Measuring Product Sustainability

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Abstract

Is our product or service sustainable? Many industrial firms are posing this question as they begin to embrace the long-term goal of sustainable development. While operational definitions of sustainability provide general guidance, the actual evaluation of sustainability for a specific product or service has proven challenging. The authors review current practices of leading companies, and then propose a Sustainability Performance Measurement framework that embodies three principles ¾ separation of resource and value measures, explicit representation of the triple bottom line, and consideration of the full life cycle.

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Introduction

Sustainability is a compelling concept — who can resist the argument that all products of commerce should contribute to preserving the quality of the societal and ecological environment for future generations? However, putting this concept into practice has baffled some of the best minds in leading global corporations. How does one distinguish a "sustainable" product from one that is not? This question poses new challenges for the design community, extending far beyond the traditional scope of product development. Some of the difficulties that arise are the:

- Lack of consensus on a pragmatic definition of sustainability
- Breadth of scope of sustainability issues, many of which are beyond the firm's control
- Potentially large amount of information required to evaluate product sustainability
- Difficulty in quantifying the societal and ethical aspects of sustainability

Perhaps one of the most formidable difficulties is the challenge of business integration. To successfully develop sustainable products, a company must learn how to effectively integrate sustainability concepts into its product development process. Sustainable product design cannot be practiced in isolation; rather it must be one facet in a multi-faceted approach that considers cost, ease of use, functional performance, manufacturability, and other key product requirements.

However, trying to achieve this type of integration raises both organizational and technical issues. Organizational issues include the establishment of appropriate company policies and incentives, modification of existing business processes, capture and dissemination of sustainable design knowledge via training and information technology, and achievement of consistent practices across diverse business units. Technical issues include the implementation of various design strategies — e.g., modifying the material composition of products so that they generate less pollution and waste, or changing the assembly requirements so that fewer material and energy resources are consumed per product unit — as well as systematic adoption of sustainable design guidelines, metrics, and tools.

These organizational and technical issues are equally important, and must be addressed from the strategic, tactical and operational perspectives, as suggested in Table 1. In reviewing this scope, one fact becomes clear: *a fundamental element of any successful program is the establishment of measurable goals and performance indicators*. Without a concrete basis for measuring success, policy statements are ineffectual, accountabilities are ambiguous, and design evaluation remains subjective and imprecise. Therefore, this paper focuses upon the emerging field of sustainability performance measurement.

Table 1: Scope of Sustainable Product Design Issues

	Strategic	**Tactical**	**Operational**
Organizational	Company policy and commitment	Reward systems and accountability	Performance indicators and targets
Technical	Next-generation R&D strategy	Key design concepts and features	Design evaluation and improvement tools

While a number of performance indicators have recently been developed to measure *eco-efficiency*, little work has been done in a less tangible aspect of sustainability; namely, measuring the *socioeconomic* impacts of products. Most organizations that have published sustainability indicators have focused upon macro-environmental features for a community or a society as a whole. In contrast, product developers need more focused indicators that address the beneficial or adverse impacts associated with particular design innovations.

To address that need, this article first characterizes the current state of the art with respect to sustainability performance measurement, and then presents a conceptual framework that will support systematic development of performance indicators for virtually any type of product. Although sustainability as a business practice is still at an embryonic stage, a viable approach toward measuring sustainability can be forged by building on the general principles of performance measurement and on the lessons learned by companies during the past decade in establishing environmental performance evaluation systems.

Review of Sustainability Measurement Practices

> *"Meeting the needs of the present without compromising the ability of future generations to meet their own needs."* - Brundtland Commission, 1987

The original definition of sustainable development, provided by the Brundtland commission, proved to be too ambiguous to allow organizations interested in pursuing sustainability to establish meaningful goals and metrics. Therefore, several groups have revised this definition to include three key aspects of business performance – *economic*, *environmental* and *societal*.

