}$)
- Step 3: Calculate Second Law Efficiency according to Equation H.1

$$\eta_{exergy} = \frac{m_{output} \cdot (\mathbf{b}_{output})^{\mathbf{T}}}{m_{input} \cdot (\mathbf{b}_{input})^{\mathbf{T}}} \tag{H.1}$$

Table H.1: Algorithm for Exergy Analysis

Algorithm for ICEC Analysis

- Step 1: Identify Material and Energy Inputs ($\mathbf{m}_{input,\delta}$) and Outputs ($\mathbf{m}_{output,\ \delta}$) where δ = environmental (e) or purchased (p)
- Step 2: Identify Standard Exergy Values ($\mathbf{b}_{input,\delta}$, $\mathbf{b}_{output,\delta}$)
- Step 3: Prices of Purchased inputs ($\mathbf{p}_{input,p}$)
- Step 4: Monetary Transaction $\boldsymbol{\mu}_{input,p} = \mathbf{m}_{input,p} \times \mathbf{p}_{input,p}$
- Step 5: Assign purchased inputs to Industry Sectors
- Step 6: Obtain ICEC/money ratios, $\xi_{ICEC/\$}$, from Thermodynamic Input-Output Analysis of 1992 or 1997 model of the US economy
- Step 7: Calculate ICDP according to Equation H.2

$$\eta_{ICDP} = \frac{\mathbf{m}_{output} \cdot (\mathbf{b}_{output})^{\mathbf{T}}}{(\mathbf{m}_{input,e} \cdot (\mathbf{b}_{input,e})^{\mathbf{T}}) + (\boldsymbol{\mu}_{input,p} \cdot (\boldsymbol{\xi}_{ICEC/\$})^{\mathbf{T}})} \tag{H.2}$$

Table H.2: Algorithm for ICEC Analysis

Algorithm for ECEC Analysis

- Step 1: Identify Material and Energy Inputs ($\mathbf{m}_{input,\delta}$) and Outputs ($\mathbf{m}_{output,\delta}$)
- Step 2: Identify Standard Exergy Values ($\mathbf{b}_{input,\delta}$, $\mathbf{b}_{output,\delta}$)
- Step 3: Prices of Purchased inputs ($\mathbf{p}_{input,p}$)
- Step 4: Monetary Transaction $\boldsymbol{\mu}_{input,p} = \mathbf{m}_{input,p} \times \mathbf{p}_{input,p}$
- Step 5: Assign purchased inputs to Industry Sectors
- Step 6: Obtain ECEC/money ratios for Individual Resources ($\boldsymbol{\xi}$) from Thermodynamic Input-Output Analysis of 1992 or 1997 model of the US economy. Let $\boldsymbol{\xi}^{x}_{ECEC/\$}$ be the vector of ECEC/money ratios, where x represents non-renewable (NR), renewable (REN) and human resources (HR) and impact of emissions (IMPACT).
- Step 7: Calculate ECEC Inputs of Non-renewable resources, Human Resources and Impact of emissions embodied in purchased inputs according to Equation H.3

$$\theta_{x,p} = \boldsymbol{\mu}_{input,p} \cdot (\boldsymbol{\xi}^{x}_{ECEC/\$})^{\mathbf{T}} \quad x = NR, HR, IMPACT, REN \tag{H.3}$$

- Step 8: Obtain transformity values for direct environmental resources ($\boldsymbol{\tau}^{x}_{input,e}$)
- Step 9: Calculate ECEC inputs of non-renewable resources, renewable resources, human resources and impact of emissions as per Equations H.4 and H.5.

$$\theta_{x,e} = \mathbf{m}^{x}_{input,e} \cdot (\boldsymbol{\tau}^{x}_{input,e})^{\mathbf{T}} \quad x = NR, HR, IMPACT \tag{H.4}$$

$$\theta_{REN,e} = \max_{k=1,\ldots,\mathrm{length}(\mathbf{m}^{REN}_{input,e})} [\mathbf{m}^{REN}_{input,e}(k) \cdot \boldsymbol{\tau}^{REN}_{input,e}(k)] \tag{H.5}$$

- Step 10: Calculate total ECEC requirements according to Equation H.6

$$\begin{aligned} \theta_{x,total} &= \theta_{x,e} + \theta_{x,p} \quad x = NR, HR, IMPACT \\ \theta_{REN,total} &= \max\{\theta_{REN,e}, \theta_{REN,p}\} \end{aligned} \tag{H.6}$$

