Selecting Cost-Effective Green Building Products: BEES Approach

By Barbara C. Lippiatt[1]

Abstract: The Building for Environmental and Economic Sustainability (BEES) tool implements a rational, systematic technique for selecting cost-effective green building products. The technique is based on consensus standards and designed to be practical, flexible, and transparent. The Windows-based decision support software, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for 24 building products across a range of functional applications. BEES measures the environmental performance of building products using the environmental life-cycle assessment approach specified in the latest versions of ISO 14000 draft standards. The approach is based on the belief that all stages in the life of a product generate environmental impacts and must be analyzed. The stages include raw material acquisition, manufacture, transportation, installation, use, and waste management. Economic performance is measured using the ASTM standard life-cycle cost method. The technique includes the costs over a given study period of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performance are combined into an overall performance measure using the ASTM standard for multiattribute decision analysis.

INTRODUCTION

Buildings significantly alter the environment. Building construction consumes 40% of the raw stone, gravel, and sand used globally each year, and 25% of the raw timber. Buildings also account for 40% of the energy and 16% of the water used annually worldwide. In the United States, about as much construction and demolition waste is produced as municipal garbage. Unhealthy indoor air is found in 30% of new and renovated buildings worldwide (Roodman and Lenssen 1995).

Negative environmental impacts arise from these activities. For example, raw material extraction can lead to resource depletion and biological diversity losses. Building product manufacture and transport consumes energy, generating emissions linked to global warming, acid rain, and smog. Landfill problems may arise from waste generation. Poor indoor air quality may lower worker productivity and adversely affect human health.

Thus, building-related contributions to environmental problems are large and therefore important. Selecting environmentally preferable building products is one way to improve a building's environmental performance. However, while 93% of U.S. consumers worry about their home's environmental impact, only 18% are willing to pay more to reduce the impact, according to a survey of 3,600 consumers in nine U.S. metropolitan areas (Buchta 1996). To be practical, then, environmental performance must be balanced against economic performance. Even the most environmentally conscious building designer or building product manufacturer will ultimately weigh environmental benefits against economic costs. To satisfy their customers, manufacturers and designers need to develop and select building products with an attractive balance of environmental and economic performance.

In this spirit, the U.S. National Institute of Standards and Technology (NIST) Green Buildings Program began the Building for Environmental and Economic Sustainability (BEES) project in 1994. The purpose of the BEES project is to develop and implement a systematic methodology for selecting environmentally and economically balanced building products. The methodology is based on consensus standards and is designed to be practical, flexible, and transparent. The BEES model is implemented in publicly available decision-support software —the first version of which is available free of charge and contains actual environmental and economic performance data for 24 building products (Lippiatt 1998a). The intended result is a cost-effective reduction in building-related contributions to environmental problems.

In 1997, the U.S. Environmental Protection Agency Environmentally Preferable Purchasing Program also began supporting the development of BEES. The Environmentally Preferable Purchasing Program is charged with carrying out Executive Order 13101 (September 1998), "Greening the Government Through Recycling, Waste Prevention and Federal Acquisition" (which replaces, strengthens, and expands Executive Order 12873 (October 1993), "Federal Acquisition, Recycling, and Waste Prevention"). Executive Order 13101 encourages U.S. executive agencies to reduce the environmental burdens associated with the $200 billion in products and services they purchase each year, including building products. Over the next several years, BEES will be further developed as a tool to assist the U.S. federal procurement community in carrying out the mandate of Executive Order 13101.

This paper describes the current formulation of the BEES model for balancing the environmental and economic performance of building products and illustrates its application in the Windows-based decision support software, BEES 1.0.

BEES METHODOLOGY

The BEES methodology takes a multidimensional, life-cycle approach. That is, it considers multiple environmental and economic impacts over the entire life of the building product. A multidimensional, life-cycle approach is necessary for a comprehensive, balanced analysis.

It is relatively straightforward to select products based on minimum life-cycle economic impacts because building products are bought and sold in the marketplace. But how do we include life-cycle environmental impacts in our purchase decisions? Environmental impacts such as global warming, water pollution, and resource depletion are for the most part economic externalities. That is, their costs are not reflected in the market prices of the products that generated the impacts. Moreover, even if there were a mandate today to include environmental "costs" in market prices, it would be nearly impossible to do so due to difficulties in assessing these impacts in economic terms. How do you put a price on clean air and

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clean water? What is the value of human life? Economists have debated these questions for decades, and consensus does not appear likely.

Although environmental performance cannot be measured on a monetary scale, it can be quantified using the evolving, multidisciplinary approach known as environmental life-cycle assessment. The BEES methodology measures environmental performance using a life-cycle assessment (LCA) approach, following guidance in the ISO 14000 series of environmental management standards. Economic performance is separately measured using the ASTM standard life-cycle costing approach ("Standard" 1993). These two performance measures are then synthesized into an overall performance measure using the ASTM standard for multiattribute decision analysis ("Standard" 1995). For the entire BEES analysis, building products are defined and classified according to UNIFORMAT II, the ASTM standard classification for building elements ("Standard" 1996). All underlying data and computational algorithms are reported and documented.

