

# Metrics for supply chain sustainability

Roland Clift

240

**Abstract** Most interpretations of sustainable development recognise that there are constraints on long-term human activities imposed by material and energy availability and by the capacity of the planet to accommodate wastes and emissions; inter- and intra-generational equity within these constraints is then an ethical principle underlying sustainability. This leads to identifying three dimensions of sustainable development: techno-economic, ecological and social. This paper reviews the development of indicators to reflect these three dimensions, applicable to industrial sectors, companies and broad groups of products or services. Indicators of environmental and economic performance are relatively well established. They can be combined to indicate the sustainability of products, services and supply chains. Indicators of social performance are more problematic, particularly indicators to describe the social value of products and services. Cases from the process, petroleum and petrochemicals, electronics and fast moving consumer goods sectors are reviewed, showing that social indicators must be developed through public participation.

## Introduction: sustainability, equity and constraints

Right now, we've got freedom AND responsibility—it's a very groovy time (Austin Powers)

“Sustainable development” was placed centrally onto the international agenda by the Brundtland Commission on Environment and Development (WCED 1987), which introduced the oft-quoted statement that sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their needs”. Most of the subsequent literature has developed the concept of equity, inherent in the Brundtland statement, as an ethical principle of equal access to opportunities and resources (see e.g. Reid 1995;

Clayton and Radcliffe 1996; Clift 2000). Brundtland specifically highlighted inter-generational equity—the rights of future generations, sometimes expressed as the responsibility not to steal from our grandchildren. It is perhaps surprising that intra-generational equity—equal rights for all people inhabiting the planet at this time—was not part of the Brundtland definition; perhaps it was considered obvious that inter-generational equity is meaningless without intra-generational equity. Most subsequent attempts to make sustainable development more “operational” have recognised that it must embrace both dimensions of equity; for example, the U.K. Government states “At the heart of sustainable development is the simple idea of ensuring a better quality of life for everyone, now and for generations to come” (DETR 1999a).

“Freedom” and “responsibility” come together when it is recognised that human activities are constrained by the capacity of the planet which is, in thermodynamic terms, a closed system: it exchanges energy but not matter with the rest of the universe (see Jackson 1996). For example, it is ignorant, pointless or simply dishonest to state that all inhabitants of the planet should have the opportunity to achieve the level of consumption enjoyed at present in most of the industrialised countries, because to do so would require resources and carrying capacity many times larger than those with which the planet is equipped. Constraints arise from resources: material and energy availability; human and economic capital; or from the capacity of the biosphere to accommodate emissions and wastes from human activities, an obvious example being the effect of emissions on the global climate (which is emerging as the active constraint on the use of fossil fuels, rather than the long-term availability of those fuels; RCEP 2000); and from the capacity of human beings and human social structures to respond to pressure and remain within the ecological constraints. Recognition of constraints thus lies behind the familiar three dimensions of sustainability: techno-economic, ecological and social (Clift 1998).

## Sustainability indicators

Indicators for sustainable development must therefore cover all three dimensions of sustainability, reflecting the significant constraints on human activity and conveying information about the level of inter- and intra-generational equity. Following the approach proposed by the Global Reporting Initiative (GRI), it is useful to proceed from broad *categories* through definite *aspects* to specific *indicators*, interpreted as:

Received: 1 October 2002 / Accepted: 18 April 2003  
Published online: 23 July 2003  
© Springer-Verlag 2003

R. Clift  
Centre for Environmental Strategy, University of Surrey,  
Guildford, Surrey, GU2 7XH, UK  
E-mail: r.clift@surrey.ac.uk  
Tel.: +44 1483 689271  
Fax: +44 1483 686671

**Table 1.** Common set of environmental impact categories used in LCIA (Clift 2001)

Abiotic depletion potential	Extraction of non-renewable raw materials such as ores
Energy depletion potential	Extraction of non-renewable energy carriers; can be included in abiotic depletion potential
Global warming potential	Contribution to atmospheric absorption of infra-red radiation leading to increase in global temperature
Ozone depletion potential	Contribution to depletion of stratospheric ozone, leading to increase in ultraviolet radiation reaching earth's surface
Human toxicity	Contribution to human health problems through exposure to toxic substances via air, water or soil (especially through the food chain)
Aquatic/terrestrial ecotoxicity	Contribution to health problems in flora and fauna caused by exposure to toxic substances
Acidification potential	Contribution to acid deposition onto soil and into water
Photochemical oxidant creation potential	Contribution to formation of tropospheric ozone
Nutrication potential	Contribution to reduction of oxygen concentration in water (or soil) through providing nutrients which increase production of biomass

