THE ECONOMIC IMPACTS OF GREEN PRODUCT DEVELOPMENT

By

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ABSTRACT

Due to many recent events, environment protection has become a pressing global problem. Since pollution is an economic externality, strict laws and regulations have been imposed to penalize polluters. Traditionally, companies in the United States have used the "end-of-pipe" technologies to assess the compliance of the environmental regulations. However, in recent years, the development of greener products has become a more effective way to ensure environmental responsibilities.

Green product development involves the entire process of production and not merely on the product itself. There are various strategies in developing greener products; thus the estimation of the product's greenness is necessary to evaluate the effectiveness of the various strategies. This is best accomplished by the Life Cycle Cost Benefit Analysis.

The Life Cycle Costs Benefits Analysis can be enhanced by the use of knowledge based decision support system, since it requires a large quantity of data and modeling. The decision support system can facilitate the analysis and assist companies that lack either the resources or the expertise in environmental analysis.

Thesis Supervisor: Duvvuru Sriram
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Chapter 1 Introduction

Many recent events have contributed to the need for the development of "greener products." Most of these events are spurred by increasing public awareness of the relationship between pollution and diseases. These events include stricter environmental laws and regulations, pressures from the consumers and environmental groups, lack of environmental insurance, company's own sense of responsibilities, and to maintain a competitive edge over the competitors, and the opportunities to profit from the environmental movements.

This chapter explains the motivation behind the development of "greener products." Furthermore, this chapter specifies the objectives and the organization of the thesis.

1.1 Motivation Behind the Development of "Greener Products"

1.1.1 The Concern Over the Environment

Since the late 1960s, studies concerning the effects of the environment on human health have proliferated. These studies have shown that chronic and degenerative diseases, which have become the leading causes of death in the developed nations, are aggravated by air and water pollution. In addition, the presence of toxic substances in the environment has complicated cardiac and respiratory problems. These studies have also demonstrated the negative health effects to radiation and noise. This substantial gain in medical knowledge has spurred the public's concern to protect the environment.

1.1.2 Laws and Regulations

Pollution is an economic externality, i.e., without government intervention, businesses are not required to bear the costs of polluting the environment. Since factories producing pollution have little incentive to create "environmental-friendly" methods of production, the implementation of laws and regulations is necessary to discourage polluters.

The mounting public concerns for the environment have pressured the U.S. government to empower organizations to protect human health and the environment and to further study the effects of pollutants on human health and the ecology. These organizations, along with state and local agencies, have been imposing increasingly stricter limits on the types and the amounts of substances that a business is allowed to emit without being penalized.

The most important agency set up by the U.S. government is the Environmental Protection Agency (EPA). Established in 1970, the EPA has ten regional offices to monitor environmental quality and to control pollution caused by solid wastes, pesticides, toxic substances in air and water, hazardous wastes, and toxic chemicals.

The number of laws passed by the federal government has increased many folds in the recent period (see Figure 1). Clean Water and Clean Air Acts attempt to curb air and water pollution by issuing permits only to those businesses that meet the set standards and to provide the use of the best available control technology (BACT) in controlling harmful emissions. Comprehensible Environmental Response Compensation and Liability Act (CERCLA), also known as Superfund, was enacted in

1980. It requires companies that dumped hazardous wastes in the past be responsible for cleaning up these wastes, even when these dumpings were legal at the time [Felsenthal, 1993]. CERCLA forces companies to realize that what is legal presently may not be legal in the future; therefore, it may sometimes be less costly in the long run to control emission beyond what regulations require. Another implication of CERCLA is the cradle to grave approach for toxic wastes. Companies are responsible for the toxic wastes from the creation of the wastes to the disposal. The responsibility continues even after another firm (such as a waste management firm) has been paid to dump the wastes [Felsenthal, 1993]. Other regulations include disclosure of pollutants to the Security Exchange Commission and the general public. These regulations coupled with banks' responsibility to clean up polluted sites in case of a foreclosure severely influence the capital firms are able to attract for future investments [Bloom, et al., 1991]. Other state legislatures require companies to use at least certain percentages of recycled materials in their products.

In order to make environmental quality a factor in federal project planning, the EPA requires all U.S. government agencies to issue an environmental impact statement on any project it plans to undertake. An environmental impact statement is a report on the environmental effects of proposed projects that may significantly affect the environment. The Endangered Species Act, designed to protect nearly extinct animals and plants, has been used to block several federal projects. Recently, environmental groups have threaten to use the Endangered Species Act to influence the logging in the Northwest United States to protect the Spotted Owls. [Reinhardt, 1991, p1-p3] Another important implication of the regulation is the recent trend toward more severe measures of punishment for environmental violations. An individual knowingly violates or authorizes the violation of the environmental laws can be subject to criminal prosecution.

The U.S. Government attempted to internalize the effects of pollution by making the polluters pay for the cost of polluting. EPA recently sponsored an auction of pollution permits in a market approach to cleaner air. The participants include utility companies who are heavy polluters and environmentalists.

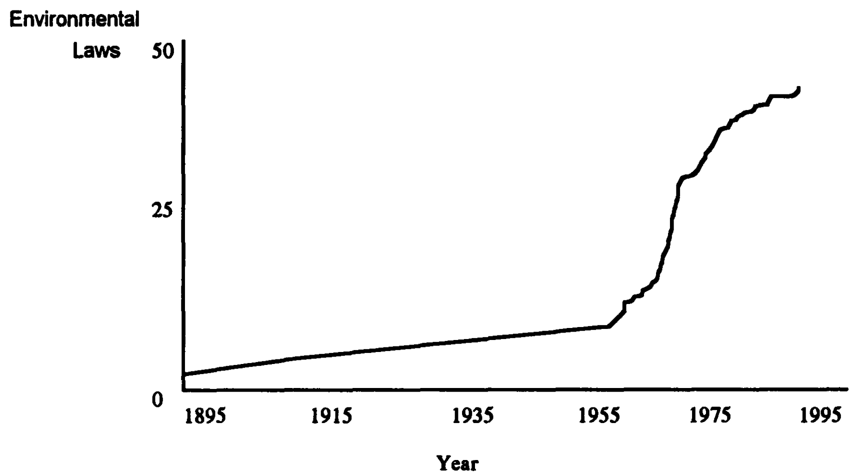

Figure 1 The number of federal environmental laws passed each year

Source: J. Ausubel and H. Sladovich, Technology and Environment, National Academy of Engineering, 1989

Global concerns have also induced the passing of many international laws aiming to protect against global environmental disasters, which include ozone depletion, global warming, and biological diversity. For instance, Montreal Protocol, an international treaty, is aimed to decrease the rate of ozone layer depletion by limiting the use of chloroflorocarbons as refrigerants and aerosol-can propellants by participating countries. Many of these international laws are the result of worries by the developed countries over the industrialization of the developing countries at the expense of the environment. Thus, funds are being transferred from the developed countries to help the developing countries with improving their environmental technology.[1]

1.1.3 Pressure from the Environmental Groups

Pressure from environmental groups, such as Green Peace, is another force that drives firms to develop "greener products." The environmental groups not only push for tougher regulations and controls on pollutants through lobbying, but they also threaten the companies which manufacture environmentally unsafe products with large law-suits. Under the U.S. environmental laws, any citizen may sue a company administrator who fails to abide by the environmental laws.

Some environmental groups take direct and confrontational actions to influence public decisions. Other environmental groups, such as Not In My Back Yard (NIMBY), have effectively pushed up the cost of waste disposal by restricting the number of solid waste disposal sites. These groups have a direct educational effect on the consumers, i.e., they make consumers more environmentally conscious. In recent years, these groups have become globally involved and have forced companies with lenient environmental policies in less stringent countries to reconsider their environmental strategies.

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[1] The knowledge about transferring of funds was adapted from a graduate course titled " Environmental Management", taught at the MIT Sloan School by Henry D. Jacobs.

1.1.4 Pressure from Consumers

Increase media coverage of environmental issues have contributed to the public's concern for a healthy environment. Companies accused by the environmental groups suffer not only by the lawsuits but also by the damage to their public image. Oftentimes, the public boycotts not just the product in question but all the products that the firm makes. McDonalds Restaurants recently replaced their styrofoam food containers with paper containers to prevent possible boycotting by consumers [Livesey, 1990]. Exxon's image suffered tremendously when the company's ship Valdez ran ashore in Alaska. Many consumers boycotted all Exxon products. Consumers' awareness of environmental issues has forced many companies to reevaluate their responsibility to their environment. Environmental groups use "green labels" as a method of disapproving products. Products not labeled green are in risk of being boycotted by consumers [OECD, 1991, pp.12-14]. An example of green labeling is the dolphin-safe label on tuna products.

1.1.5 The Insurance Crisis

During the 1980's, due to the losses suffered for the payment of cleanup fees, most insurance companies withdrew from the environmental liability market, making companies liable responsible for their own products [Baram, 1992]. Without insurance coverage, many companies must make greater efforts to be environmentally responsible so to protect themselves against future environmental liabilities, or they will suffer tremendous financial consequences.

1.1.6 Sense of Responsibility

Governmental regulations and pressures from environmental and consumer groups are not the only reasons that a company may want to "go green." A sense of responsibility to the environment also compels companies to "turn green." More American businesses now accept the challenge of environmentalism. They aim to achieve a balance between economic growth and a sound environment. Responsible Care, a program set up by the chemical industry, is established by the larger chemical companies, such as Du Pont and Dow Chemical, who feel a responsibility to the environment [Simmon, et al., 1991].

1.1.7 Profit from Environmental Movements

Environmental consciousness can sometimes save money for companies. Some companies find ways to develop products that minimize waste production. With increasing cost in waste disposal, the saving can be immense. Other companies find ways to recycle their waste. A Du Pont plant recently saved millions of dollars in disposal costs by selling their waste to a recycling company [Buchholz, et al., 1992]. Xerox decreased packaging costs by improving their environmentally sound packaging ($2 million yearly savings), and by reusing pallets and other packaging supplies ($15 million yearly saving) [Smart, 1992]. In the mean time, other companies are developing products that minimize material usage, thus reducing material cost and disposal costs.

1.1.8 Maintaining Competitive Advantage

Because of legislatures like Consumers' Right to Know More, companies that use certain chemicals in their manufacturing process are required to keep and report their inventory. In addition to the enormous expense of keeping records of inventory records, many of the companies' trade secrets are revealed. Competitors can use these data to their advantage. This is especially true in the chemical industry. "Reverse Engineering" can often be done to determine the formulas of products [Sheridan, 1992]. Companies that do not use or use very little of these chemicals are in an advantageous position because they are not required to report their use of such chemicals.

Furthermore, companies that barely comply to the environmental regulations find themselves having to redesign their products or process periodically to keep up with the stricter regulations that are passed each year. Companies that are ahead of the regulations will not need to worry about violating regulations. These companies will have advantages over companies that are behind in environmental protection.

1.2 The Objectives of the Thesis

This research intends to develop a model that measures the costs and the benefits of products. Most of the researches in this field have focused on project by project cases [Quinby-Hunt, et al., 1986]. Only government agencies or large firms have the resources available to perform such studies. There is a need for developing a model that utilizes a "cook-book" type approach.