ENVIRONMENTAL PERFORMANCE

Environmental LCA is a "cradle-to-grave," systems approach for assessing environmental performance. The approach is based on the belief that all stages in the life of a product generate environmental impacts and must therefore be analyzed, including raw materials extraction and processing, product manufacture, transportation, installation, operation and maintenance, and ultimately recycling and waste management. An analysis that excludes any of these stages is limited because it ignores the full range of upstream and downstream impacts of stage-specific processes.

The strength of environmental LCA is its comprehensive, multidimensional scope. Many "green building" claims and strategies are now based on a single life-cycle stage or a single environmental impact. A product is claimed to be green simply because it has recycled content, or claimed not to be green because it emits volatile organic compounds during its installation and use. These single-attribute claims may be misleading because they ignore the possibility that other life-cycle stages, or other environmental impacts, may yield offsetting impacts. For example, the recycled content product may have a high embodied energy content, leading to resource depletion, global warming, and acid rain impacts during the raw materials extraction and manufacturing life-cycle stages. LCA thus broadens the environmental discussion by accounting for shifts of environmental problems from one life-cycle stage to another, or one environmental medium (land, air, water) to another. The benefit of the LCA approach is in implementing a trade-off analysis to achieve a genuine reduction in overall environmental impact, rather than a simple shift of impact.

The general LCA methodology involves four steps (*Environmental* 1997). The goal and scope definition step spells out the purpose of the study and its breadth and depth. The inventory analysis step identifies and quantifies the environmental inputs and outputs associated with a product over its entire life cycle. Environmental inputs include water, energy, land, and other resources; outputs include releases to air, land, and water. However, it is not these inputs and outputs, or inventory flows, that are of interest. More important are their consequences, or impacts on the environment. Thus, the next LCA step, impact assessment, characterizes these inventory flows in relation to a set of environmental impacts. For example, the impact assessment step might relate carbon dioxide emissions (a flow) to global warming (an impact). Finally, the interpretation step combines the environmental impacts in accordance with the goals of the LCA study.

Step 1—Goal and Scope Definition

The goal of the BEES-LCA is to generate relative environmental scores for building product alternatives based on U.S. average data. These will be combined with relative, U.S. average economic scores to provide decision support to the building community for selecting environmentally and economically balanced building products.

The scoping phase of any LCA involves defining the boundaries of the product systems under study. The manufacture of any given product involves a number of unit processes. Each unit process involves many inventory flows, some of which themselves involve other subsidiary unit processes. Which of these unit processes should be included in the LCA? In the BEES system, the boundary-setting rule consists of a set of decision criteria. For each candidate unit process, mass and energy contributions to the product system are the primary decision criteria. In some cases, price is used for further decision support. (Although a high price does not directly indicate a significant environmental impact, it may indicate scarce natural resources or numerous subsidiary unit processes potentially involving high energy consumption.) Together, these decision criteria provide a robust screening process for setting product system boundaries. Fig. 1 shows the processes included in the BEES system for vinyl composition tile floor covering, including a styrene-butadiene adhesive for installation.

Defining the unit of comparison, or functional unit, is another important task in the goal and scoping phase of LCA. To make comparisons among products, units must be defined such that the products to be compared are true substitutes for one another. In the BEES model, the functional unit for most building products is 0.09 m^2 (1 ft^2) of product for 50 years. Therefore, for example, the functional unit for the BEES floor covering alternatives is covering 0.09 m^2 (1 ft^2) of the floor for 50 years. The functional unit provides the critical reference point to which all inventory flows are normalized. All product alternatives are assumed to meet minimum technical performance requirements (e.g., acoustic, moisture, and fire performance).

Scoping also involves setting data requirements. Data requirements for the BEES study include the following:

- Geographic coverage: The data are U.S. average data.
- Time period covered: The data are a combination of data collected specifically for the BEES system within the last 18 months, and data from the well-known Ecobalance LCA database created in 1990 (*DEAM* 1997). Most of the Ecobalance data are updated annually. No data older than 1990 are used.
- Technology covered: Where possible, the most representative technology is studied. Where data for the most representative technology are not available for proprietary or other reasons, an aggregated result based on U.S. average technology for that industry, obtained from sources such as trade associations, government documents, and data bases, is used.

Step 2—Inventory Analysis

Inventory analysis entails quantifying the inventory flows for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water. Fig. 2 shows the categories under which data are grouped in the BEES system.