Efforts to evaluate each aspect of this "triple bottom line" of sustainability have progressed somewhat independently, and have reached different levels of sophistication. As shown in Figure 1, corporate reporting practices for these three aspects have evolved over vastly different time frames. Corporate *financial* reporting has been providing information on economic performance since the beginning of the 20th century, while corporate *environmental* reporting has been practiced for less than a decade. Corporate *social* reporting was first attempted in the 1970's, and has recently been revived. Corporate *sustainability* reporting, which combines elements of all three aspects, has been attempted only in the last few years, and is still in an exploratory phase. The sections that follow discuss the current state-of-the-art in each of the three aspects of sustainability performance measurement.

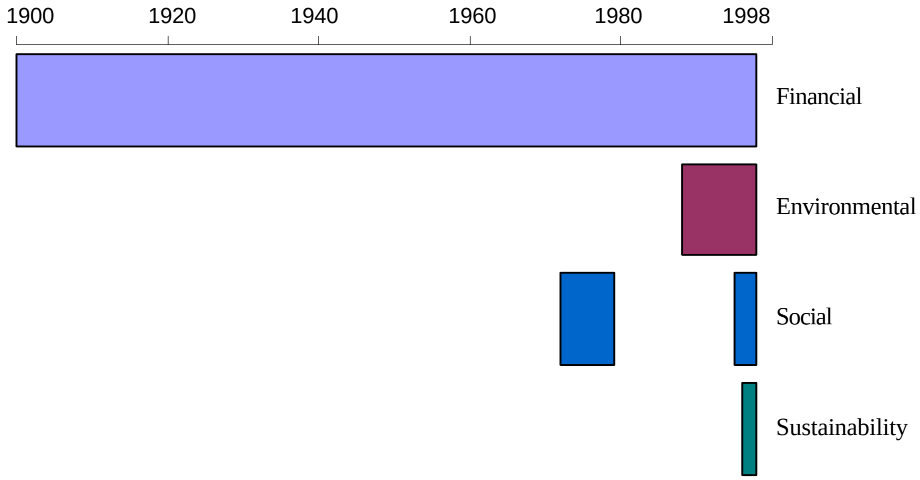

Figure 1: Comparative Time Frames of Triple Bottom Line Reporting

Economic Performance Evaluation

Economic performance evaluation has been practiced for almost a century, although, it is perhaps better known as financial reporting. Standards for externally reporting financial results are highly developed, and a variety of rigorous guidelines and standards exist for these financial indicators. In contrast to this high level of standardization for external financial accounting, firms can choose from a wide variety of managerial accounting practices to support internal decisions. Over the last 20 years, the introduction of new accounting methods such as activity-based accounting and economic value added (EVA) accounting has helped to reveal the underlying drivers of economic performance and shareholder value (Blumberg, 1997).

To address the full scope of sustainability, economic performance evaluation must evolve beyond traditional techniques based solely on profitability and cash flow. Specific issues include (Epstein, 1996):

- Quantification of hidden costs associated with the utilization of material, energy, capital, and human resources
- Estimation of uncertain future costs associated with external impacts of industrial production and consumption
- Understanding the costs and benefits incurred by various stakeholders (customers, employees, communities, interest groups, etc.) across the life cycle of a product or process

A host of new research in life cycle accounting, environmental accounting, and full cost accounting has introduced new techniques that serve to highlight costs and benefits that are not explicitly addressed with conventional approaches. One of the leading practitioners of these new approaches is Chrysler Corporation. In designing several new automotive components, Chrysler considered the direct, potentially hidden and contingent costs associated with each design option.

Direct and potentially hidden costs were evaluated with activity-based costing methods, and contingent costs were estimated with proprietary risk factors developed by Chrysler.