There are three objectives that this thesis tries to achieve. The first objective is to develop an inexpensive model that performs relatively quick environmental assessment. The second objective is to make the model flexible to a product, that is even if the product changes attributes. Third, the model one should be able to be utilized in assessing various products.

1.3 Organization of the Thesis

Chapter Two of this thesis describes the definition and the concept of "green products." It includes current efforts in "green product" development, and micro-economic framework of environmental concerns. Chapter Three illustrates the life cycle benefit cost models in assessment of a product. It includes measuring the social costs and benefits of a product, the discounting factors in assessing cash flows that occurred in different periods of time, and the application of the decision support system framework. Chapter Four is a case study, which compares the environmental soundness of two diaper systems. Finally, Chapter Five discusses the advantages and disadvantages of the model and summarizes this thesis.

Chapter 2 Background of Green Product Development

2.1 Introduction

This chapter is divided into three parts. First, a formal definition of "green products" will be presented. Second, micro-economic frameworks will be used to argue for the importance of measuring the "greenness" of products. Finally, current efforts and strategies in developing "greener products" will be summarized.

2.2 Definition of Green Products

Businesses and environmentalists often have different definitions of "greenness." Most companies think that "greenness" refers to minimization of waste level within a company. Environmentalists, on the other hand, believe "greenness" is sustainability, which is defined by the WCED (1987) as development that meets the needs of the present without compromising the ability of future generations to meet their own needs [Gardner, 1989]. Besides for minimization of waste, sustainability also includes maintaining bio-diversity, minimizing use of depletable resources, and preservation of natural resources.

A common goal must be realized by both the industries and the environmentalists. Industries must realize that minimization of wastes does not necessarily make a company "green." "Greenness" relates to all the processes of a product from manufacturing to disposal. On the other hand environmentalists must understand that there are tradeoffs between economic growth and the environment. Certainly, stopping all business activities will minimize all kinds of pollution; however, this does not provide future generations with better living standards. Furthermore, many specialized environmental groups are often only concern with their own causes, thus creating conflicts between the various groups. To achieve a healthy environment, these groups must realize that the environment encompasses all elements.

"Green product" development should focus on the entire production process and not just on the products itself. There are numerous ways to achieve "green product" development. All the market externalities of the product must be considered. These market externalities include both costs, such as environmental damages, and benefits such as job creations. The assessment of these market externalities will be discussed in the next chapter.

2.3. Micro-economic Frameworks of Green Products

2.3.1 The Supply and Demand of Goods (Including Environmental Considerations)

Assume a firm is in a competitive market (horizontal demand curve) with supply and demand curves as shown in Figure 2.1. Without internalizing the cost of environmental impacts, the firm sells its product at price P* and quantity Q*. Assume the total cost in manufacturing Q quantity of product is C, then the profit of the firm is P*Q* - C. A firm using such a strategy is not maximizing its profit because it underestimates the costs of the products. The costs of the products should also include future liabilities for clean ups. The firm would therefore sell more products than it should. Instead, the firm should be supplying at Supply' (see Figure 2.2). The firm will supply lower quantity of the product. The same conclusion can be derived from the firm's marginal cost curve (see Figure 2.3). The firm should be selling at the quantity where its marginal cost equals to its marginal revenue. Without internalizing environmental costs, the firm's marginal cost curve is lower than the actual marginal cost; therefore, the firm would have over-sold the products. The same analysis can be shown when a firm operates under a non-competitive market. In this case, the firm would have under-priced and over-sold the product.

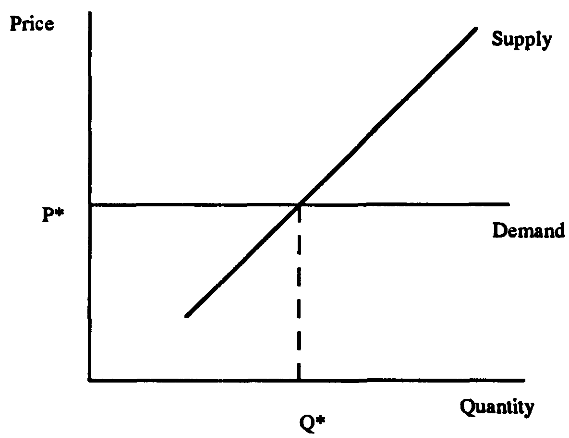

Figure 2.1 The Supply and Demand of a Product in a Competitive Market

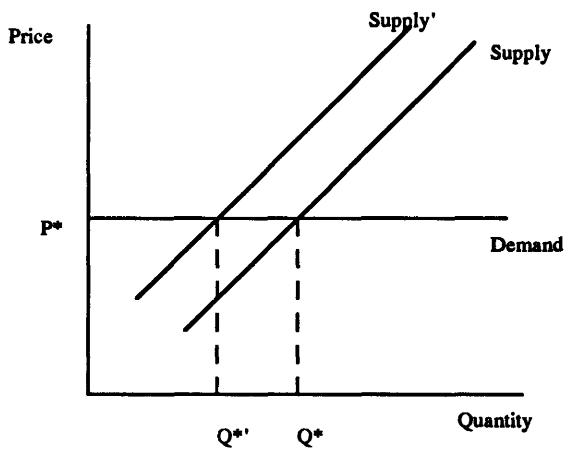

Figure 2.2 Firm's Supply and Demand Curves When Environmental Concerns Are Included.

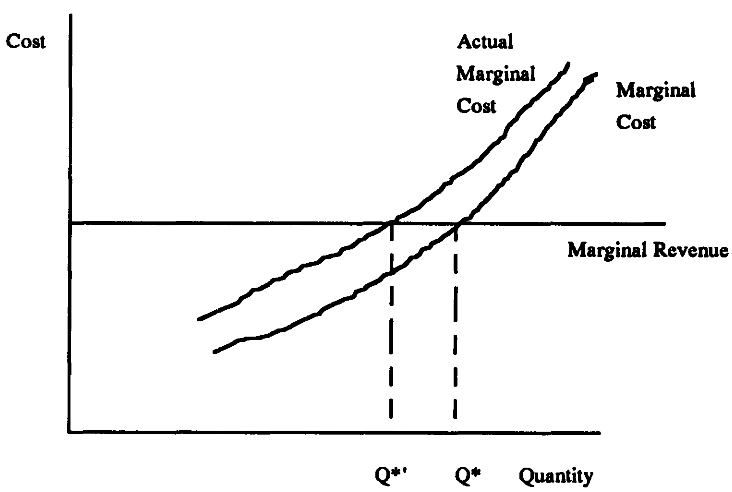

Figure 2.3 Marginal Cost and Marginal Revenue in a Competitive Market (Actual Marginal Cost Includes Environmental Consequences)

Since the future liabilities are unknown, the firm must estimate these liabilities by finding the true marginal cost (marginal social cost) of the product. In the next chapter, an attempt to assess the marginal social cost will be presented.

Consumers usually are willing to pay a premium for a "greener" product. The premium depends on many factors. These factors will be described in the next chapter.

2.3.2 The Marginal Benefits and Marginal Costs of Greening of Goods

To maximize profit, the marginal benefit of "greening" a product must be equal to the marginal cost (see Figure 2.4). The marginal benefit is defined as the benefit derive from an additional unit of "greenness" of the product. The marginal cost, on the other hand, is the additional cost incurred in achieving an additional unit of "greenness." The marginal cost curve is upward sloping because the cost increase more rapidly as "greenness" increases. The marginal benefit curve is downward because the benefit achieved by "greenness" (the premium pay by consumers) decreases when the product is increasingly "green."

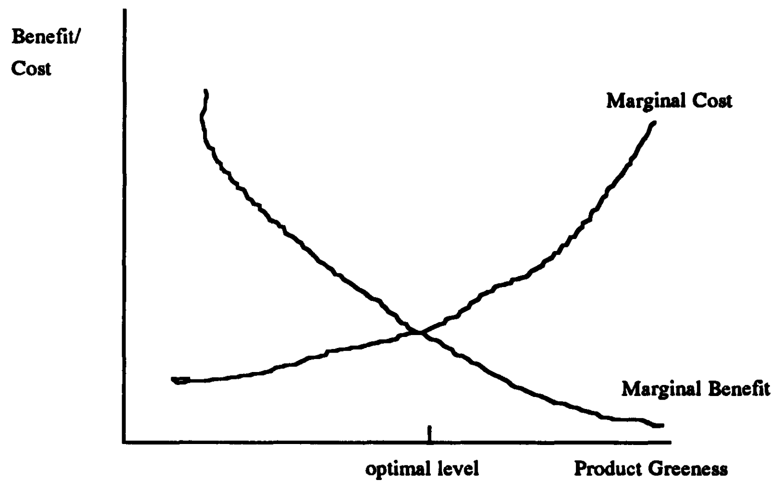

Figure 2.4 Marginal Benefit and Marginal Cost Curves for Level of Product Greenness

2.4 Strategies in Product Development for Environmental Concerns

2.4.1 Introduction

Traditionally, the method employed to control environmental pollution is the so called "end of pipe" technology. The regulations often require the best available technology to control the emission at the output level. Often a device, such as an air scrubber or a taller smoke stack, is installed to achieve a satisfactory level of emission.

The reduction cost with the end of pipe method is very high, and it often involves transforming from one form of pollution into another. For example, the scrubber limits the pollution in air but creates sludge that is released in water or in solid waste dump sites. Taller smoke stacks lower the concentration of human exposure to pollutants, but they do not reduce pollution, and have caused an increase in acid rain.

The cost of removing an additional percentage of a pollutant increases rapidly as a greater percentage of the pollutant is removed. Use of such technologies is justified only under the following two scenarios: first, in an old plant that does not meet the recently adopted stricter emission requirements, and it is too expensive to replace the old machines; second, in a product that meets the emission standards in most regions but not in a region that has tougher requirements. Installation of the device for selling in the region may be justified if redesigning the product costs too much, e.g., the catalytic converter used in automobiles in regions of stricter regulations.

The most effective way to achieve environmental protection is the inclusion of environmental policies during product development. This involves developing products that results in the best combination of material usage, choice of material, waste emission, and cost effectiveness without compromising the quality of the product [Navin-Chandra, 1993]. Europe is ahead of the U.S. in the incorporation of environmental policies in the product development phase. Design for disassembly (DFD), an idea started in Europe, involves simplifying parts and materials to make them easy and inexpensive to be disassembled, sorted and recycled. German legislation recently required German car makers to take their cars back to be recycled [Nassbaum, 1990]. Car makers, such as BMW and Opel, have developed cars that can be easily recycled. These cars have characteristics of ease of disassembly, ease of sorting and the use for recycled thermo-plastics [Smock, 1992].

2.4.2 Green Development Strategies

Many people consider recycling as the only mean to achieve "greenness," but recycling is only one of the techniques. There are many other alternatives to recycling. Especially when the costs of collecting and sorting materials are expensive (see Table

2.1) compared to their market values, all other alternatives must be considered. These alternatives include end of pipe technologies described earlier, making the products more durable, minimizing energy usage, energy alternatives, minimizing materials usage, use of more replenishable materials, and use of biodegradable materials. However, one must keep in mind the economy of any strategy. It is not a good strategy if the cost prevents the product from being commercialized.