Data collection is done under contract with Environmental Strategies and Solutions, Inc., McLean, Va., and Ecobalance, Inc., Bethesda, Md., using the Ecobalance LCA database covering more than 6,000 industrial processes and compiled from

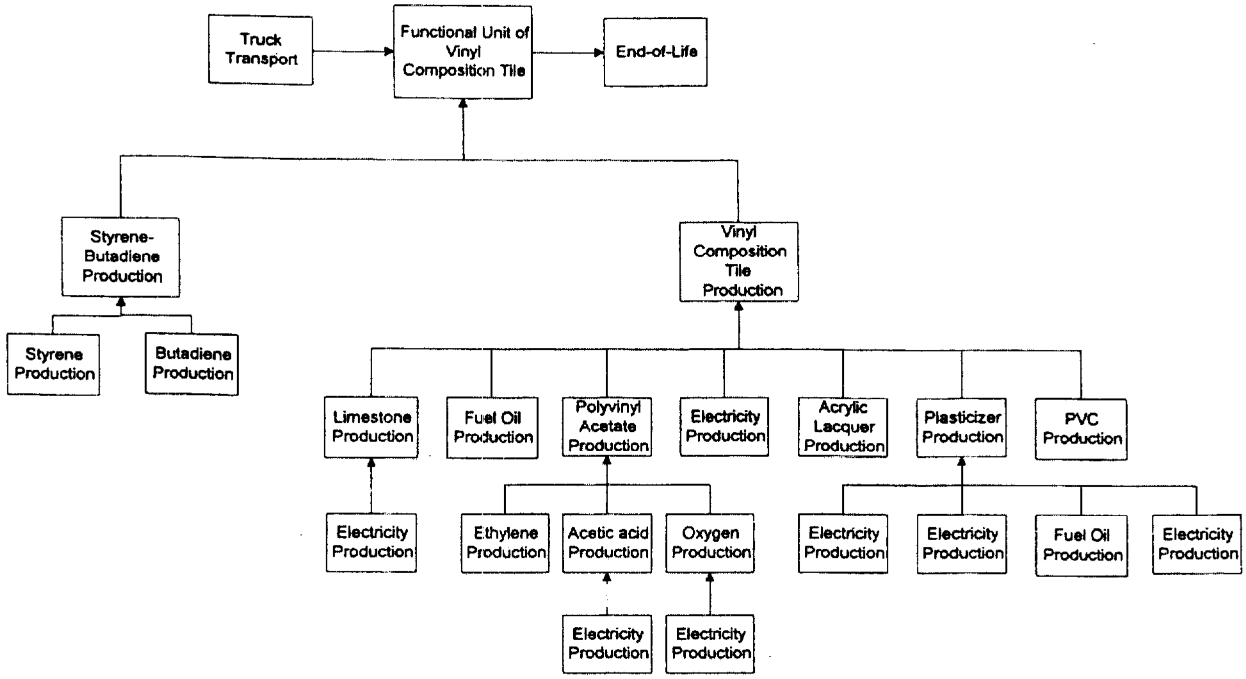

FIG. 1. Unit Processes for Vinyl Composition Tile Floor Covering

actual site and literature searches from more than 15 countries. Where necessary, the data are adjusted to be representative of U.S. operations and conditions. Approximately 90% of the data come directly from specific industry sources, with about 10% coming from generic literature and published reports. The generic data include inventory flows for electricity production from the average U.S. grid and for selected raw material mining operations (e.g., limestone, sand, and clay raw material mining operations). In addition, Environmental Strategies and Solutions, Inc. and Ecobalance, Inc. gathered additional LCA data to fill data gaps for the BEES products. Assumptions regarding the unit processes for each building product were verified through experts in the appropriate industry to assure the data are correctly incorporated in BEES. Table 1 shows selected inventory flows per functional unit for two floor covering alternatives—linoleum sheet flooring and vinyl composition tile.

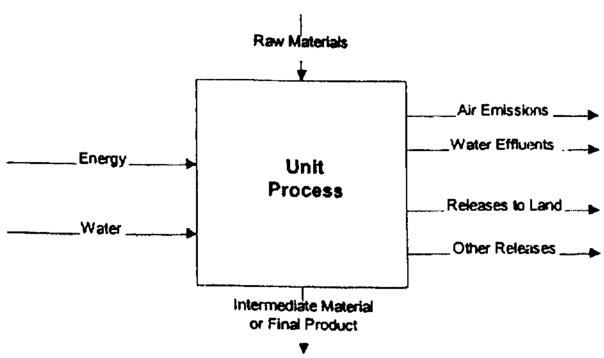

FIG. 2. BEES Inventory Data Categories

TABLE 1. BEES Inventory Analysis: Selected Air Emissions Results for Floor Coverings

Inventory flow (1)	Linoleum (g/functional unit[a]) (2)	Vinyl tile (g/functional unit[a]) (3)
Ammonia	1.08526	0.00000
Carbon dioxide	381.20300	1,347.09000
Hydrogen chloride	0.10124	0.28529
Hydrogen fluoride	0.01037	0.01245
Methane	2.80955	1.97961
Nitrogen oxides	4.24570	6.19194
Nitrous oxide	0.08667	0.04173
Sulfur oxides	9.43610	7.60987

[a]Functional unit is 0.09 m^2 (1 ft^2) of floor covering for 50 years.