Continued

Table H.3: Algorithm for ECEC Analysis

Table H.3 continued

- Step 11: Calculate ECDP according to Equation H.7

$$\eta_{\text{ECDP}} = \frac{\mathbf{m}_{\text{output}} \cdot (\mathbf{b}_{\text{output}})^{\mathbf{T}}}{\theta_{\text{NR,total}} + \theta_{\text{REN,total}} + \theta_{\text{HR,total}} + \theta_{\text{IMPACT,total}}} \tag{H.7}$$

- Step 12: Calculate Performance Metrics According to Equation H.8

$$YR = \frac{\sum_{\text{x}} (\theta_{\text{x,p}} + \theta_{\text{x,e}})}{\sum_{\text{x}} \theta_{\text{x,p}}}$$

$$ELR = \frac{\theta_{\text{NR,total}}}{\theta_{\text{REN,total}}} \tag{H.8}$$

$$SI = YR / ELR$$

APPENDIX I

MATLAB CODE FOR DETERMINING DIRECT, INDIRECT AND TOTAL ECEC THROUGHPUTS OF INDUSTRY SECTORS

```
% THIS FILE CONTAINS PSEUDO-CODE FOR CALCULATING DIRECT, INDIRECT AND TOTAL
% ECEC THROUGHPUTS OF NATURAL AND HUMAN RESOURCES AND IMPACT OF EMISSIONS ON
% HUMAN HEALTH FOR INDUSTRY SECTORS FROM THE CHOSEN ECONOMIC MODEL.

% STEP 1: DEFINE ECONOMIC NETWORK
n   %NUMBER OF INDUSTRY SECTORS; n = 488 FOR 1997 BENCHMARK MODEL, n = 91 FOR 1992
COMPACT MODEL
gmat=[n x n];    %TRANSACTION MATRIX (DIRECT REQUIREMENTS)FOR THE ECONOMIC NETWORK
econ=[n x 1];   %VECTOR OF ECONOMIC THROUGHPUTS

% STEP 2: DEFINE DIRECT INPUTS OF NATURAL AND HUMAN RESOURCES AND IMPACT OF
% EMISSIONS ON HUMAN HEALTH (DIRECT INPUTS VECTORS CAN REPRESENT ICEC OR
% ECEC OF NATURAL AND HUMAN RESOURCES). EACH VECTOR IS OF DIMENSION (n x 1)

LSD     % DIRECT INPUT VECTOR FOR LITHOSPHERE
BSD     % DIRECT INPUT VECTOR FOR BIOSPHERE
HSD     % DIRECT INPUT VECTOR FOR HYDROSPHERE
ASD     % DIRECT INPUT VECTOR FOR ATMOSPHERE
sld     % DIRECT INPUT VECTOR FOR SUNLIGHT
hydrod  % DIRECT INPUT VECTOR FOR HYDROPOTENTIAL
geod    % DIRECT INPUT VECTOR FOR GEOPOTENTIAL
windd   % DIRECT INPUT VECTOR FOR WIND PONTENTIAL
erod    % DIRECT INPUT VECTOR FOR FERTILE SOIL
hrd     % DIRECT INPUT VECTOR FOR HUMAN RESOURCES
ESO2d   % DIRECT INPUT VECTOR FOR IMPACT OF SO2 EMISSION ON HUMAN HEALTH
ENO2d   % DIRECT INPUT VECTOR FOR IMPACT OF NO2 EMISSION ON HUMAN HEALTH
EPM10d  % DIRECT INPUT VECTOR FOR IMPACT OF PM10 EMISSION ON HUMAN HEALTH
ECO2d   % DIRECT INPUT VECTOR FOR IMPACT OF CO2 EMISSION ON HUMAN HEALTH
EMETHd  % DIRECT INPUT VECTOR FOR IMPACT OF SO2 EMISSION ON HUMAN HEALTH
EAMMd   % DIRECT INPUT VECTOR FOR IMPACT OF METHANOL EMISSION ON HUMAN HEALTH
ETOLd   % DIRECT INPUT VECTOR FOR IMPACT OF TOLUENE EMISSION ON HUMAN HEALTH
ETCEd   % DIRECT INPUT VECTOR FOR IMPACT OF 1,1,1-TRICHLOROETHANE EMISSION ON HUMAN
HEALTH
ESTY-Ad % DIRECT INPUT VECTOR FOR IMPACT OF STYRENE EMISSION TO AIR ON HUMAN HEALTH
ESTY-Wd % DIRECT INPUT VECTOR FOR IMPACT OF STYRENE EMISSIONS TO WATER ON HUMAN HEALTH