Material	Cost to Collect and Sort ($ / ton)	Market Value
Paper	$75-$125	$30
Aluminum	$500-$1,000	$750
Plastic	$750-$1,500	$80
Steel	$250-$300	$60
Glass	$125-$175	$18

Table 2.1 The cost of recycling compare with the market value

Source: Waste Management Inc., Prodigy Interactive Service, Mar. 7, 1993.

2.4.3 Recycling

Although the costs of collecting and sorting recycled materials are expensive, some recycling is required by legislatures. In addition, as better recycle techniques are developed and the costs of virgin materials increase, it will be worthwhile to consider recycling. Also, a growing number of consumers are willing to pay a premium for recycled products. As one can see from Table 2.1, aluminum has the most potential to be considered for recycling, because the cost of collecting and sorting is the closest to the market value; plastic has the least potential.

Recycling can be done with two methods: reuse and remanufacture. Examples of reuse products include refillable bottles, upgradable computers, as well as auto parts from auto junk yards. Reuse product is more efficient because there is no need to remelt and to reshape the product. Old products are collected, cleaned, and refilled. For example, Hewlett Packard recently began collecting their old printer cartridges to be refilled. This method also has the advantage of allowing products to be made with more kinds of material without having to consider if the material can be melted and remolded. There are also disadvantages. Transportation cost often precludes bottles from being reused. For example, the bulkiness of bottles makes it cheaper to compact the bottle and remanufacture it. In addition, not all products can be reused. Newspaper, for example, cannot be reused. Remanufacturing is the second and more common method of recycling. Products are disassembled, sorted, and remanufactured into new products. Examples are recycled paper, recycled plastic, etc.

Products that are designed to be recycled must be able to be disassembled easily and inexpensively. There must be a well-developed recycle infrastructure to collect the used products. State sponsored collections of bottles are more successful because of the well developed recycle infrastructures.

Design for Disassembly (DFD) can be used to facilitate recycling. By making products easily disassembled, consumers can sort the parts by the types of materials which makes recycling easier. Increasingly, consumer products are made with snap-on parts. This design not only makes disassembly easier, but it also saves material. In addition, there is no need to clean the glue off the material. Making products with uniform material is another way to make the recycling process easier. Products that are made of uniform material and are freed of glue will not have to be disassembled before recycling.

In addition to meeting the mandated recycling bill, an assessment must be made to exam whether additional recycling is needed. The net cost of recycling is the difference between the market value of the material and the cost of collecting, sorting, and remanufacturing. The benefits are the sum of the premium that consumers are willing to pay for the recycled product and the improvement to the company's public image that would enable it to increase sale of its other products.

2.4.4 End of Pipe Technologies

End-of-pipe method is comparatively more expensive than other methods; thus, when possible, it should be avoided. However, it is sometimes necessary to adopt such strategies because of the mandated legislature or lack of other methods. As described earlier, it is sometimes too expensive to redesign a product to fit a region with stricter environmental laws, and it may be too expensive to replace old machinery that does not meet the current requirements. In these cases, end-of-pipe technology is appropriate.

Sometimes, it is necessary to install additional treatments for wastewater to meet the federal or state regulations. Wastewater treatments include screening for larger particles and settling out suspended material in tank. Additional treatment uses bacteria to break down organic matter, and, if necessary, the wastewater is chlorinated to kill microorganisms. The sludge (the leftovers) is reduced in volume by dewatering or by incineration and is disposed of in land fills. Other more effective, but also more costly, methods of treatment can be used to treat wastewater to a level that meets drinking water standards. Air pollution treatment methods include wet scrubber, precipitator, and cyclone separator to remove particles in air.[2]

An interesting but controversial treatment process is the incineration of solid waste. Local concerns over air pollution and the disposal of incinerated ash have made it very difficult to site such facilities [Siskind, et al., 1990].

2.4.5 Improve the Durability of a Product

The durability of a product has major impacts on the environment. When a product is built to last longer, there is less need for replacement; hence, less emission is produced and less waste results. Furthermore, the cost of disposal is delayed until later.

Repairability is an important factor in the durability of a product, and hence the product's environmental soundness. Because of high labor cost, many of our consumer products are made to be replaced rather than repaired. With increasing environmental concerns, focus should shift back to making products that are easy and inexpensive to be repaired.

Making a product repairable at home is one way to extent the product's life. Another way is to make products with standardized parts. Making products with

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[2]The knowledge on the treatments are adapted from an undergraduate course titled "Introduction to Environmental Engineering" taught by Professor Williamson in the Department of Civil Engineering at U.C. Berkeley.

standardized parts not only minimize parts inventory, but also make repairs easier and less time consuming.

Oftentimes, products may be durable, but technological obsolescence precludes products from being used for a prolong period of time. Upgradablility lengthen the useful life of a product that may be obsolete otherwise.

2.4.6 Total Quality Management

Total Quality Management (TQM) can also be applied to the environmental context. Many of the TQM methods, such as the Just in Time (JIT) method, minimize storage of inventory and finished products. Materials are delivered right before they are needed to be processed. This minimizes storage sites required as well as the possibility of a disastrous event especially in dealing with the storage of chemicals and other hazardous materials. Making products defects-free increases the durability of the products, and saves disposal space.

2.4.7 Energy Alternative

Selecting the type of energy for manufacturing and transporting raw materials and products is an important decision. Some alternatives to utilizing petroleum and coal as fuel should be considered since the pollution from such fuels greatly contributes to the urban smog problem. The energy alternatives include methane, natural gas, water power, nuclear, solar, and wind; however, these alternatives all have their own advantages and disadvantages.

2.4.8 Material Usage

Selection of materials is very important in achieving environmental soundness of a product. Product developer must consider both the functional aspects and the environmental aspects of a material. There are tradeoffs between these two aspects in selecting materials. There are also tradeoffs between different environmental aspects. For example, in the case of paper verses styrofoam, paper has the advantage of being biodegradability, and the raw material for paper, or trees, are replenishable. However, the continual cutting of trees has resulted in an increase in green-house gases. These tradeoffs are sometimes hard to determine. For example, in 1990, McDonalds used one study that showed use of Styrofoam food containers is more environmental friendly than the use paper containers, while other studies have shown that paper is better [Livesey, 1990].

Because our landfill wastes consist mostly of consumer packages, EPA has mandated the requirements to reduce packaging. Many consumer product manufacturers have switched to less packaging. For example, detergent manufactures have now made their product more concentrated, hence, reducing packaging requirements. Making products more compact not only saves package, but it also requires less storage space and makes the transportation of products easier.

Materials that are environmental friendly should emit little pollutants during extraction and production. Recyclability is another important aspect of a material. When a material can be easily recycled, the solid wastes it generates will be significantly less. In addition, extraction of virgin material, which generates more pollution, will be unnecessary.

2.4.9 Environmental Claims

Environmental claim is an important strategy for companies. The public's awareness today prevents any company from making false claims. Companies should invite all the relevant and established environmental groups to test their products for the environmental claims. Having the seal of approval, such as "ozone safe", can improve the marketability of a product [OECD, 1990].

In product development, a firm must consider the criteria used for environmental labeling by the environmental groups. Working closely with environmental groups is one way to assure that the criteria imposed by the environmental groups are used in designing products.

Chapter 3 Social Costs Benefits Model for Green Development

3.1 Introduction

This chapter presents the life cycle social cost benefit model, which is used to assess the social value of a product. This chapter is divided into four parts: the social costs of a product, the social benefits of a product, the discount rate used to calculate present values, and the implementation of a decision support system.

3.2 The Social Costs of a Product

In the traditional business context, environmental concerns are rarely issues for a company. Before the 1960's, when environmental costs are external to market prices, and hence the profitability of a product, the traditional approach made sense. However, the business enterprises are now required to pay for the social costs either present or in the future. It is best to measure and minimize these costs now.

In assessing the best combination of the strategies to achieve "greenness," we must have a common way to assess the cost. For example, how do we compare the environmental soundness of a product that is 100% recyclable to a product that is made of 100% recycled material? The assessment of a product's social value is best done by "life cycle" costs-benefits analysis. The life-cycle of a product is depicted in Figure 3.1. Life cycle of a product consists of virgin material extraction, re-manufacturing material, re-used material, manufacturing, useful life and disposal. Greening of a product consists of making greater use of remanufactured or reused material, making longer useful life, making product recyclable and therefore decreasing the amount of disposal at the end of the useful life. The social costs-benefits analysis takes all these aspects into account.

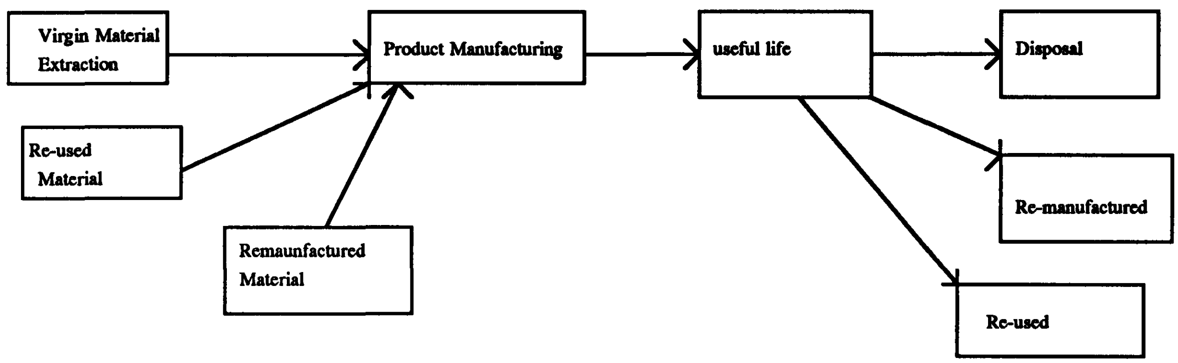


Figure 3.1 The Life Cycle of a Product

Life cycle analysis takes into consideration the types and the amounts of pollutants emitted during the manufacturing process, mineral extraction, energy creation, useful life, and the disposal of the product. It also considers the types of mineral needed, the possibility of a disastrous event during life, and the geographical characteristics. In addition, life cycle analysis considers the benefits a company can gain from being labeled green. These benefits include direct benefits of the product being label green as well as the "spill-over" effects to the other products of the company as the company is being labeled green. Each of these attributes will be explained in detail in this chapter.

3.2.2 the Damages by pollution

3.2.2.1 Types, Potency and Amount of Pollutants Emitted

The first step in assessing a product is to identify the types of pollutants emitted during the life of the product. The pollutants include emissions during the manufacturing process, raw material extraction, energy creation, as well as during the useful life and disposal. Emissions during material recycling process should also be included, if recycled materials are used.

Both chemical and thermal pollution should be included. Discharge of heated water into waterway can cause ecological imbalance by decreasing the ability of water to hold dissolved oxygen, thereby effecting aquatic life. Noise produced during the life cycle of the product should also be included.