Step 3—Impact Assessment

The impact assessment step of LCA quantifies the potential contribution of a product's inventory flows to a range of environmental impacts. There are several LCA impact assessment approaches. The primary approach used in the BEES impact assessments is the classification/characterization approach, because it enjoys some general consensus among LCA practitioners and scientists (Lippiatt 1998a).

The classification/characterization approach to impact assessment was developed within the Society for Environmental Toxicology and Chemistry. It involves a two-step process as follows (DeSmet et al. 1992; Consoli et al. 1993; Fava et al. 1993):

- Classification of inventory flows that contribute to specific environmental impacts. For example, greenhouse gases such as carbon dioxide, methane, and nitrous oxide are classified as contributing to global warming.
- Characterization of the potential contribution of each classified inventory flow to the corresponding environmental impact. This results in a set of indexes, one for each impact, which is obtained by weighting each classified inventory flow by its relative contribution to the impact. For instance, the global warming potential index is derived by expressing each contributing inventory flow in terms of its equivalent amount of carbon dioxide. Table 2 shows the derivation of the global warming potential indexes for linoleum and vinyl composition tile flooring—Table 1 inventory flows for the three greenhouse gases are multiplied by their corresponding carbon dioxide equivalency factors, and the results are summed.

This classification/characterization method does not offer the same degree of relevance for all environmental impacts. For global and regional effects (e.g., global warming and acidifi-

TABLE 2. BEES Global Warming Impact Assessment Results for Floor Coverings

Inventory flow (1)	Carbon dioxide equivalency factor (*Radiative* 1994) (2)	Carbon Dioxide Equivalents ($g\ CO_2$/functional unit[a])	
		Linoleum (3)	Vinyl tile (4)
Carbon dioxide	1	381	1,347
Methane	24.5	69	49
Nitrous oxide	320	28	13
Global warming potential	—	478	1,409

[a]Functional unit is 0.09 m^2 (1 ft^2) of floor covering for 50 years.

TABLE 3. BEES Impact Assessment Results for Floor Coverings

Impact category (1)	Units (2)	Linoleum (3)	Vinyl tile (4)
Global warming	Carbon dioxide equivalents (g/functional unit[a])	478	1,409
Acidification	Hydrogen equivalents (g/functional unit)	0.454	0.381
Nutrification	Phosphate equivalents (g/functional unit)	41.388	0.825
Natural resource depletion	Resource depletion factor (per functional unit)	0.046	0.048
Indoor air quality	Dimensionless score	100	55
Solid waste	Volume to landfill (C.Y./functional unit)	0.033	0.028

[a]Functional unit is 0.09 m^2 (1 ft^2) of floor covering for 50 years.

cation) the method may result in an accurate description of the potential impact. For impacts dependent upon local conditions (e.g., smog) it may result in an oversimplification of the actual impacts because the indexes are not tailored to localities. For this reason, and because BEES has a U.S. average scope, local impacts such as smog are not included. The following global and regional impacts are assessed using the classification/characterization approach and included in BEES: global warming potential, acidification potential, nutrification potential, and natural resource depletion. Indoor air quality, and solid waste impacts are also included in BEES, for a total of six impacts. Besides local impacts, other potential environmental impacts are not included. Ozone depletion is excluded because the primary contributing inventory flows (chlorofluorocarbons, halons, and chlorine-based solvents) are being phased out. Thus, inventory flow data are quickly changing, and soon there will be little left to report. Human health impacts are also not explicitly included in the first version of the BEES system because the science is still being developed. (Work is now under way to include human health impacts in BEES version 2.0.) If the BEES user has important knowledge about these or other potential environmental impacts, it should be brought into the interpretation of the BEES results.

Table 3 shows the BEES impact assessment results for linoleum and vinyl composition tile flooring.

Step 4—Interpretation

At the LCA interpretation step, the impact assessment results are combined. Few products are likely to dominate competing products in all six BEES impact categories. Rather, one product may out-perform the competition relative to natural resource depletion and solid waste, fall short relative to global warming and acidification, and fall somewhere in the middle relative to indoor air quality and nutrification.

Synthesizing the six impact category performance measures into a single, meaningful measure of overall environmental performance involves combining apples and oranges. BEES expresses global warming potential in carbon dioxide equivalents, acidification in hydrogen equivalents, nutrification in phosphate equivalents, natural resource depletion as a factor reflecting remaining years of use and reserve size, solid waste in volume to landfill, and indoor air quality as a dimensionless score. How can these diverse measures of impact category performance be combined? The most appropriate technique is multiattribute decision analysis (MADA). MADA problems are characterized by trade-offs between apples and oranges, as is the case with the BEES impact assessment results. The BEES system follows the ASTM standard for conducting MADA evaluations of building-related investments ("Standard" 1995).