- *Categories*: broad areas or groupings of economic, environmental or social issues of concern to stakeholders
- *Aspects*: general types of information related to a specific category (e.g. greenhouse gas emissions, or donations to host communities)
- *Indicators*: specific measurements of an individual aspect that can be used to track and demonstrate performance.

Although general indicator frameworks can be developed (e.g. Azapagic and Perdan 2000; IChemE 2002), it is commonly agreed that indicators need to be established on a sector-by-sector or even case-by-case basis. Sustainability indicators may be used at various levels: national economies, industrial sectors, companies, business areas or product groups, and specific products or services. The focus in this paper is on indicators which might be applied to sectors, companies and broad groups of products or services. Indicators are interpreted as parameters to show which aspects of performance must be improved and to indicate the direction of change, rather than measuring incremental improvements.

For the environmental and economic dimensions of sustainability, indicators are already available (e.g. Biswas et al. 1998; Lehni 1999). Environmental impacts can usefully be aggregated into the set of categories commonly used in Life Cycle Assessment (summarised in Table 1) leading naturally to quantitative indicators, such as atmospheric emissions weighted according to their Greenhouse Warming Potential to indicate the category of global climate change (Wright et al. 1997). A commonly used economic indicator for sectors, companies and business areas is value added (VA), defined as the value of sales less the cost of goods, raw materials (including energy) and services purchased<sup>1</sup>. VA also represents the contribution of an activity to gross domestic product (GDP).

<sup>1</sup>Variants on the simple VA have been proposed allowing, for example, for capital depreciation, but VA remains the most common metric for economic performance; see Azapagic and Perdan (2000).

In formulating and estimating the values of indicators, it is necessary to distinguish between application to “in-house” activities and to complete supply chains. The former is appropriate when describing the performance of a sector or a company (Behmanesh et al. 1993; Wright et al. 1997) while the latter (life cycle) approach is to be used when assessing products or services. Some authors, particularly in life cycle assessment, advocate aggregating the environmental impacts in Table 1 into a single metric measured as “ecopoints” or damage costs. However, this level of aggregation loses information and transparency, and is therefore to be avoided for the kind of strategic assessment which is the topic of this paper.

It is also useful to use some form of normalisation to indicate the significance of indicators. For example, estimates of the environmental impact of an activity may be “normalised” by dividing by the total impact of human activities globally, or in the relevant region or country, or in the industrial sector to which the activity belongs. Normalisation using a combination of environmental and economic indicators can give valuable insights into the sustainability (or otherwise) of products and supply chains; see below.

Notoriously, it is the social dimension of sustainable development which presents the greatest difficulty. Some indicators give the impression of having been proposed because they are measurable (DETR 1999b; see also Azapagic and Perdan 2000), without the discipline of examining what aspect of what category they represent. Possible approaches to developing social indicators will be explored later in this paper.

## Economic and environmental indicators for supply chains

### Overall business impact assessment

An indicator set which relates both environmental and economic performance has been developed by Unilever (Taylor and Postlethwaite 1996) in the approach known as Overall Business Impact Assessment (OBIA). OBIA was developed originally for businesses and groups of consumer products. The OBIA parameter measuring the performance of business or product group  $j$  in environmental impact category  $i$  is defined as:

$$\emptyset_{ij} = \frac{\text{Impact in category } i / \text{Value of business } j}{\text{Total anthropogenic contribution to impact category } i / \text{Total global economic activity}} \quad (1)$$

where the environmental impact is evaluated over the whole life cycle and the “value” is taken as the total sales from the business.