Each kind of pollutant is then assigned a "potency" factor (in $ per amount of pollutant) based on the damaging effects of such pollutant to the environment. This includes effects, both short term and long term, on human health, animal and plants, aesthetic, social economic, land, and property.

3.2.2.2 Human Health Effects

The human effects take into consideration premature death, human suffering, health-care costs, and lost time. Many environmental impact studies seem to concentrate only on carcinogenic effects of a pollutant. Other diseases that are linked to pollution, such as reproductive effects and neurological effects, are largely ignored [Sibergeld, 1990]. In deriving the potency factor, one should consider all possible health effects. The World Bank's checklist of environmental health factors is helpful in estimating the potency factor (see Figure 3.2).

Figure 3.2 Checklist of Environmental Health Factors

Effects on inhabitants
Communicable disease
Housing and sanitary facilities
Dietary Changes
Effects on ground water
Changes in ecological balance
Changes in agriculture
Change in risk of road accident

Effects on workers
Work accident
Exposure to chemical and physical hazards
Exposure to local disease
Nutritional status of worker

Indirect effect:
Introduction of new disease vectors
New infection or re-infection of existing vectors
Increase propagation and spread of existing vectors

Source: World Bank

3.2.2.3 Animals and Plants Effects

Effects of a pollutant to the animal and plant population should also be included. These effects include direct effects such as decline in animal and plant population due to construction of facilities. It should also include the secondary effects such as disruption of the food chains for other animals. The pollution that damages animals and plants can often transfer to humans. For example, pollution causes high level of toxins accumulating in the tissue of many species of the fishes. Eating these species of fish will transfer the toxins to human. In addition, lose to agriculture and domestic animals should be considered.

3.2.2.4 Aesthetic Effects

Loses in landscapes aesthetics due to the construction of factories or other facilities should also be included. The effects include the loss in tourism, local residents' view, etc. Moreover, the decrease in visibility caused by urban smog and other pollution may contribute to an increase in auto accidents.

3.2.2.5 Social Effects

The pollution and the unsightly views of factories may induce people to move out of the area. The cost and inconvenience in moving should also be taken into consideration.

3.2.2.6 Land and Property Effects

The pollutants may and are likely to deteriorate local buildings and properties, making their values decline. The decrease in value of the properties caused by the pollutant must also be included.

3.2.2.7 Longer Term Effects

The factors should also include the contributions to long term effects such as global warming and breaking of ozone layer. These effects are the most difficult to estimate.

3.2.3 Elements that influence the potency factor

3.2.3.1 Population, Terrain, Weather and Location

The potency factor varies in different geographical regions as the damages are different. The factor is influenced by the population within the vicinity of emission, the terrain (possibility of trapping the pollutants in a basin, the possibility of soil erosion and the contamination of ground water), the weather (wind, temperature, humidity that either transport the pollutant or facilitates the chemical reactions by the pollutant) and the availability and the proximity of solid waste disposal sites. Other contributions to the potency factor include the concentration of the pollutant already in the environment, and the concentration of its chemical reagents.

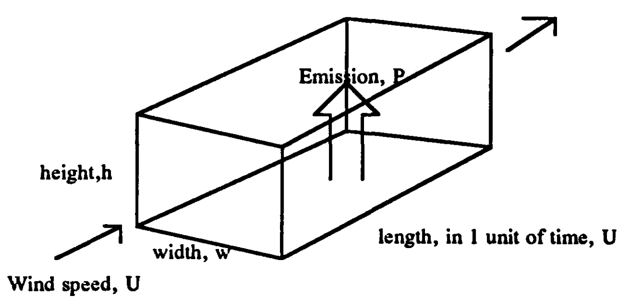
3.2.3.2 Methods of Emission

The potency factor is also influenced by the way the pollutants are emitted. Same pollutants may have different damaging effects depending on the methods of emission. Emission from a higher smoke stack may decrease the effects of the pollutants.

3.2.4 Modeling and Auditing

Models are used to estimate the potency factor. The models should encompass all environmental factors. These models include air pollution models, such as the box models (see Figure 3.3), roll back models, static models, Gaussian plume models (see figure 3.4), etc. [Ortolano, 1984]; water pollution models (for estimating water pollution); solid waste models (to estimate leaching of toxic waste into surrounding environments such as ground water); noise models; social economic models (to estimate social issue such as jobs, and economic condition); and cost models (in relating impacts to costs).

Figure 3.4 Box Models for Air Pollution



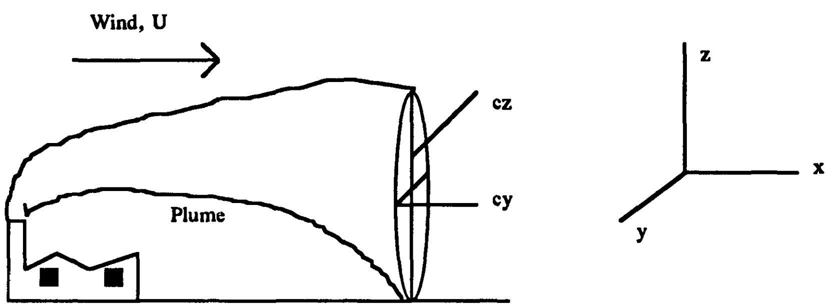
$$\frac{\text{Volume of air}}{\text{time}} = h(L).w(L).U(L/T)$$

$$\frac{\text{mass of residuals}}{\text{time}} = P(M/T)$$

$$c = \frac{P}{Uhw}$$, c is the average concentration under steady-state condition

Source: Ortolano, Leonard, Environmental Planning and Decision Making, John Wiley and Sons, Inc., 1984

Figure 9: Gaussian Plume Models (Point Source)



$$c(x,y) = \frac{Q}{\Pi cycz} \exp(-\frac{y^2}{2cy^2} - \frac{h^2}{2cz^2})$$

Q = constant emission rate (μg/sec)
U = constant wind speed (m/sec)
h = effective emission height of the stack (m)
cy= horizontal dispersion coefficient
cz = vertical dispersion coefficient

Source: Ortolano, Leonard, Environmental Planning and Decision Making, John Wiley and Sons, Inc., 1984

The models are tested and refined through environmental impact assessment audits. Environmental impact assessment audits measure the actual results and compare them with the planned results. Third party audits may be suitable to ensure unbiased results; however, third parties understand less about the business than the insiders. A combined auditing approach may be appropriate with periodic self-assessment coupled with follow-ups by third party evaluations [Hunt, et al., 1992].

3.2.5 Sources of Data

The sources of data necessary to estimate the medical costs and premature deaths, caused by pollutants resulted from both animal research and human research. Animal research is done by injecting chemicals into animals and detecting and measuring the harm of the diseases. Extrapolation is required to translate the results into human effects. Direct human tests are very difficult to conduct. Often, the researches consist of statistical analysis of disease cases between different cities, with different pollution level, between urban and rural areas, between different time periods of the same city, and between workers of different industries. The data is often poor, especially in assessing non-cancer diseases [Sibergeld, 1990].

In cases where the pollution are more local, such as thermal pollution, the effects of the pollution are easier to estimate. However in most cases, the estimation of the potency factor is very difficult because the effects can travel very far. In addition, many of these damaging effects are not very well understood. For example, many pollutants are carcinogenic to animals in high dosage in a short period of time, but their effects in human in low dosage and longer periods of time are not known [Ames, et al., 1990]. The weakness is mainly due to the lack of human data and the fact that many of the carcinogens work slowly.

Some sources of data are shown on Table 3.1. There are great difficulties in the collection of the data because the data is scattered in various agencies and organizations.

Table 3.1 Sources of Data in Environmental Assessment

Organizations

- American Agricultural Economics Documentation
- CAIN System (Catalog and Indexing)
- Center for Air Environment Studies: The Pennsylvania State University
- Air Pollution Technical Information Center
- National Air Data Branch, Air Pollution Office (EPA)
- Air Quality Implementation Planning Program, Computer Tape
- Projection Algorithm for Vehicular Emission
- Hazardous Air Pollutants Enforcement Management System (HAPEMS)
- Central Abstracting and Index Service, American Petroleum Institute
- Franklin Institute Research Laboratories
- General Electric Company, Space and RESD Divisions
- Center for Urban Regionalism: Kent State University
- Textile Research Center; Illinois Institute of Technology
- Freshwater Institute Numeric Database (FIND)
- Environmental Information Retrieval On-Line (EPA)
- Tatsh Associates
- Eric Clearinghouse for Science, Mathematics and Environmental Education
- Computerized Products and Services; Data Courier, Inc.
- Waterways Experiment Station; U.S. Army Corps of Engineers
- NASA Regional Center; Los Angeles
- American Society of Civil Engineers
- Smithsonian Science Information Exchange; Smithsonian Institution
- Center for Short Life Phenomena; Smithsonian Institution
- Scientists' Institute for Public Information
- Ecology Forum, Inc.: Environmental Information Center
- Biosciences Information Services of Biological Abstracts
- Environmental Mutagen Information Center
- Mineral Supply; U.S. Bureau of Mines
- Overview of the Water Quality Control Information System (STORET)
- Institute for Scientific Information
- National Weather Service River Forecast System
- Battle Energy Information Center (BEIC)
- Federal Aid in Fish and Wildlife
- Environmental Technical Information Center; Institute for Paper Chemistry
- Transportation Noise Research Information Service
- Noise information Retrieval System; Office of Noise Abatement and Control
- Toxicology Information Program; U.S. National Library of Medicine
- Analysis and Evaluation of Sources, Transport, Fate and Effects of Nuclear and Nonnuclear Contamination in Biosphere
- Poison Control Toxicological Inquiry
- Pesticides Data Bank (EPA)
- Pesticide Information Center
- Mathematical Model for Outfall Plume
- National Center for Resources Recovery, Inc.
- A Generalized Computer Model for Steady-State Performance of the Activated Sludge Performance

- Environmental Systems Application Center
- Wastewater Treatment Plant Cost Estimating Program
- Databases: Solid Earth and Solar-Terrestrial Environmental Data
- Databases: Oceanography
- Analysis of Natural Gases
- Energy and Environmental Systems Division
- American Geological Institute
- National Technical Information Service
- Nuclear Science Abstracts (ERDA)

Source: Environmental Impact Data Book

3.2.6 Amount of Pollutants

The next step in the model is to estimate the amount of each pollutant a product emits during its life cycle. The amount of a pollutant includes emission from manufacturing, energy creation, as well as during the useful life and disposal. It may be expensive to set up an accounting system to measure all pollutants; however, the government and other agencies, such as the SEC, already require reporting of the major pollutants. An accounting system with databases will not significantly increase the costs over the required system. Polaroid has implemented a very good system to measure all pollutants [Nash, et al., 1992].

3.2.7 Damage Cost

The amount of each pollutant is multiplied to the corresponding potency factor to achieve the monetary damage of the pollutants (Cost of each pollutant = PQ). The costs of all pollutants, after appropriately discounted to present value, are summed up across all pollutants to get the total social cost of pollution of the product (total cost =

Σ PQ). Discounting is very important because not all pollutants are emitted at the same time. Some pollution, such as the disposal of products, are done years after the emissions of pollutants during manufacturing. Discount rates will be discussed in Section 3.4.