MADA combines impact category performance measures by weighting each impact category by its relative importance to environmental performance. In the BEES software, the user defines the set of importance weights. Two alternative weight sets are provided as guidance. These weight sets are based on studies by the U.S. EPA's Scientific Advisory Board (SAB) and by Harvard University and represent two different ways in which U.S. experts value the environment. The BEES user may choose to use either of these weight sets unchanged or as a starting point for developing their own set of weights.

EPA SAB Study

In 1990, EPA's SAB developed lists of the relative importance of various environmental impacts to help EPA best allocate its resources. The following criteria were used to develop the lists:

- Spatial scale of the impact
- Severity of the hazard
- Degree of exposure
- Penalty for being wrong

Five of the BEES impact categories were among the SAB lists of relative importance (U.S. EPA 1990):

- Relatively High-Risk Problems: global warming and indoor air quality
- Relatively Medium-Risk Problems: acidification and nutrification
- Relatively Low-Risk Problems: solid waste

The SAB did not explicitly consider natural resource depletion as an impact. For this exercise, natural resource depletion is assumed to be a relatively medium-risk problem, based on other relative importance lists (Levin 1996).

Verbal importance, such as "relatively high risk," may be translated into a numerical importance weight by an explicit mathematical method provided by MADA. The importance weights derived for the six BEES impacts based on the verbal rankings from the EPA SAB study are shown in Table 4.

TABLE 4. Relative Importance Weights Based on EPA and Harvard Studies

Impact category (1)	Relative Importance Weights (%)	
	EPA (2)	Harvard (3)
Global warming	27	28
Acidification	13	17
Nutrification	13	18
Natural resource depletion	13	15
Indoor air quality	27	12
Solid waste	7	10

TABLE 5. Deriving BEES Environmental Performance Scores for Floor Coverings Based on EPA Importance Weights

Impact category (1)	Linoleum: Normalized impact assessment score (2)	Linoleum: Normalized, weighted impact assessment score (3)	Vinyl Tile: Normalized impact assessment score (4)	Vinyl Tile: Normalized, weighted impact assessment score (5)
Global warming	34	9	100	27
Acidification	100	13	84	11
Nutrification	100	13	2	0
Natural resource depletion	96	12	100	13
Indoor air quality	100	27	55	15
Solid waste	100	7	83	6
Environmental performance score	—	81	—	72

Harvard University Study

In 1992, an extensive study was conducted at Harvard University to establish the relative importance of environmental impacts (Norberg-Bohm et al. 1992). The study developed separate assessments for the United States, The Netherlands, India, and Kenya. In addition, separate assessments were made for "current consequences" and "future consequences" in each country. For current consequences, more importance is placed on impacts of prime concern today. Future consequences place more importance on impacts that are expected to become significantly worse in the next 25 years.

Five of the BEES impact categories were among the studied impacts. The study did not explicitly consider solid waste as an impact. For this exercise, solid waste is assumed to rank low for both current and future consequences, based on other relative importance lists (Levin 1996).

As with the EPA study, verbal importance rankings specified in the Harvard study may be translated into numerical, relative importance weights by following guidance provided by MADA. Sets of relative importance weights are derived for current and future consequences and then combined by weighting future consequences as twice as important as current consequences (the Harvard study ranks impacts "high" in future consequences if the current level of impact is expected to double in severity over the next 25 years based on a "business as usual" scenario). Table 4 lists the combined relative importance weights for the six BEES impacts based on the Harvard study. This set of combined importance weights is offered as an option in BEES.

Table 5 illustrates how the impact assessment results for linoleum and vinyl composition tile flooring in Table 3 are synthesized into environmental performance scores using the MADA technique. MADA synthesizes the impact category performance measures by first placing them on a common scale (normalizing) and then weighting each category's normalized score by its relative importance to environmental performance. Within an impact category, each product's performance measure is normalized by dividing by the highest measure for that category. All performance measures are thus translated to the same dimensionless, relative scale from 0 to 100, with the worst performing product in each category assigned a normalized score of 100. In Table 5, the normalized scores are then weighted using the EPA importance weight set from Table 4. The sum of the normalized, weighted impact assessment scores is the environmental performance score, taking into account both relative performance and importance. Table 5 illustrates the trade-offs among environmental impacts that are often found in LCAs. As shown, linoleum performs better (has lower scores) than vinyl composition tile on global warming and natural resource depletion and performs worse (has higher scores) on acidification, nutrification, indoor air quality, and solid waste. The environmental performance score indicates that, taking into account all six impacts, vinyl composition tile performs better environmentally than linoleum.