As an example, when Chrysler developed an oil filter for a new line of vehicles, they estimated the direct material costs, some of the potentially hidden manufacturing expenses, and possible liabilities associated with waste disposal (Armstrong and White, 1997). This evaluation revealed that the design option with the lowest direct costs (materials and production labor) did not have the lowest overall life cycle cost because the hidden and liability costs were greater than the direct costs. Chrysler's experience illustrates how these new life cycle accounting methods can help design teams to assess product sustainability in economic terms.

Environmental Performance Evaluation

As shown in Figure 1, corporate environmental performance reporting has been practiced for at least the past decade. Recent research has demonstrated a plausible connection between improved environmental performance and increased shareholder value (Feldman, Soyka and Ameer, 1997), and a growing number of corporations have begun to voluntarily report their product and company environmental performance (Blumberg, 1997). These reporting efforts, in turn, have led to an increased demand for standard environmental reporting criteria, similar to those for financial reporting. For example, in 1992 the Public Environmental Reporting Initiative (PERI), a consortium of global firms, developed an influential set of guidelines for environmental reporting. The types of performance indicators typically presented in conventional environmental reports include wastes and emissions, employee lost-time injuries, notices of violation, spills and releases, etc.

With the introduction of the ISO 14000 series of standards, an international consensus was developed on the elements of an Environmental Performance Evaluation process, documented in ISO 14031 (Fiksel, 1997). An even more recent standardization initiative is the Global Reporting Initiative (GRI). Launched by the Coalition for Environmentally Responsible Economies (CERES) in the fall of 1997, the objective of the GRI is to standardize the methodology and format of corporate environmental and sustainability reports, and GRI hopes to propose standard indicators by the year 2000 (BATE, 1998). Although the standardization debate continues, one indicator of environmental performance has been used by over twenty companies to measure environmental/economic relationships – *eco-efficiency*.

Eco-efficiency is generally defined as a measure of environmental performance relative to economic input or output, and has been implemented in a variety of ways, as illustrated in Table 2. There are currently several initiatives seeking to standardize eco-efficiency measurement; for example, Canada's National Round Table on the Environment and Economy (NRTEE) has enlisted a number of firms in a pilot test of material and energy intensity indicators (NRTEE, 1997). Such eco-efficiency indicators, whether intended for enterprise-level goal setting or for product design, will be essential components of any quantitative evaluation of sustainability.

Table 2: The Use of Eco-Efficiency Indicators

Company	Current Eco-Efficiency Practice
Novo Nordisk	Novo Nordisk has implemented an eco-efficiency indicator that is calculated as the ratio of indexed turnover in constant prices to indexed resource consumption (NRTEE, 1997).
Northern Telecom (Nortel)	Nortel has developed a composite Environmental Performance Indicator (EPI) that is annually tracked and reported relative to baseline 1993 performance (NRTEE, 1997).
Sony Europe	Sony is utilizing an EPI for batteries that is calculated as economic value added over the product life time divided by the sum of the non-recyclable material consumption and the production energy use (Lehni, 1998).
Dow Chemical	Dow utilizes a unique EPI in their product environmental assessments – the Eco-Compass. This structure includes evaluations of mass intensity, risk potential, energy intensity, reuse, resource conservation, and extent of service. Each of these compass directions is evaluated using product life cycle analysis data and the results are intended for use in design decision making (Lehni, 1998) (James, 1997).

Societal Performance Evaluation

In the 1970's, many organizations began developing standards for corporate social accounting (Epstein, 1996). While interest in social evaluation faded in the 1980's, efforts to measure and report social performance have resurfaced in the last few years. This change is due partially to the need for societal indicators in the evaluation of sustainability, and partially to the increased media interest in the social impacts of corporate operations. Companies such as Nike and Shell have discovered that stakeholder concerns about management policies and practices can rapidly generate adverse publicity, damage brand image, and alienate customers.