ESTY-Sd % DIRECT INPUT VECTOR FOR IMPACT OF STYRENE EMISSION TO SOIL ON HUMAN HEALTH

matresdir=[LSD BSD HSD ASD sld hydrod geod windd erod hrd ESO2d ENO2d EPM10d ECO2d EMETHd
EAMMd ETOLd ETCEd ESTY-Ad ESTY-Wd ESTY-Sd];

% STEP 3: CALCULATE TOTAL AND INDIRECT THROUGHPUTS

matr=inv(eye(n)-gmat'); % CALCULATE TOTAL REQUIREMENTS MATRIX, FOR DETAILS REFER TO
SECTION 2.1

for i=1:21
    matrestot(:,i)=matr*matresdir(:,i);
    matresind(:,i)=matrestot(:,i)-matresdir(:,i);
    matsuper((3*i-2),:)=matresdir(:,i)';
    matsuper(3*i-1,:)=matresind(:,i)';
    matsuper(3*i,:)=matrestot(:,i)';
```

```
end

% STEP 4: WRITE OUTPUT TO EXCEL FILE thesis_code.xls

fid=fopen('thesis_code.xls','w');
fprintf(fid,'%12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t
%12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t
%12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t
%12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t
%12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t
%12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\t
%12.8f\t %12.8f\t %12.8f\t %12.8f\t %12.8f\n',matsuper);
fclose(fid);

% thesis_code.xls CONTAINS ALL THE REQUIRED RESULTS. THESE RESULTS CAN BE
% MANIPULATED TO GIVE TOTAL ECEC REQUIREMENTS AND ECEC/MONEY RATIOS OF
% INDIVIDUAL INDUSTRY SECTORS. IMPLICATIONS OF THESE RATIOS HAVE BEEN
% DISCUSSED IN CHAPTERS 4 AND 5, AND THEIR APPLICATIONS FOR MICRO- AND
% MACRO-SCALE DECISION MAKING HAVE BEEN DISCUSSED IN CHAPTER 6. SIMILAR
% CODE CAN ALSO BE WRITTEN FOR ICEC CALCULATIONS WITH matresdir CONTAINING
% DIRECT INPUTS VECTORS IN ICEC TERMS.

% STEP 5: CALCULATE TOTAL ECEC REQUIREMENTS FOR NON-RENEWABLE RESOURCES,
% RENEWABLE RESOURCES, HUMAN RESOURCES AND IMPACT OF EMISSIONS ON HUMAN
% HEALTH

nonren=matrestot(:,1)+matrestot(:,2); % LITHOSPHERE & BIOSPHERE

for i=1:n

ren(i)=max(matrestot(i,3)+matrestot(i,4)+matrestot(i,5)+matrestot(i,6)+matrestot(i,7)+mat
restot(i,8)+matrestot(i,9));
end

% DUE TO ALLOCATION RULES IN ECEC ANALYSIS RENEWABLE RESOURCES ARE NOT
% ADDED TO AVOID DOUBLE COUNTING, RATHER A MAXIMUM IS TAKEN ALONG EACH
% BRANCH OF THE NETWORK

hr=matrestot(:,10);

impact=zeros(n,1);
for i=11:21
    impact=impact+matrestot(:,i);
end

totECEC=nonren+ren+hr+impact; % CALCULATE TOTAL ECEC REQUIREMENT

% STEP 6: CALCULATE ECEC/$ RATIO

for i=1:n
    ECEC2mon(i)=totECEC(i)/econ(i);
end

% SIMILAR CALCULATIONS CAN BE DONE FOR ICEC AS WELL. THE DIFFERENCE WOULD
% BE IN CALCULATING TOTAL RENEWABLE INPUTS. UNLIKE ECEC CALCULATIONS, ICEC
% CALCULATIONS DON'T NEED TO TAKE A MAXIMUM AMONGST INDIVIDUAL RENEWABLE
% RESOURCES. FOR FURTHER DETAILS REFER TO SECTION 2.5 OF THIS DISSERTATION.
```

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