ECONOMIC PERFORMANCE

Measuring the economic performance of building products is more straightforward than measuring environmental performance. Published economic performance data are readily available, and there are ASTM standard methods for conducting economic performance evaluations. First cost data are collected for the BEES system from the R.S. Means publication, *1997 Building Construction Cost Data*, and future cost data are based on data published by Whitestone Research in *The Whitestone Building Maintenance and Repair Cost Reference 1997*. The most appropriate method for measuring the economic performance of building products is the life-cycle costing (LCC) method. Thus, the BEES system follows the ASTM standard method for LCC of building-related investments ("Standard" 1993).

It is important to distinguish between the study periods used to measure environmental performance and economic performance. The lengths and elements of these study periods are different, as shown in Fig. 3. Recall that in environmental LCA, environmental performance is measured over the product environmental life cycle, beginning with raw material acquisition and ending with product end-of-life. The economic life cycle, on the other hand, is limited to a fixed period beginning with the purchase and installation of the product, and ending at some point in the future that does not necessarily correspond with product end-of-life.

Economic performance is evaluated beginning at product purchase and installation because this is when out-of-pocket costs begin to be incurred, and investment decisions are made based upon out-of-pocket costs. The economic study period ends at a fixed date in the future. Its length is often set at the useful life of the longest-lived product alternative. However, when all alternatives have very long lives, (e.g., more than 50

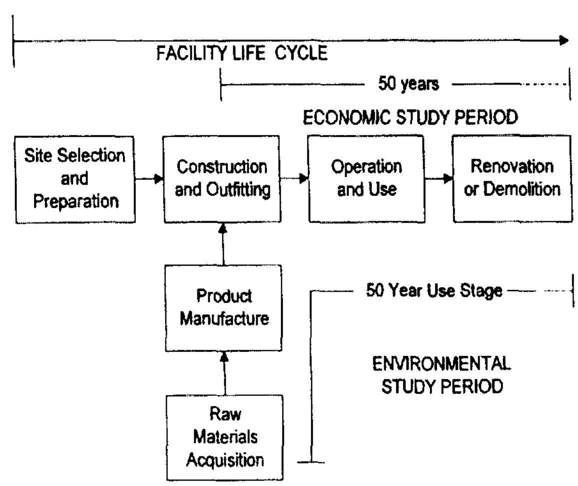

FIG. 3. BEES Study Periods for Measuring Product Environmental and Economic Performance

years), a shorter study period may be selected for three reasons:

- Technological obsolescence becomes an issue
- Data become too uncertain
- The farther in the future, the less important the costs

In the BEES model, economic performance is measured over a 50-year study period. The same 50-year period is used to evaluate all products, even if they have different useful lives. This is one of the strengths of the LCC method. It adjusts for the fact that different products have different useful lives when evaluating them over the same study period. For consistency, the BEES model evaluates the use stage of environmental performance over the same 50-year study period. Product replacements over this 50-year period are accounted for in both the economic and environmental performance scores.

The LCC method sums over the study period all relevant costs associated with a product. Alternative products for the same function, say floor covering, can then be compared on the basis of their LCCs to determine which is the least cost means of providing that function over the study period. Categories of cost typically include costs for purchase, installation, maintenance, repair, and replacement. A negative cost item, or one that reduces LCC, is the residual value. The residual value is the product value remaining at the end of the study period. In the BEES model, the residual value is computed by prorating the purchase and installation cost over the product life remaining beyond the 50-year study period.

The LCC method accounts for the time value of money by using a discount rate to convert all future costs to their equivalent present value. Future costs must be expressed in terms consistent with the discount rate used. The BEES model computes LCCs using constant 1997 dollars and a real (excluding inflation) discount rate. As a default, the BEES system uses a real discount rate of 3.6%, the 1997 rate mandated by the U.S. Office of Management and Budget for most federal projects ("Guidelines" 1992, 1997).

Table 6 illustrates the computation of life-cycle costs for linoleum and vinyl composition tile flooring. Both products have useful lives of 18 years, with purchase and installation costs in constant 1997 dollars totaling $3.29 for linoleum and $1.71 for vinyl composition tile. Over the 50-year study period, both products are replaced in years 18 and 36. At the end of year 50, both products have 4 years, or 22.2%, of their useful lives remaining, giving linoleum a residual value of $0.73 (=$3.29 × 0.222) and vinyl composition tile a residual value of $0.38 (=$1.71 × 0.222) in 1997 dollars. Discounting these constant dollar costs using the U.S. Office of Management and Budget real discount rate of 3.6% gives the present values shown in Table 6. Summing the present value costs for each product gives its life-cycle cost. As shown, linoleum's LCC is almost twice that of vinyl composition tile.

OVERALL PERFORMANCE

BEES combines the environmental and economic performance results into a single, overall performance score. To combine them, the two results must first be placed on a common scale. The environmental performance score reflects relative environmental performance, or how much better or worse products perform with respect to one another. The life-cycle cost reflects absolute performance, irrespective of the set of alternatives under analysis. Before combining the two, the life-cycle costs are converted to the same, relative scale as the environmental scores, with the highest-LCC product assigned a normalized score of 100, as shown in Table 6.