One company that has pursued social reporting aggressively is The Body Shop. The UK-based hair and skin care product manufacturer and retailer released its first *Social Report* in 1995. In this and in the *1997 Values Report* (a combined social-ecological performance report), The Body Shop presents performance results on over 200 stated targets grouped into nine stakeholder categories. Although impressive in scope, The Body Shop's performance results are generally derived from surveys and results are presented as percentages of stakeholder responses. This type of information is no doubt useful in policy setting and internal performance tracking; however, it does not directly address the issue of sustainability. British Petroleum (BP) has attempted to evaluate its social performance in a slightly different manner. BP's *1997 Social Report* provides case studies in social impact assessment. Despite being generally non-quantitative, BP's report acknowledges that an important aspect of their social performance is creating value in the communities where they operate. As companies advance toward more sophisticated sustainability performance measurement, the value created by products and operations will become increasingly important.

With the emergence of efforts like those of BP and the Body Shop, there is an increased need for social performance evaluation methodologies and tools. Responding to this need, the Council on Economic Priorities (CEP) has proposed SA 8000, a social accountability standard designed to follow in the path of other “quality” standards. CEP hopes that like ISO 9000 and ISO 14000, SA 8000 will become the *de facto* standard for evaluating the quality of a company’s social performance. Although SA 8000 makes significant advances in standardizing the evaluation of corporate commitment to human rights issues, such as worker safety and equality, the issues covered by the standard include only a limited subset of the issues implied by sustainability (Ranganathan, 1998).

Recognizing that existing approaches do not address the full scope of sustainability concerns, a coalition has recently formed to develop appropriate societal performance measures. The group, led by Shell, plans to develop indicators that enable a firm to evaluate its societal impact. Although the effort will be specific to Shell, the results are likely to have implications for sustainability evaluation in other organizations as well.

Sustainability Performance Measurement (SPM)

As standards and accepted methodologies have evolved in economic, environmental and societal performance evaluation, a few companies have begun to publish integrated sustainability reports. In 1997, Interface, a US carpet manufacturer, published what is believed to be the first sustainability report. This early reporting effort demonstrates that Interface is committed to sustainable development and has taken initial steps to identify potential sustainability indicators. However, this initial report does not clearly indicate a framework which will be utilized in future performance measurement and progress evaluation.

Monsanto, the newly emerged life-sciences company, has also published a sustainability report. The Monsanto report provides an initial framework for product sustainability evaluation. However, Monsanto admits that this framework has yet to be implemented.

The lack of quantified performance indicators in the Interface and Monsanto sustainability reports is not surprising, SPM is still in its infancy and these companies are attempting to expand the boundaries of available methodologies. These early attempts at integrated sustainability measurement highlight the need for a framework that facilitates meaningful indicator development.

The Sustainable Business Centre in the UK has developed a product design tool to address the need for sustainability measurement – *the sustainability circle* (James, 1997). The circle is a graphical representation of product performance based on the results of 16 indicators. These indicators are grouped into categories which encompass the triple-bottom line perspective. The Sustainable Business Centre uses five categories to evaluate product sustainability, they are: physical environmental impacts, product attributes, social impacts, transport, and customer value. Indicator scores are provided to the decision maker by shading the appropriate section of the circle a specific color.

For example, if the design team determines that the product has excessive energy use, the corresponding section of the circle would be red. If the product has a major sustainability advantage, such as elimination of hazardous waste, another section of the circle would be shaded dark green. This process continues until each section of the circle has been assigned a color, thus providing decision makers with an easy-to-grasp visual display of the tradeoffs. This type of graphical representation is universally understandable, and leaves it up to the product development team to determine what specific performance indicators would be most meaningful within each category of sustainability.

Influencing the Product Development Process

As described above, a number of pioneering companies are adopting sustainability goals and beginning to introduce sustainability considerations into the product development process. Influencing this process is essential if a company is to achieve "step-changes" in performance, as opposed to incremental improvements. A first step toward sustainable product development is practicing *eco-design*, or Design for Environment (DFE), which may be defined as systematic consideration of design performance with respect to environmental, health and safety (EH&S) objectives over the full product life cycle (Fiksel, 1996). This definition encompasses not only environmental protection issues but also traditional health and safety concerns that may be important considerations in product design. Indeed, many practitioners of eco-design find it a useful "umbrella" concept that integrates a variety of related disciplines, including environmental risk management, product safety, occupational health and safety, pollution prevention, resource conservation, accident prevention and waste management.