3.2.8 An Example

Table 3.2 shows emission factors for an average motorcycle with a two-stroke engine or a four-stroke engine. The two cycle engine generates more hydrocarbons, particulate, sulfur oxides, and aldehydes but less carbon monoxide and nitrogen oxides per mile. Without weighting these costs to the environment, one has no idea which motorcycle creates more damages to the environment.

Table 3.2 Emission Factors for Motorcycles: Emission Factor Rating B

	Emissions	
	Two Stroke Engine	Four Stroke Engine
Pollutant	(g/mi.)	(g/mi.)
Carbon Monoxide	27	33
Hydrocarbon	16.36	3.86
Nitrogen Oxide	0.12	0.24
Particulates	0.33	0.046
Sulfur Oxides (SO_2)	0.038	0.022
Aldehydes (RCHO)	0.11	0.047

Source: Golden, Jack; Saari, Sharon; Ouellette, Robert P.; Cheremisinoff, Paul, Environmental Impact Data Book, Ann Arbor Science, 1979

Assume an estimation of the cost per gram of each pollutant emitted by the two types of motorcycles are performed and the figures are shown in Table 3.3. After multiplying the cost per gram and the emission factors, the costs are totaled, to achieve the total emission cost per mile (see Table 3.3).

Table 3.3 Hypothetical Potency Factors and Emission Costs for Motorcycles Emissions

Pollutant	Emissions Potency Factors (\$/g)	Emissions Cost 2-cycle (\$/mi.)	4-cycle
Carbon Monoxide	0.012	0.324	0.396
Hydrocarbon	0.009	0.111	0.0347
Nitrogen Oxide	0.25	0.03	0.06
Particulates	0.089	0.0294	0.004
Sulfur Oxides (SO_2)	1.58	0.0600	0.0348
Aldehydes (RCHO)	0.198	0.0218	0.009
Total		0.5762	0.5385

Base on the above data and calculation, a conclusion can be drawn: the social cost of the emission from a four-cycle engine is lower than that of a two-cycle engine ($0.5385/mile verse $0.5762/mile).

3.2.9 An Inferior Alternative

Due to the difficulties in obtaining the potency factor, some authors have recommended the use of compliance cost [Bailey, 1991]. Using compliance cost is much easier than using social cost analysis. The cost of materials, for example, would simply just be the sale prices if the vendors are complying with the regulations. However, using the compliance cost may underestimate the actual cost because firms may be required to clean up in the future. In addition, compliance cost excludes the cost of pollution that is emitted during energy creation; therefore, it may underestimate the importance of conserving energy. It also does not consider emissions during use and disposal. So when using compliance cost, all the above factors should be included. Furthermore, environmental regulatory agencies now considers cradle to grave approach in determining the social responsibilities of a company. Merely using compliance cost may induce a company to pick the least socially responsible material vendors because of lower prices of the materials. Besides, only complying with the regulations may not be enough. There is a need to go beyond compliance.

3.2.10 Life Cycle Analysis of a Product

The social costs of each stage of a product's life cycle are aggregated and summed together with the manufacturing costs to make up the total cost of a product. These costs will be described in detail in this section (see Figure 3.1 again for life cycle of a product).

3.2.10.1 From Material Extraction to Manufacturing

When a product requires any virgin material to be manufactured, the social impact of material extraction must be estimated. These materials include direct material in making the product and any agents used to process the product. These costs include energy usage, pollution emissions during extraction and transportation, opportunity cost, and the cost of the material including direct transportation cost of the material.

3.2.10.1.1 Energy Usage

The pollution emitted during to the creation of energy used for extracting raw material should be considered. For example, if electricity is used, pollutants emitted during the creation of the electricity must be considered. The cost is equal to the potency factor of the each pollutant multiplied by the corresponding amount of the pollutant released during the creation of the energy.

$$\text{Cost} = \Sigma P_i Q_i$$

P_i: the potency factor of ith pollutant emitted during the extraction of virgin raw material

Q_i: the amount of ith pollutant emitted during the extraction of raw material.

3.2.10.1.2 Extracting and Transporting Process

Pollution also occurs during the extraction of material. For example, trucking raw materials from extracting site to the factory pollutes the environment. The cost of this pollution must be determined.

$$\text{Cost} = \sum P_i Q_i$$

P_i: the potency factor of each pollutant emitted during the extracting and transporting of raw materials.

Q_i: the quantify of each pollutant emitted during the same process

3.2.10.1.3 Opportunity Costs

The opportunity costs are the benefits forgone if the material were extracted. For example, cutting down trees for lumber damages environment in other ways than pollution. The trees could have absorbed carbon dioxide which contributes to global warming. The trees also make the sites more pleasant to the eyes. Furthermore, animals populations may decrease because their living places are destroyed. Therefore, it is important to consider the geographical location of the trees.

3.2.10.1.4 Costs of Virgin Materials

Finally, the costs of virgin materials which include all delivering costs, must be included. These costs, however, should be net of compliance cost. Compliance cost is only a transfer of money to the government; therefore, it should not be considered as a social cost.

3.2.10.2 Remanufactured Material to Manufacturing

Using the remanufactured material is less damaging to the environment since there is no opportunity costs involved. Moreover, the emissions during the remanufacturing process are often lower. However, if the cost of using remanufactured material is higher than using virgin material, it may not be worthwhile to use remanufactured materials. The costs we must consider when using remanufactured materials are energy use, emission during remanufacturing, collecting and transporting, and the cost of remanufactured materials.

3.2.10.2.1 Energy Usage

Similar to material extraction, energy usage must be considered during re-manufacturing of recycled products. This includes the energy used in collecting the used product, taking the product apart, sorting and , transporting the components of the product, and remanufacturing the parts into material desired. The cost is similarly:

$$\text{Cost} = \Sigma\ P_iQ_i$$

P_i: the potency factor of each pollutant emitted during the creation of energy required for the remanufacture of materials.

Q_i: the quantify of each pollutant emitted during the same process

3.2.10.2.2 Emissions During Remanufacturing and Transporting

Pollutants emitted during remanufacturing and transporting as well as during collecting and sorting. The cost of pollution again is:

$$\text{Cost} = \Sigma\ P_iQ_i$$

P_i: the potency factor of each pollutant emitted directly by the process of remanufacturing

Q_i: the quantify of each pollutant emitted during the same process

3.2.10.2.3 Costs of Remanufactured Materials

The costs of the remanufactured materials must be considered. Again, the costs should be net of compliance costs. It is justified to pay more for the remanufactured materials than virgin materials if the total costs of remanufactured materials are lower than those of virgin materials; otherwise, virgin materials should be used.

3.2.10.3 Reused material to Manufacturing

Reused materials are even better environmentally than remanufactured materials. The materials do not have to be reprocessed. However, transportation cost sometimes precludes the reuse of materials. The social costs are the cost of energies use in collecting, taking apart, sorting, and transporting of reused material, the corresponding emission during these processes, and the cost of the reused material.

3.2.10.3.1 The Cost of Energy

As in the case of remanufactured material, the cost of energy used in collecting and transporting the reused material is also ΣP_iQ_i P_i refers to the potency factor of each pollutant during the creation of the energy required to transport and to collect the reused material into production process. Q_i refers to the amount of each pollutant.

3.2.10.3.2 The Cost of Emission

The emissions in transporting and collecting the reused material must be taken into consideration. The total cost of emissions is ΣP_iQ_i. P_i here refers to the potency factor of each pollutant emitted during transportation and collection. Q_i refers to the amount of each pollutant.

3.2.10.4 Manufacturing Process

The manufacturing process is an important component in the determination of the greenness of a product. This process is the only element that companies have good control over. This is also the part that is easiest to measure. It considers energy usage and emission during manufacturing, recycling and treatment costs, and costs of manufacturing.

3.2.10.4.1 Energy Usage

The emissions released during the creation of the energy used during the manufacturing processes damage the environment; therefore, in considering the social costs of a product, these damages must be taken into consideration. The total cost of the damages is :

$$\text{Cost} = \Sigma\ P_i Q_i$$

P_i: potency factor of each pollutant in creation of energy necessary for manufacturing

Q_i: amount of each pollutant

3.2.10.4.2 Costs of Treatment, Recycling

When wastes are treated or recycled, the costs of such treatments must be taken into account. The total cost may be negative (for benefit) if the wastes were sold for a profit.

3.2.10.4.3 Emissions during Manufacturing

The pollution during manufacturing process is heavily monitored by the government. Most regulations also focus in this area. There is a considerable cost for not complying with the regulation. Furthermore, there are possible future costs for dumping hazardous waste even if such dumping of such waste is currently legal. The cost of manufacturing is :

$$\text{Cost} = \Sigma\ P_iQ_i$$

P_i: potency factor of each pollutants emitted during the manufacturing process

Q_i: the amount of each pollutant emitted

3.2.10.4.4 Costs of manufacturing

The manufacturing costs include energy, plants and machinery, and personnel cost as well as capital cost. The costs also include certain compliance costs such as reporting, price of permit, etc.

3.2.10.5 Useful Life

Social costs of a product during its useful life include energy usage and emission. Social costs due to usage are significant to some products, but not as important to others. For example, it is important to measure the emission and energy usage of an automobile, but not as important to do so for a desk.

3.2.10.5.1 Energy Usage

The emission during the production of energy used to power the product should be included in the social cost. This cost is similar to the costs in all other cases (Cost = $\Sigma\ P_iQ_i$, P_i refers to the potency factor of each pollutant emitted during the creation of energy requires to run the product and, Q_i refers to the quantity of each corresponding pollutant).

3.2.10.5.2 Emissions during Usage

The emission of pollutants during usage should be estimated. The cost of emission is also ΣP_iQ_i, where P_i is the potency factor of pollutants emitted during the useful life of the product, and Q_i is the quantity of pollutants.

3.2.10.6 Disposal of the Product

At the end of a product's useful life, if any portion of the product must be disposed of, the social cost of such disposal must be considered. The social cost depend on factors such as biodegradability and toxicity of the product. The same formula, Cost = ΣP_iQ_i, can be applied. P_i here refers to the potency factor of the disposed product; Q_i is the quantity of the disposed product.

3.2.10.7 Catastrophes

Another cost of the product life is associated with disastrous events. When manufacturing and transporting of a product may cause a disastrous event, the cost of such an event must be taken into consideration. For example, when Union Carbide's plant in Bhopal released deadly gas that killed 2,000 people and injured hundred of thousands and when Exxon Valdez spilled oil in the Alaskan Coast, these companies must pay for the direct damages of cleaning up and settling lawsuits. They must also pay for the indirect cost of declined sales when consumers boycott their products. Ramsay (1984) developed a useful model for assessing such risk (see Table 3.4). Ignoring this cost can significantly underestimate the costs of a product. For example, a nuclear power plant, if properly operated, has less pollution; however, there is a large cost associated with a potential disastrous event. To appraise the cost of such an event, both the probability of the event in a given year and the cost of such an event must be estimated. The two numbers are then multiplied together and discounted to arrive in the estimated cost of potential catastrophes.