Ecometrics like  $\emptyset_{ij}$  can be used to identify highly unsustainable activities, or to distinguish between discrete options or scenarios. The OBIA approach provides a means of screening product or business areas which should be targeted for environmental improvement or substitution. Figure 1 shows the screening process schematically. Business for which  $\emptyset_{ij}$  is around unity—such as 1–4, 6, 8 and 9 in Fig. 1—show adequate environmental performance at the present levels of expectation. If the value of  $\emptyset_{ij}$  is much less than unity, then the performance in this environmental category is unusually good. However a product or business area for which  $\emptyset_{ij}$  is much larger than unity—such as 5 and 7 in Fig. 1—shows disproportionate environmental impacts in those categories for which  $\emptyset_{ij}$  is large.

Other variants on the OBIA approach have been reported. The World Business Council for Sustainable Development recommend an indicator which is essentially the reciprocal of  $\emptyset_{ij}$  (Lehni 1999). BASF are amongst the companies using this kind of approach to estimate eco-efficiency and hence select potential products and processes for commercial development (Saling 2002). Applied to complete industrial sectors, with  $\emptyset_{ij}$

evaluated for the sector rather than the complete supply chain, these indicators have been used to explore the implications of different economic development scenarios (e.g. Zakotnik and Radej 2002).

**Application to supply chains**

OBIA has been extended to analyse the environmental and economic performance of supply chains (Jackson and Clift 1998; Clift and Wright 2000). The approach is shown schematically in Fig. 2. The abscissa aggregates the VA along the supply chain; VA at any point is less than the sales price by the cost of energy and ancillary materials purchased, but this difference may be small by comparison with VA particularly for the later segments of the supply chain. The “environmental impact” ordinate refers to the quantified contribution to one of the impact categories in Table 1, or to some other category such as solid waste. Thus Fig. 2 is a projection of a multi-dimensional surface in the different environmental impact categories, to avoid reducing the categories to a single metric. The origin represents primary resources, while point A represents the finished product. The gradient of the chord OA represents  $\emptyset_{ij}$  for the product. As indicated above, the overall eco-efficiency of the product is improved when this gradient is reduced.

The convex segmented curve shows the supply chain. Each segment represents one of the principal steps in production and distribution, with the gradient indicating  $\emptyset_{ij}$  for that specific step. The strong convexity is typical (Clift and Wright 2000). It may be noted that Fig. 2 actually understates the convexity. For example, for electronic equipment (including mobile telephones, the

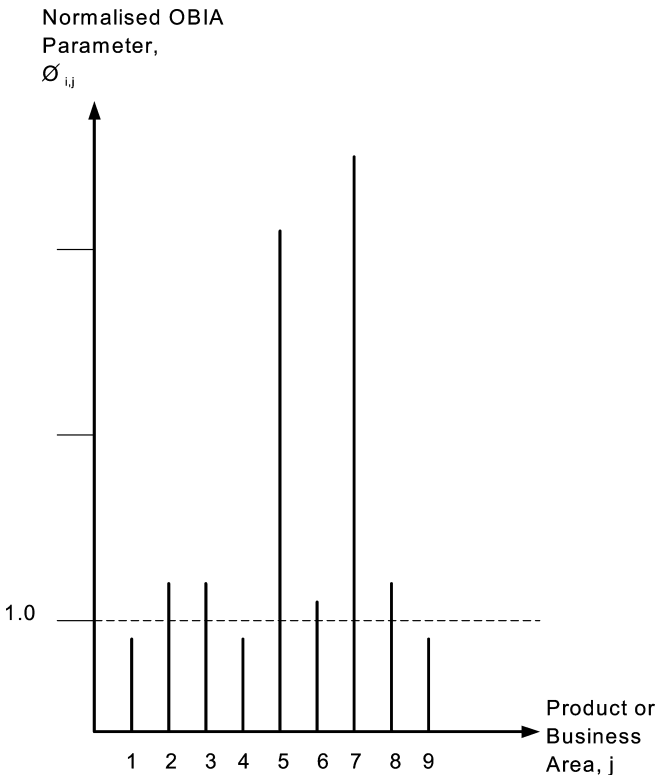


Fig. 1. Use of OBIA normalised metric to identify least sustainable products or business areas