The boundaries associated with eco-design are broader than those in the usual definition of a product "system." Rather than merely considering how the product interacts with its physical environment, it considers the entire supply chain — upstream processes that produce the components, raw materials and energy to fabricate the product, as well as downstream processes involved in its distribution, use and disposal. DFE also addresses how by-products might be beneficially used and how waste products may affect humans or the environment. A key approach in eco-design is the pursuit of *eco-efficiency*, enabling simultaneous improvements in resource productivity (which contributes to profitability), and environmental conservation (which contributes to sustainability). In other words, by eliminating waste and using resources more wisely, eco-efficient companies can reduce costs and become more competitive. However, the scope of *sustainable* product design must move beyond efficiency to also consider the societal aspect of the triple bottom line, including issues such as quality of life and social equity.

The Need for Integration

For sustainable design to be adopted in a meaningful way, it must be fully integrated into the product development process. This requires an understanding of the primary product design drivers, including reduction in product development cycle time, continuous improvement in product quality, and responsiveness to the "voice of the customer." As an example, certain sustainability characteristics — e.g., durability, modularity, waste elimination — are naturally synergistic with cost of ownership, which is an increasingly important customer criterion. However, to capture these types of synergies, a design organization must incorporate sustainability awareness systematically into the daily work of development teams. This is a logical extension of the modern practice of Integrated Product Development (IPD), whereby cross-functional teams begin at the conceptual design stage to consider life cycle issues including quality, manufacturability, reliability, maintainability, environment and safety. Many companies use a "stage-gate" process, requiring that a product satisfy a variety of performance criteria before passing on to the next stage of development. Clearly, sustainability considerations need to be woven into this stage-gate process and the associated criteria.

The eco-design tools that are being used today tend to be relatively simple, ranging from rudimentary "advisory" systems that provide on-line design guidance to performance tracking tools that represent multi-dimensional indicators. A number of companies have developed internal systems, although they are seldom fully integrated into the design automation environment. For example, a "Green Index" software tool was developed by AT&T to assess a product's overall environmental performance. Hughes Aircraft has implemented a similar system called the "Green Notes Environmental Rating and Measurement System", which is used to automatically provide ratings as designers develop their product and process specifications. A few companies are using streamlined life cycle assessment tools to provide somewhat more rigorous product evaluations.

In today's exploratory phase, simple tools are preferable to help the rapid establishment of sustainable product design with minimal disruption to existing business processes. Eventually, new types of information technology, such as "intelligent assistant" design tools, will facilitate the transformation from traditional ways of doing business to a more integrated approach. Once sustainability principles become embedded into decision support software tools, they will become more accessible to the vast majority of companies that are extremely busy meeting the needs of their stakeholders and do not have the time or resources for developing new processes and systems. These companies will be primarily interested in practical applications of sustainable design, to the extent that it contributes to their success in the marketplace.

Creating a Measurement Framework

An essential element in the practice of sustainable product design is the capability to evaluate and predict product performance in objective, measurable terms. In this context, one of the key challenges is to incorporate a life-cycle view of sustainability performance into measurement tools that can be easily implemented. The remainder of this article suggests how decision-makers can design and implement a Sustainability Performance Measurement framework for their products, processes, or services. This framework is built upon the following three principles:

Resource and Value

A sustainable product should minimize resource consumption while maximizing value creation in the triple bottom line sense. Here, <u>resources</u> are defined broadly to be natural or anthropogenic stocks that are required for the creation, use and disposition of a product. Examples of resources include materials, energy, labor, and land. <u>Value</u> is defined as a condition, attributable to a product, that benefits one or more of the enterprise's stakeholders. Examples of value creation include increased profitability, reduced pollution, improved nutrition, and liberation of time.