Table 3.4 Quantitative Risk Assessment Method

Stage 1: Quantitative Plant Description
- Location and layout of site
- Process flow schemes
- Equipment list
- Inventories and normal conditions
- Number and diameters of pipework connection
- Remote operated valve

Stage 2: Identification of Failure Cases
- From hazard and operability study(systematic questioning of every part of the process of the plant)
- From technical audit (study and design, construction and operating procedures)
- From examination of the historical record

Stage 3: Estimation of Primary Failure Frequencies
- Possibility that plant failures postulated will occur in a given period of time
- Methods: fault tree analysis-analysis of probabilities of failure case-based on probabilities of contributory events
  - Historical Experience

Stage 4: Prediction of Discharges
- Quantity, speed, and form of hazardous material escapes

Stage 5: Prediction of Dispersion
- Modeling of dispersion characteristics of released material

Stage 6: Calculation of Impact and Hazard Distances
- Flammable materials: Distance to lower flammable limits; ignition probability
- Toxic materials: Distance to toxic threshold criterion, taking into account duration of exposure

Stage 7: Risk Contour Plots
- Hazard distances corresponding to selected damage levels and associated probabilities for each failure case
- Assessment of probability of domino damage
- Superimposition of risk contour plots onto a population map of the area

Source: Ramsay, 1984

In addition to the potential cost of a catastrophic event, the psychological cost of such an event must also be considered. The psychological cost refers to the nervousness of people who live near the potentially disastrous plant. Daily life may be interrupted by the fear of a disastrous event.

3.2.11 An Example of Life Cycle Cost Analysis

Referring to the earlier example of a two cycle verses a four cycle motorcycle engine, the life cycle of a motorcycle is shown in Figure 3.5. Because the engines use different composite and amount of materials, all pollutants and costs are tracked from the creation to the disposal of the materials. Emission during the use of the motorcycle is only one of several issues that must be evaluated. Other issues include fuel mileage (and, therefore, emission during creation of the fuel), manufacturing costs (including emission during manufacturing), and transportation cost (including emissions during transportation).

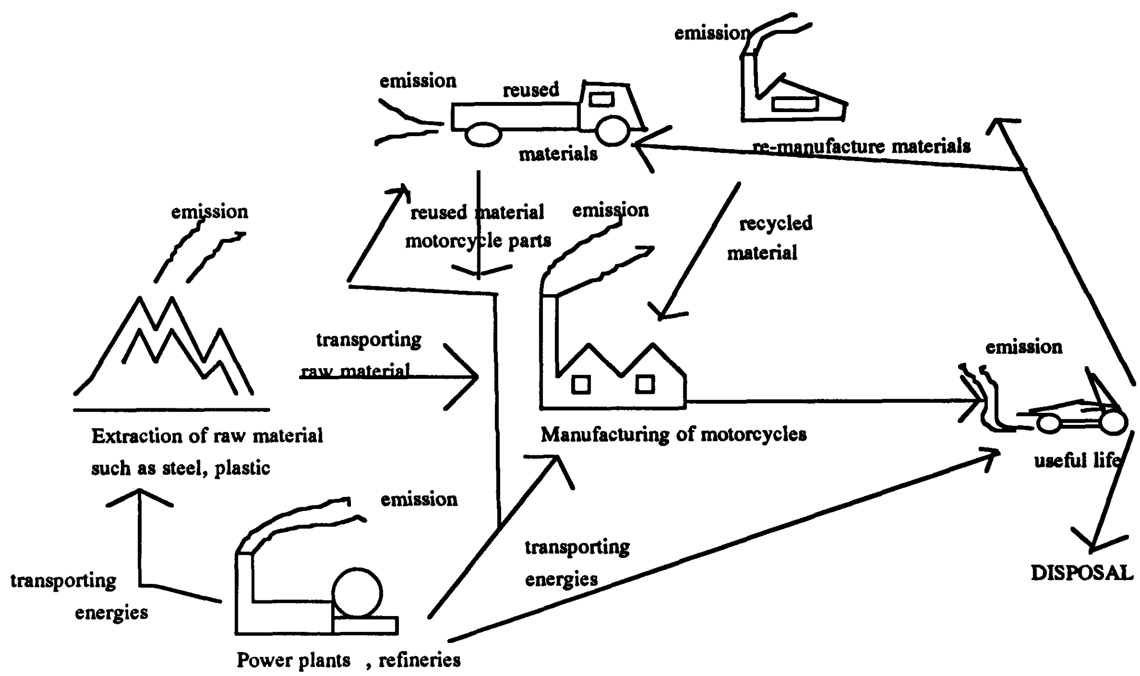


Figure 3.5 Life cycle of an motorcycle

3.3 Social Benefits from a Product

3.3.1 Introduction

The social benefits derived from a product include the consumer value of the product (willingness to pay), relative ease of obtaining funding, social economic benefits, and boost to employees' morale (and, thus, productivity).

3.3.2 Willingness to Pay

The benefits of a product derived from consumers can be measured by consumers' willingness to pay. Consumers' willingness to pay a premium for greener products depends on factors such as personal income, current economic condition, education, and competitions. It also depends on the price elasticity of the product and the availability of substitutes.

This willingness to pay should include the price of the product and the spill-over effect. Consumers may pay more for a company's other products if the company has the good reputation of being a green company.

3.3.3 Easier to Obtain Funding

Additional benefits include ease of obtaining funding from banks or investors. Chevron has found in a survey of its stockholders, that environmental responsibleness is considered to be a sound investment for a company [Smart, 1992]. Banks recognize that lending to a greener company reduces its potential future liability. This benefit is measured by the difference between the cost of borrowing for a company when it produces green products and when it does not.

3.3.4 Social-Economic Benefits

Most studies on environmental impact studies have ignored the social consequences of a product [Craig, 1989]. The most important consequence is another economic externality: job creation. A commercialized product creates employment in the product industry as well as in the material industries and the output industries (retail chains). However, we must also consider the possible shifts in the labor force. In a full employment economy, any jobs created by the products means a job is lost somewhere else. Furthermore, there may be a loss of tourism due to the product; thus, there is really no positive effects from the product during an economic boom. During a recession, however, the benefits of job creation would be significant [McDonald, 1990].

A regional economic impact assessment would be helpful in determining the effects of change in employment (both direct or indirect). The direct effects are job creation and income created by the jobs. The indirect effects are the effects due to the multiplier, i.e. income is spent and more jobs are created. The assessment involves high complexity of estimating input, output, income, spending, etc. Many models are used to run these social economic assessments. These models include Regional Keynesian Multiplier and Input-Output Analysis based upon the Leontief matrix [McDonald, 1990].

3.3.5 Boost in Employee's Morale

Another benefit that is difficult to quantify is the employees' morale. Greening of the company's product tends to boost employees' morale as well. Monsanto Company found very positive reactions from its employees after its announcement of Monsanto Pledge -- a program design to improve the quality of the environment [Smart, 1992]. This boost in morale can transform to higher productivity.

3.4 Discount Rates

3.4.1 Introduction

Not all cash flows occur at the same time. Many effects such as the disposal of products occur years after the production; therefore, discounting is required to determine the present values of the benefits and the costs of a product.

3.4.2 Discount Rate for Manufacturing Cost

The discount rate for the manufacturing cost (excluding social cost) and revenues derived from a product is the company's cost of capital. This discount rate is determined by the business risk of this product. CAPM model can be applied to determine this rate.

3.4.3 Social Discount Rate

The discount rate for the social costs is more difficult to determine. Many authors argue that discounting the future is unethical because we are not weighing the future generations with equal importance; thus, they propose using a zero discount rate. However, it is likely that future generations may be more able to cope with the same problems, such as health care, than we can now through advances in technologies. Also, what we consider as an important environmental effect may not be as important during the future generations. The future needs are uncertain; therefore, the cash flows derived from current estimate of future needs should not be weighted the same as the current needs. So, the use of a positive discount rate could be justified. The cost of a product is very sensitive to the discount rate; hence, the determination of a social discount rate is very important. Lind (1982) proposes the use of a 3 percent rate for the risk-adjusted social rate of time preference.

3.5 Implementation of a Decision Support System in Estimating

A decision support system can greatly facilitate the process of estimation of the cost and benefit of a product. Such a system is shown in Figure 3.6. Users of the system input data based on the site conditions and the amount of emission. Information used as inputs is shown in Table 3.5. Using the information inputted by the user, the rules based system selects the appropriate models and data in the databases to calculate the potency factor and the cost of each pollutant. The costs are then aggregated to arrive at the total cost. The benefits of a product is similarly calculated.

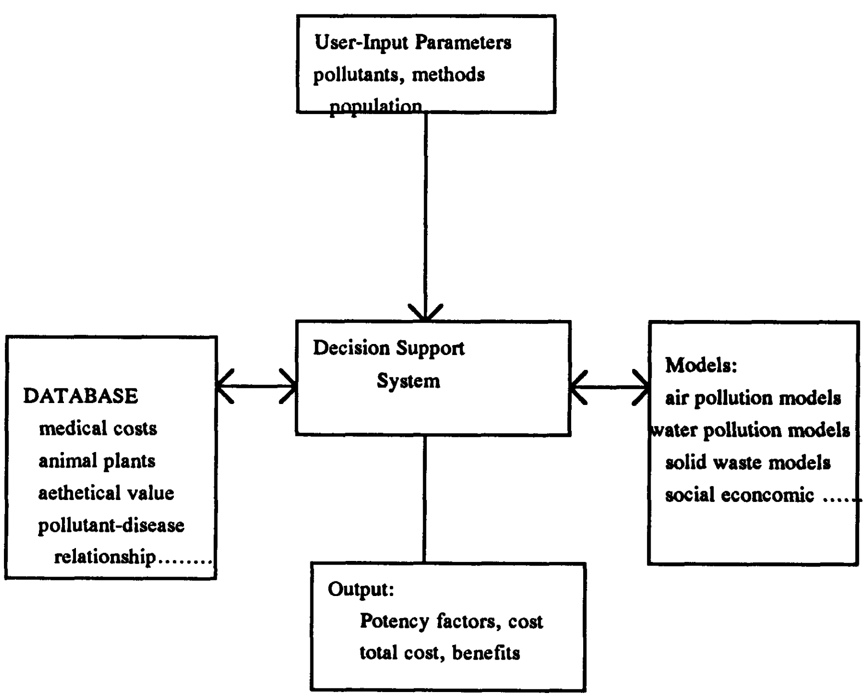


Figure 3.6 Decision Support System in Estimating Social Cost

Table 3.5 The Parameters to be inputted by users in a Decision Support System

Human Population:
number, distribution from the source of pollution
age distribution
percentage with certain diseases such as diabetes
culture: percentage of smoking population, diets, work ethic, etc.

Animals and Plants:
Estimate population of each animal and plant species
Food chains
Approximate value of each specie

Weather:
Average temperature, humidity, wind velocity, direction, rain fall, snow fall, etc.