To combine environmental and economic performance scores using the MADA technique, the scores are weighted and then normalized. The BEES user specifies the relative importance weights for environmental versus economic performance and is encouraged to test the sensitivity of the overall scores to different sets of relative importance weights. Using equal environmental and economic performance weights, Table 7 shows how the performance scores from Tables 5 and 6 are weighted and then normalized to derive the overall performance scores for linoleum and vinyl composition tile flooring (59 and 40, respectively).

Fig. 4 illustrates the display of overall performance results in the BEES system using Table 7 results for linoleum and

TABLE 6. Deriving BEES Economic Results for Floor Coverings

Life-cycle cost component (1)	Linoleum: Constant \$/functional unit[a] (2)	Linoleum: Present value \$[b]/functional unit (3)	Vinyl Tile: Constant \$/functional unit[a] (4)	Vinyl Tile: Present value \$[b]/functional unit (5)
Purchase and installation cost, year 0	3.29	3.29	1.71	1.71
Replacement cost, year 18	3.29	1.74	1.71	0.90
Replacement cost, year 36	3.29	0.92	1.71	0.48
Residual value, year 50	−0.73	−0.12	−0.38	−0.06
Life-cycle cost	—	5.83	—	3.03
Economic performance score[c]	—	100	—	52

[a]Functional unit is 0.09 m^2 (1 ft^2) of floor covering for 50 years.
[b]Based on a 3.6% discount rate. Present value of future cost occurring in year t, F_t, given a discount rate, d, is $F_t/(1 + d)^t$.
[c]Computed by dividing product life-cycle cost by life-cycle cost for highest life-cycle cost product and multiplying by 100.

TABLE 7. Deriving BEES Overall Scores for Floor Coverings Based on Equal Importance Weights for Environmental and Economic Performance

Floor covering (1)	Weighted Scores: Environmental (50% weight) (2)	Weighted Scores: Economic (50% weight) (3)	Weighted Scores: Overall (4)	Weighted, Normalized Scores[a]: Environmental (5)	Weighted, Normalized Scores[a]: Economic (6)	Weighted, Normalized Scores[a]: Overall (7)
Linoleum	40	50	90	26	33	59
Vinyl tile	36	26	62	23	17	40
Sum	—	—	152	—	—	—

[a]Weighted scores are normalized by dividing by sum of weighted overall scores (152).

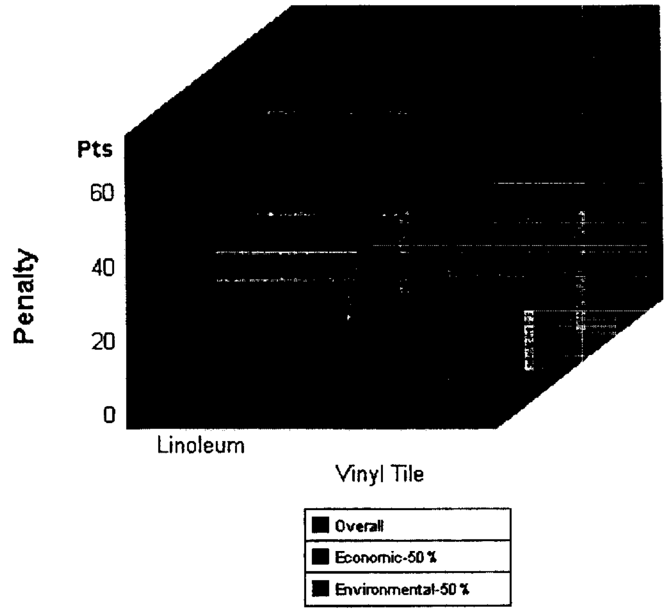

FIG. 4. BEES Overall Performance Scores for Floor Coverings

vinyl composition tile flooring. The graph displays for each product its weighted, normalized environmental and economic performance scores and their sum—the overall performance score. Note that the more penalty points, the worse the performance. Because linoleum scores worse than vinyl flooring on both environmental and economic performance, linoleum will score worse on overall performance for any set of environmental/economic performance weights.

SUMMARY

The BEES approach measures and combines product environmental and economic performance into a single, overall performance score, as illustrated in Fig. 5. The approach offers a unique blend of environmental science, economics, and decision science. Economics dictates how to combine a stream of costs over time into a single measure of financial worth. However, measures of financial worth do not adequately account for the environmental performance of most products. Thus, environmental science is used to measure and combine inventory flows, or environmental inputs and outputs over the life of a product, into meaningful measures of environmental performance. But how can nonfinancial measures of environmental performance, such as global warming and resource depletion indexes, be combined with financial measures of worth, such as a life-cycle costs? This is where decision science comes in. Decision science specifies how to synthesize multiple, noncommensurate measures of performance so that both financial and nonfinancial impacts may be included in the product evaluation. In doing so, it structures and systematizes the way in which value judgments are introduced into the decision-making process. The process separates the value judgments from the environmental science and the economics so that the effects of changes in judgment on the evaluation results may be tested.