The first principle of sustainability measurement is that evaluations must address the dual perspectives of resource consumption and value creation.

Three Aspects

Effective sustainability measurement should consider the complete triple bottom line as it relates to the product in question. This means that both resource consumption and value creation should be considered in terms of economic, environmental, and societal aspects. For example, an automobile consumes economic resources in terms of operation and maintenance costs, environmental resources in terms of fossil fuel, and societal resources in terms of personal time spent driving.

Most product indicator frameworks focus exclusively on economic or environmental performance, and very few address societal concerns (James, 1997). Based on the resurgence of attention to companies' societal performance, we anticipate an increased focus on the societal impacts of products and services.

The second principle of sustainability measurement is that evaluations must include economic, environmental, and societal aspects.

Life Cycle

Finally, resource consumption and value creation, in terms of all three aspects, take place throughout the life cycle, including the supply, manufacturing, use and disposition of a product. An evaluation that focuses exclusively on one life cycle stage (e.g., manufacturing) may fail to capture significant product benefits or impacts that occur in either upstream or downstream stages (Fiksel, 1996). Referring again to the automobile example, it is only recently that designers have begun to consider the end-of-life stage, and the potential impacts of disassembly, recycling, recovery, refurbishment and re-use.

The third principle of sustainability measurement is that evaluations must systematically consider each stage in the product life cycle.

Holistic Framework

These three principles can be integrated visually to create the framework depicted in Figure 2. The sustainability of a product can be evaluated by considering the economic, environmental and societal aspects of resource consumption and value creation throughout its life cycle. (In Figure 2 the halves of the circles represent resource consumption and value creation.)

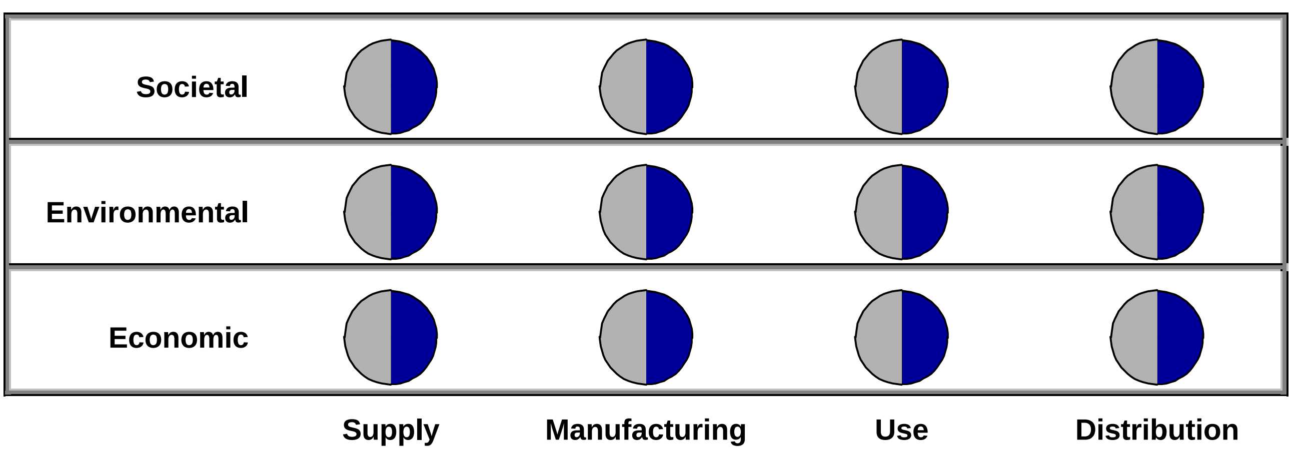

Figure 2: Sustainability Performance Measurement Framework

Performance Indicators and Metrics

Once a sustainability measurement framework has been established, design teams can proceed to select appropriate performance indicators and accompanying metrics that best represent the contributions of their product to sustainability. A recommended approach to selecting indicators and metrics is discussed briefly below.