Terrain:
Composition of ground, location of ground water, mountains, bodies of water, average water temperature, etc.

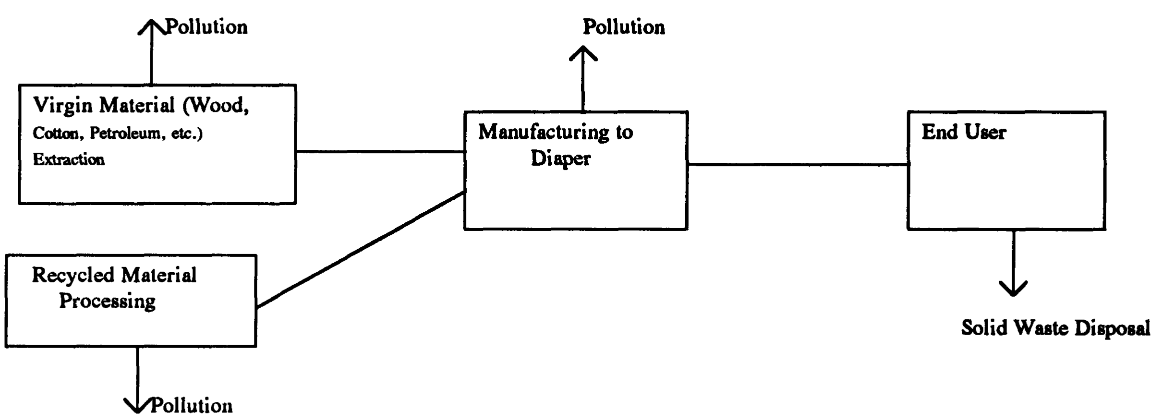
Besides for being expeditious, a decision support system is user friendly. As long as the rules are written correctly, an environmental expert is not required to run the system. It is also easy to update and revise data after the environmental assessment audits are performed.

Chapter 4 Case Study- Disposable Diaper vs. Cloth Diaper

4.1 Introduction

The limitation on solid waste disposal sites has sparked the controversy over disposable products. Of these products, disposable diapers have received much attention because of its high visibility as a consumer product. The alternative-- use of cloth diaper, however, may not be environmentally superior since it requires more energy for washing, and creates more water pollution than disposable diapers. This case study uses life cycle analysis to compare the emission costs of the two diapers and give an objective answer to which product is more environmentally sound. The life cycle of a diaper is shown in Figure 4.1. This case attempts to estimate the social costs of the pollution created by both types of diapers.

Figure 4.1 The Life-Cycle of a Diaper



4.2 Emission Data

The emission data in this case study is extracted from Energy and Environmental Profile Analysis of Children's Single Use and Cloth Diapers prepared by Franklin Associates, Ltd. The data is reproduced in Figure 4.2-4.7. Franklin Associates estimated that a baby uses on the average of about 5.4 disposable diapers a day or about 9.7 cloth diapers per day. Therefore, the emission data are based on these diapers usage.

As one can see from Figure 4.2.1, the energy requirement for cloth diapers (during manufacturing and washing) is higher than the energy requirement for disposable diapers; therefore, the emission from energy creation is higher for cloth diapers (see Figure 4.2.2 and Figure 4.2.3). The direct emission due to manufacturing and washing is shown in Figure 4.2.4 and Figure 4.2.5., respectively. Disposable diapers generally produce more atmospheric emission but less water emission. Disposable diapers also create more solid wastes than cloth diapers (see Figure 4.2.6).

Figure 4.2.1 Energy Requirements for Diapers (For 6 months period)

	Net Energy Requirements (million Btu)
Disposable Diaper- at 5.4 Diaper per day	3.31
Cloth Diaper- at 9.7 Diaper per day	4.41

Source: Franklin Associates, Ltd

Figure 4.2.2 Atmospheric Emissions From Creation of Energy (1b., 6 Months)

	Disposable Diaper @ 5.4 per day	Cloth Diaper @ 9.7 per day
Particulates	0.55	1.38
Nitrogen Oxides	1.23	2.92
Hydrocarbons	0.87	2.03
Sulfur Oxides	1.90	4.94
Carbon Monoxide	0.49	2.85
Aldehydes	0.00084	0.054
Other Organics	0.014	0.19
Ammonia	0.00122	0.0022
Lead	0.0000090	0.00094

Source: Franklin Associates

Figure 4.2.3 Water Pollution From Creation of Energy (lb., 6 Months)

	Disposable Diaper @ 5.4 per day	Cloth Diaper @ 9.7 per day
Dissolved Solids	0.12	0.40
Acid	0.25	0.40
Metal Ion	0.025	0.080
Other	0.035	0.11

Source: Franklin Associates, Ltd.

Figure 4.2.4 Atmospheric Emissions Due to Processing of Diapers (6 Months)

	Disposable Diaper @ 5.4 per day	Cloth Diaper @ 9.7 per day
Particulates	0.78	0.089
Nitrogen Oxides	0.54	0.0019
Hydrocarbons	0.87	0.035
Sulfur Oxides	0.44	0.013
Carbon Monoxide	0.36	0.0023
Aldehydes	0.0033	0.000059
Other Organics	0.030	0.00048
Ordorous Sulfur	-	0.0000024
Ammonia	0.00022	0.00027
Lead	0.00079	-
Chlorine	0.054	0.14
Chemicals	-	0.000041

Source: Franklin Associates

Figure 4.2.5 Water Pollution Due to Processing of Diapers

	Disposable Diaper	Cloth Diaper
Fluorides	-	0.0000034
Dissolved Solids	0.16	2.83
BOD	0.32	1.04
Phenol	0.0000015	0.0000041
Sulfides	0.00000037	0.000000033
Oil	0.0027	0.00042
COD	0.04968	4.45
Suspended Solids	0.49	1.29
Acid	0.011	0.0031
Metal Ion	-	0.00000086
Chemicals	0.00051	0.00021
Cyanide	-	0.000000067
Chromium	0.000004	0.00075
Iron	-	0.0000039
Phosphates	-	0.29
Ammonia	0.00028	0.000062
Phosphorus	-	0.0058
Nitrogen	-	0.023

Source: Franklin Associates, Ltd.

Figure 4.2.6 Solid Waste Disposal Volume (Cu ft)

Disposable Diaper- at 5.4 Diaper per day	7.3
Cloth Diaper- at 9.7 Diaper per day	3.5

Source: Franklin Associates, Ltd.

4.3 Cost Data

The cost data should be assessed by using environmental and social-economic models. However, due to the lack of resources and data, the cost data presented in this case is fictional.

The unit cost (potency factor) data is presented in Figure 4.3.1. and Figure 4.3.2. The data is presented in dollar of cost per pound of pollutant emission. Same pollutants emitted during the manufacturing process or during energy creation may have different costs in society as the environment to which the pollutant is emitted is different, e.g. different terrain and population at the diaper factory and at the power plant. The assumption here is that both disposable diaper and cloth diaper factories are at the same location, i.e. they have the same emission costs. Another assumption is that all of the waterborne pollutions from the cloth diapers are due to diaper washing of diaper; therefore, the water pollution from cloth diapers should have different cost data than that of disposable diapers. The assumption is that each pollutant costs less for disposal diapers because it is easier to centralize the polluted water and treat it before it is released to the environment.

Figure 4.3.1 Atmospheric Emissions Unit Cost Due to Process ($/lb.)

	Disposable Diaper and Cloth Diaper
Particulates	0.2
Nitrogen Oxides	0.4
Hydrocarbons	0.9
Sulfur Oxides	1.7
Carbon Monoxide	0.9
Aldehydes	0.4
Other Organics	0.2
Ordorous Sulfur	0.9
Ammonia	0.7
Lead	1.9
Chlorine	0.8
Other Chemicals	3.4

Figure 4.3.2 Process Water Emission Unit Cost of Two Diaper Systems ($/lb.)

	Disposable Diaper	Cloth Diaper
Fluorides	30	32
Dissolved Solids	0.7	0.8
BOD	1.3	1.6
Phenol	27	45
Sulfides	45	60
Oil	5.6	7.8
COD	1.7	1.9
Suspended Solids	0.3	0.3
Acid	1.3	1.5
Metal Ion	0.8	0.9
Chemicals	1.2	1.7
Cyanide	45	56
Chromium	32	45
Iron	0.2	0.5
Phosphates	0.7	0.8
Ammonia	0.6	0.9
Phosphorus	0.9	1.5
Nitrogen	0.3	0.4

Figure 4.3.3 Unit Cost of Atmospheric Emissions From Creation of Energy ($/lb.)

	Both Diapers
Particulates	0.1
Nitrogen Oxides	0.3
Hydrocarbons	0.7
Sulfur Oxides	1.5
Carbon Monoxide	0.8
Aldehydes	0.4
Other Organics	0.2
Ammonia	0.6

Lead	1.9

Figure 4.3.4 Unit Cost of Water Pollution Emissions From Creation of Energy ($/lb.)

	Both Diapers
Dissolved Solids	0.6
Acid	1.1
Metal Ion	0.8
Other	0.9

4.4 Emission Cost of The Diaper Systems

Each pollutant is multiplied by its corresponding unit cost to achieve the emission cost of the pollutant for 6 months of diaper usage. These costs are shown in Figure 4.4.1. to Figure 4.4.5. The total cost of emission for each diaper is shown in Figure 4.4.6. In this case, the cost of disposable diaper is lower than that of cloth diaper ($33.57 vs. $37.02).

Figure 4.4.1 Process Atmosphere Emission Cost of Two Diaper Systems for 6 months

	Disposable Diaper @ 5.4 per day	Cloth Diaper @ 9.7 per day
Particulates	0.16	0.18
Nitrogen Oxides	0.22	0.00076
Hydrocarbons	0.78	0.032
Sulfur Oxides	0.75	0.022
Carbon Monoxide	0.32	0.0021
Aldehydes	0.0013	0.000024
Other Organics	0.006	0.000096
Ordorous Sulfur	-	0.0000022
Ammonia	0.00015	0.000019
Lead	0.0015	-
Chlorine	0.043	0.11
Chemicals	-	0.00014

TOTAL	2.28	0.35

Figure 4.4.2 Water Pollution

Fluorides	-	0.00011
Dissolved Solids	0.112	2.3
BOD	4.16	1.7
Phenol	0.000041	0.00018
Sulfides	0.000017	0.000002
Oil	0.015	0.0033
COD	0.085	8.5
Suspended Solids	0.15	0.39
Acid	0.14	0.0047
Metal Ion	-	0.00000077
Chemicals	0.0061	0.0036
Cyanide	-	0.0000038
Chromium	0.00013	0.0034
Iron	-	0.000002
Phosphates	-	0.23
Ammonia	0.00017	0.000056
Phosphorus	-	0.00087
Nitrogen	-	0.0092
TOTAL	4.67	13.15

Figure 4.4.3 Emission Cost of Atmospheric Emissions From Creation of Energy ($/lb.)