The BEES tool uses life-cycle concepts, is based on consensus standards, and is designed to be practical, flexible, and transparent. It is practical in its systematic packaging of detailed performance data in a manner that offers useful decision support. It is flexible in allowing tool users to customize judgments about key evaluation parameters for which there is no consensus, such as the environmental impact category weights. Finally, it is transparent in documenting the supporting performance data and computational algorithms.

CONCLUSIONS

Applying the BEES approach to linoleum and vinyl composition tile floor covering reinforces the importance of taking a quantitative, multiattribute, life-cycle approach to assessing product environmental and economic performance. Carrying out such an approach is important because it can lead to conclusions that argue against conventional wisdom. Linoleum is widely believed to be environmentally preferable because it is an agriculturally based product made from renewable linseed oil, cork, and jute. Vinyl composition tile is widely thought not to be environmentally preferable because it is a petroleum-based product. However, relative to other types of vinyl flooring (e.g., vinyl sheet flooring), vinyl composition tile actually contains a low proportion of petroleum-based constituents and a high proportion of inorganic filler (limestone). Furthermore, agriculturally based products such as linoleum typically involve fertilizer use, which leads to flows of large quantities of nutrients contributing to undesirable nutrification impacts. In addition, linoleum manufacture and distribution for U.S. consumption involves significant energy use, as linoleum is typically manufactured in Europe using linseed oil imported from the United States, cork imported from Portugal, and jute from the Philippines. Linoleum is then exported to the United States. When these and other life-cycle environmental attributes are quantified and combined using the EPA importance weights, the net effect is environmental scores slightly favoring vinyl composition tile. Coupled with linoleum's relatively poor economic performance due to first costs that are almost double that of the equally-durable vinyl composition tile, linoleum fares significantly worse overall. Note that if linoleum

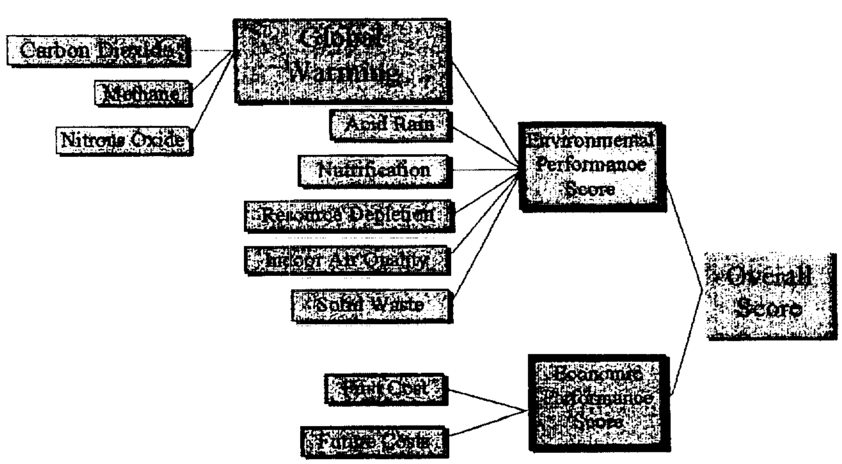

FIG. 5. Deriving BEES Overall Performance Score

were typically manufactured in the United States, the likely drop in embodied energy and first costs could significantly change its environmental and economic performance.

Applying the BEES approach to the other 22 building products included in BEES 1.0 (including roof coverings, exterior wall cladding, basement walls, sheathing, and insulation) leads to several general conclusions. First, environmental claims based on single attributes, such as recycling, should be viewed with skepticism. These claims do not account for the fact that other impacts may indeed cause equal or greater damage. Second, assessments must always be quantified on a functional unit basis, such that the products being compared are true substitutes for one another. One product may be environmentally superior to another on a kilogram-for-kilogram basis, but if that product requires twice the mass as the other to cover 1 m^2 of roof, the results may reverse. Third, a product may contain a high-impact constituent, but if that constituent is a small portion of an otherwise relatively benign product, its significance decreases dramatically. Such is the case for the petroleum basis of vinyl composition tile, as noted above, and for the cement content of concrete. Concrete is often derided for the embodied energy of cement, but cement constitutes only 10–15% of concrete's total mass. Finally, a short-lived, low first-cost product is often not the cost-effective alternative. A higher first cost may be justified many times over for a durable, maintenance-free product. In sum, the answers lie in the trade-offs.

The BEES tool will be expanded and refined over the next several years. Product technical performance will be added to the overall environmental/economic balance, and more environmental impacts will be included in the environmental performance score. Users will have the option of entering their own environmental and economic performance data. U.S. region specificity and greater flexibility in product specifications (e.g., useful lives) will also be incorporated. Finally, many more products will be added to the system so that entire building components and systems can be compared.

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