Basic concepts

A performance indicator is a specific, measurable product attribute that characterizes its contribution to some aspect of sustainability (Fiksel, 1997). Performance indicators can be grouped into two categories: *lagging* and *leading*. Commonly used lagging indicators, also known as "result" indicators, include air emissions released, environmental costs incurred, and customer benefits provided. These indicators can only be validated in a retrospective fashion once the product has been released. In contrast, leading indicators, also known as "process" indicators, measure internal practices or efforts that are expected to improve performance; e.g. employee training or quality control. Thus, the purpose of process indicators is not to measure results but rather to encourage a focus on product or service performance drivers.

Each selected performance indicator must be associated with at least one metric that defines a specific means of tracking and reporting that indicator. Metrics should ideally be verifiable, objective, and meaningful to decision-makers and stakeholders. A variety of metrics can be chosen for most indicators; e.g., potential metrics for *solid waste generation* include annual volume (tons/yr.), annual improvement (% weight reduction), cost ($/yr.), or quantity avoided (tons recycled/yr.). Two broad categories of metrics exist: the first is quantitative metrics that rely upon empirical data and characterize performance numerically, e.g., dollars of revenue. The second category is qualitative metrics that rely upon semantic distinctions based on observation and judgment. For example, to track a product's societal performance, a company could survey its stakeholders to determine how its performance was perceived. An illustration of the above indicator and metric categories is provided in Table 3.

Table 3: Examples of Indicators and Metrics

	Quantitative Metric	Qualitative Metric
Leading Indicator	Sustainability Training (# of employees trained)	Sustainability Training (employee evaluation of training courses)
Lagging Indicator	Product Eco-Efficiency (lbs. product/total lbs. input)	Product Eco-Efficiency (stakeholder satisfaction or number of awards)

Selecting Indicators and Metrics

The Sustainability Performance Measurement Framework, shown in Figure 2, can provide a starting point for designers when selecting the most appropriate set of performance indicators and metrics. One approach would be to qualitatively characterize each aspect of the product's performance (as done in the sustainability circle discussed earlier) as 1) an area of concern, 2) an area without significant weakness or strength, or 3) one of possible sustainability advantage. Under this approach, the design team would assess subjectively how their product will create value and consume resources throughout it life cycle. Such a qualitative assessment can be conducted through a workshop session involving an expert team, and the results can be displayed visually. The obvious advantage of this approach is its relative simplicity compared to the data-intensive steps required to quantify the entire life cycle performance.

A more rigorous and demanding approach would focus on the critical aspects of product performance and devise either leading or lagging indicators that could be quantitatively evaluated. In this case, the primary benefit of the framework is helping ensure that all relevant aspects are addressed. Table 4 illustrates a number of different categories of sustainability performance indicators that could potentially be quantified. Generally, practitioners are advised to select as few indicators as necessary to address the most important aspects of product performance. Efforts to track numerous indicators (more than 12) have often proven burdensome and have eventually been scaled back.

Table 4: Categories of Sustainable Product Indicators

Economic	Environmental	Societal
Direct • Raw material cost • Labor cost • Capital cost	***Material Consumption*** • Product & packaging mass • Useful product lifetime • Hazardous materials used	***Quality of Life*** • Breadth of product availability • Knowledge or skill enhancement
Potentially Hidden • Recycling revenue • Product disposition cost	***Energy Consumption*** • Life cycle energy • Power use during operation	***Peace of Mind*** • Perceived Risk • Complaints
Contingent • Employee injury cost • Customer warranty cost	***Local Impacts*** • Product recyclability • Impact upon local streams	***Illness & Disease Reduction*** • Illnesses avoided • Mortality reduction
Relationship • Loss of goodwill due to customer concerns • Business interruption due to stakeholder interventions	***Regional Impacts*** • Smog creation • Acid rain precursors • Biodiversity reduction	***Accident & Injury Reduction*** • Lost time injuries • Reportable releases • Number of incidents
Externalities • Ecosystem productivity loss • Resource depletion	***Global Impacts*** • CO_2 Emissions • Ozone Depletion	***Health & Wellness*** • Nutritional value provided • Food costs