	Disposal Diaper	Cloth Diaper
Particulates	0.055	0.14
Nitrogen Oxides	0.37	0.88
Hydrocarbons	0.61	1.4
Sulfur Oxides	2.9	7.4
Carbon Monoxide	0.39	2.3
Aldehydes	0.00034	0.022
Other Organics	0.0028	0.038
Ammonia	0.000736	0.0013
Lead	0.000017	0.0018
TOTAL	4.32	12.18

Figure 4.4.4 Emission Cost of Water Pollution Emission of Diapers for Six Months

	Disposable Diaper	Cloth Diaper
Dissolved Solids	0.072	0.24
Acid	0.28	0.44
Metal Ion	0.02	0.064
Other	0.032	0.099
TOTAL	0.40	0.84

Figure 4.4.5 Solid Waste Cost: (Assume unit cost @ $3.00/cu ft)

Disposal	21.9
Cloth	10.5

Figure 4.4.6 Total Cost of Emissions:

Disposal	33.57
Cloth	37.02

4.5 Conclusion

Base on the above assumption and calculation, a conclusion can be drawn that the disposable diapers are more environmentally friendly than cloth diapers.

However, merely comparing the costs of emission is not enough. Other factors to be considered include job creation, convenience to consumers, time loss in washing diapers, etc. In addition, the solid wastes must be further broken down into smaller components to prevent the possible leaching into the ground water. All these factors should be considered and their costs estimated before one can assess which is the better diaper system.

Chapter 5 Summary and Conclusion

5.1 Introduction

In this chapter, a description of the model's application, the advantages and disadvantages of the model, and the final remarks of the model will be presented.

5.2 Application of the Model

In addition to the decision on whether the product is worth producing, the system is very useful in the planning stage. It can be used to choose technologies, product designs (material selection, energy consideration, etc.), manufacturing sites, material vendors, etc.

When the assessment is used to compare two similar products with different life spans, the cost must be based on considered on the same life-span. For example, when Product A is twice as durable as Product B, comparison must be made by assuming that two of Product B are used, one after another, to compare to one of product A. Similarly, the products can be compared on an equivalent annual cost basis. When the capacity of the two products being compared are different, the figures must be adjusted so the same capacity applies.

The system can be used to assist with making budgeting decisions. If the decision maker has only a limited budget to lower the social cost of the product, he can pick the combination that yields the highest net benefit.

The system can be broken to perform sub-tasks. For example, the system can be used to select material vendors. Because the new liabilities imposed by regulations are joined and several, dealing with an irresponsible supplier can be costly for a company. The lowest social cost in producing the material can be used as a criterion for choosing vendors. Another sub-task is for selecting a manufacturing site. Land cost as well as other social costs (pollution cost, aesthetic cost, etc.) can be taken into consideration in deciding on a manufacturing site.

Furthermore, decision maker can use the system as an insurance decision on where and how much to invest to minimize potential future liabilities.

5.3 Advantages of the Model

The model has the following advantages: gives an objective answer, educates employees, improves public relationships, reduces compliance costs, is easy to be modified, and is easy to assess data.

5.3.1 Gives an Objective Answer

The system weighs the different methods of emission reduction as well as other costs, such as materials and manufacturing, and assigns a cost number that is easy to understand. The model is very flexible. This cost system can help management set goals in reducing waste. It helps to identify the potential problems and to allocate resources and capitals accordingly to improve the problem. For example, if a treatment program costs \$1m in present value, then the net benefit (reduction in cost) in present value must exceed \$1m for it to be a worthy project.

5.3.2 Educating Employees

The cost system not only evaluates trade-offs between different methods of abatement but is also a very useful management tool. It makes all employees understand and be conscious of the costs of emissions. Oftentimes, employees will be able to come up with alternatives that may lower the costs.

5.3.3 Improve Public Relationship by Educating the Public

A study by Michael Elliot (1984) shows that the up to 50% of the residents can be persuaded to support a project if the project are of high quality. Often, the success of a project depends on the support of local residents. This is especially true in the siting of facilities. The analysis will assist local residents in understanding the costs and the benefits of the product. The system improves public relations by disclosing all information.

5.3.4 Reduce Compliance Cost

The system can be easily modified to satisfy the multiple reporting requirements imposed by various federal and state agencies as well as banks and the SEC.

5.3.5 Easy to Modify

The system can be modified and reused for other projects. This is especially helpful for developing countries where insufficient manpower and resources are available for environmental studies [Brown, 1990].

5.3.6 Easy Access of Data

Brown (1990) found that there are difficulties in assessing environmental data. There were many gaps between agencies; information is often outdated; and its reliability is questionable, Information that is available is often scattered across agencies. With the help of a decision support system, the data can be centralized. This will facilitate the impact study.

5.4 Disadvantages of the Model

The model has two types of weaknesses: technical weakness and ethical weakness. Technical weakness refers to the lack of research data, quality of such data, and the lack of understanding for the cause-and-effect relationships. There are many doubts regarding the reliability of computer models, especially in determining the long term effects. Many environmental assessments that study the same project have different results because they are based on different assumptions. Furthermore, new technological processes, materials, and chemicals that are untested environmentally contribute to the weakness. Ethical weakness refers to the putting of numerical value on human lives, a practice that is considered unethical by many. Lastly, there is also the possibility of manipulation by the user to achieve desire results.

5.4.1 Technical Weaknesses

As the technologies for modeling and measuring the pollutants improve, the extent of the technical weakness declines. The weakness also diminishes as environmental audits are performed to test the model.

5.4.1.1 Health risk

As mentioned earlier, the effects of human exposure to many chemicals are unknown since human tests are impossible or limited. Assessing the diseases that an additional pollutant will cause is extremely difficult. In addition, the discoveries of these effects are further complicated by the presence of other chemicals and/or diseases. Human culture and behavior, such as cigarette smoking are also factors. Furthermore, there seem to be thresholds for the effects of most chemicals on humans, and the thresholds are very difficult to determine [Kalkstein, 1989]. Besides, the thresholds differ for everybody. All these health factors are interrelated and very hard to be separated.

Martin (1986) points out that there have been problems with the identification of hazards, limitations of epidemiological methodology, and inadequacies in biological knowledge of chemical toxicity and environmental disease processes. This is largely due to the lack of direct human data and the difficulties in relating animal research data to human health. There are also lack of resources and abilities to test new chemicals or materials.

5.4.1.2 Modeling Weakness

There are serious limitations to using a model. Models can only approximate the actual situation. Rubin (1986) characterized various uncertainties about models: (1) statistical variation (random error), (2) subjective judgment (systematic error); (3) linguistic imprecision; (4) sampling variability; (5) inherent randomness; (6) scientific disagreement; and (7) approximations. The most serious limitation is that models are usually based on questionable assumptions. For example, the models used to study the shifts in the labor force assumes static conditions, e.g., unemployment rate stays the same, etc. However, the economy is dynamic and its actual ability is more complex and very difficult to predict.

5.4.1.3 Too Many Long Term Uncertainties

Many of these effects are long term in nature. Estimating long term risks is extremely difficult. For example, the effects of global warming and ozone depletion are both uncertain and long-term in nature, and the cost of these events is very difficult to estimate. Kalkstein (1989) studied the possible effects of premature death of human due to global warming. The finding is very inconclusive and is dependent upon many assumptions that are hard to verify. In addition, many future events are very uncertain. For example, the main reason for preserving many animal and plant species is to develop potential new medicines. Nevertheless, the value of each species cannot be determined without knowing what medicine will be developed from it. Furthermore, many human health impacts are also long term in nature. There is usually a time lag between exposure to the pollutants and the development of health problems.

5.4.1.4 Requirement of Large Amount of Data

The system requires a large amount of data and models. Furthermore, data are scattered among many agencies (see Table 3.1). Researching for the data will take a tremendous amount of time and resources. However, once the system is complete, refining it will be easy.

5.4.1.5 Value Conflicts

Perhaps the biggest problem with the cost system is the conflict of value. Even if health care cost could be estimated, people have different values for other environment problems and for aesthetic view. People also place different values on the cost of suffering due to sickness. What the appropriate costs are depends on who is making the decision. For example, preserving old growth trees save animal and preserve aesthetic view. However, these benefits are more valuable to animal lovers and out-door lovers than for others. The major problems were the use of subjective opinions to arrive at objective estimates.

5.4.2 Ethical Weakness

The ethical weakness of the model refers to the numeric valuation on human life and the possible manipulation by model user. These weaknesses do not reduce with advances in technologies.

5.4.2.1 Human Life Value

In order to arrive at a cost estimate, it is necessary to place a monetary value on human life. Many people have objected to this approach, since very few people can agree on the exact monetary value of a human life. In an EPA estimate, the value of a death avoided is in the range of $400,000 to $7 million [Whittington, 1990]. Even if this range is accurate, the high end and the low end of the range differ by a factor of almost 20. Using one number or another will significantly affect the outcome of the model.

5.4.2.2 Manipulation

Many of the data are based on subjective assumptions, so there are possibilities that the system may be manipulated. Model and data can be used in one way or another to achieve desired results. For example, one can place a large discount rate for long term effects, thus, place greater burden on the future generation. Furthermore, the data researched by the industries may be biased to achieve the desired outcome. Monitoring is, therefore, very essential in keeping the system objective.

5.5 Final Remarks

There are four concluding remarks that can be drawn from this thesis. The remarks represent changes that must be made to firm policies for environmental concerns. They are the need for changes in corporate structure, the utilization of the "cook book" approach, EPA involvement and the sharing of environmental data, and public and environmental group involvement.

5.5.1 The Need for Changes in Organizational Structure

Few companies today are concerned with protect themselves against future environmental liabilities. The strategy for pollution control has always been to reduce rather than to prevent. The organizational structure in this case is a bottom up approach. Engineers at the lower level direct the need for controlling the pollution to achieve compliance. Development of greener product is a required step in avoiding these liabilities. In developing greener products, there is an urgency to adapt a new organizational structure. The new organizational structure is a combination of both the top-down and bottom-up approaches. Top management in the corporate level should fully support the research and development efforts to develop a greener product. Engineers at the local level who better understand the manufacturing process better should provide ideas on ways to produce product that reduces damage to the environment.

5.5.2 the Importance of "Cook-Book" Type Approaches

Because of the large resources and expertise requirements, currently only very large firms and governmental agencies are able to complete environmental assessment studies. Smaller companies are often under-protected. Because small companies together make up a very large percentage of most of the important industries, it is urgent to develop environmental assessments that utilize the "cook-book" approaches for small companies to employ. The knowledge based decision support system described in Chapter Three is the easiest approach.

5.5.3 Sharing of Data and EPA Involvement

The environmental studies and data are very scattered, and the qualities of the data are inconsistent. Some data that are done by industries are biased to achieve certain results. There is a need to centralize these data and to discard the biased data. The EPA has both the resource and the expertise for the task. When compiling the data, it is very important that the EPA remain unbiased.

5.5.4 Public Participation

There is often an adversarial relationship between the companies (potential polluters) and the public. The NIMBY approach by the local public has frustrated many companies' effort to build new factories. To alleviate this problem, companies should make the public more involved in the development process. The same can also be done with the environmental groups. Having cooperation from the public and the environmental groups more efficient than having confrontation. Unfortunately, this is usually not the step taken by corporations.

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