In many cases, practical limitations of data resources or methodology may hinder the ability of a development team to evaluate indicators over the full life cycle. In other cases, companies may wish to exclude certain life-cycle stages from consideration because they are not relevant to business decision-making. Therefore, the intended scope and rationale for indicators should always be clarified. For example, rather than speaking of "energy use reduction" we should specify "reduction in energy use during manufacturing and distribution" or "reduction in power consumption during product end use".

Finally, a mixed approach uses quantitative indicators when the measurement data can be obtained cost effectively, and then relies upon qualitative indicators for the other critical aspects of sustainability. The application of this approach is shown in the following example.

A Biotechnology Example

Life science companies are currently developing a host of biotechnology-based products that they claim will enable a shift to sustainable agriculture. One class of these new agricultural products is pest-resistant crops; biotechnology enables the insertion of genetic material into the crops that can help deter a variety of harmful pests. Proponents claim that this technology will increase agricultural productivity and lower consumer costs, while opponents are concerned about possible health and environmental impacts. The three measurement principles proposed earlier can help internal and external decision-makers compare the sustainability of these biotechnology-based product systems to alternatives.

- How do these product systems create value and consume resources?
- How will customers or stakeholders be affected economically, environmentally, and socially?
- What are the most significant impacts across the full life cycle of these product systems?

In comparison to a conventional crop, biotech products create value by reducing pesticide use during crop production, with corresponding reductions in toxic emissions during pesticide manufacture. Similarly, both the raw materials required to produce the pesticides and fuel required to apply them are reduced. These indicators and several others that were derived using the aforementioned sustainability measurement principles are provided in Figure 3.

	Supply	Manufacturing	Crop Production	Consumption
Societal		Employee Injuries (#/year)		Public Health Risk (qualitative)
Environmental	Material Intensity (lbs./year)	Toxic Emissions (lbs./ year)	Genetic Transference Risk (qualitative) Pesticide Use (gal/bushel) Fuel Consumption (gal/bushel)	
Economic		Economic Value Added ($/year)	Farmer Productivity (bushels/year)	Food Costs ($/bushel)

Figure 3: Sustainability Indicators for a Biotech Agricultural Product

Conclusion

This paper has set forth a general framework for sustainability performance measurement and illustrated how it can be applied. The framework provides a comprehensive organizing scheme for reviewing the many different ways that a product "system" can have adverse or beneficial impacts upon the triple bottom line. The framework embodies three principles — separation of resource and value measures, explicit representation of the triple bottom line, and consideration of the full life cycle.

Already, many companies have begun to incorporate sustainability measurement into their product development and performance evaluation processes, and we believe that the use of an organizing framework will help to ensure consistency and thoroughness in the practice of sustainability measurement. Looking ahead, we anticipate that a number of trends will emerge:

- Those companies that have committed in principle to sustainable development will begin developing practical ways of assessing the sustainability of specific products and services.
- In pursuing sustainability performance measurement, these companies will develop or adopt frameworks such as the one presented here to ensure that they address the full spectrum of relevant impacts or benefits.
- The implementation of product sustainability indicators will require some "shortcuts" such as relying upon qualitative instead of quantitative metrics. Many companies will choose to track and report leading indicators that are likely to contribute to sustainability.

The practices for measuring product sustainability will continue to evolve rapidly during the next several years. By understanding the principles of sustainability performance measurement, practitioners can design a process that is best suited to the needs of their organization.

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