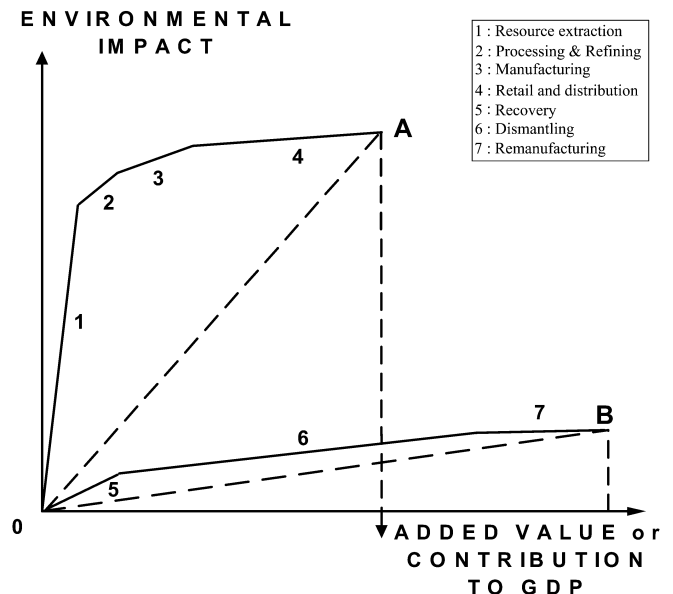


Fig. 2. Accumulation of economic value and environmental impact along the supply chain

specific case examined by Clift and Wright 2000 using data from Ectel 1997) the quantity of solid waste produced per kg of final product is of order 200 kg in extraction, processing and refining and 20 kg in manufacturing (McLaren et al. 2000). The significance is that the primary resource industries incur disproportionately high environmental impact but receive disproportionately low economic benefit. Thus the convexity of the supply chain is an indicator of unsustainability: for equity along the supply chain, i.e. equitable distribution of impacts and benefits, the curve should be essentially straight. As well as reducing environmental impacts, the primary resource industries need to deliver much more economic and social benefit. The curve also demonstrates how companies and economies can “export unsustainability” by restructuring to concentrate on the later, high VA activities in the supply chain. This kind of analysis can help to illuminate the source of inequity, but leaves no indication that present economic structures can deliver equity. However, as a small example, the analysis illustrates why the “Fair Trade” movement, which aims to return more income to primary producers at the expense of profits in later parts of the supply chain (particularly retailing), is to be seen as a genuine attempt to develop more sustainably.

### End-of-life products

For many manufactured products, including vehicles and electronic or electrical equipment (see below), management at end-of-life is recognised as an environmental concern (e.g. Ectel 1997). In Europe, the issue has been framed as one of managing used products to ensure that toxic components do not escape into the environment. This has led to the banning of some components, but also to the introduction of “take-back” legislation which extends the responsibility of the manufacturer to liability for the product at the end of its service life. The real objective of the “take-back” approach is to promote re-use of components and recycling of materials, to reduce environmental impacts over the supply chain. Even so, legislated “take-back” has met much industry resistance, with claims that it will increase costs.

The extreme convexity of the supply chain curve also helps to explain why recovery and re-use or recycling of the product can appear to be uneconomic even if the environmental impacts are reduced (Clift and Wright 2000). Figure 2 illustrates this case as curve OB, where the used product is treated as equivalent to virgin material, i.e. starting from O. Although Fig. 2 is only schematic, again the form of OB is consistent with (proprietary) data, specifically for mobile telephones. Collection of the dispersed product (segment 5) and particularly dismantling so that components can be re-used or materials reprocessed (segment 6) are associated with high costs and VA. The re-manufactured product, at B, therefore turns out to be more expensive (and therefore economically uncompetitive) compared to the “new” product at A, even though it is associated with much reduced environmental impact. This simple conclusion helps to show why the European Union, for example, has found it necessary to introduce mandatory recovery targets for “end-of-life” manufac-

tured goods rather than relying on economic incentives. In the longer term, “take-back” legislation is intended to drive manufacturers to design their products for ready dismantling, to reduce the economic cost of segment 6 even if this means increasing the economic cost of manufacturing (segment 4). However, this does nothing to improve equity along the supply chain, of either new or remanufactured products.

## Categories, aspects and indicators for social benefits

### Human needs

Indicators for the social dimension of sustainability have, thus far, concentrated on a company’s own activities (see Azapagic and Perdan 2000; IChemE 2002). Ethical indicators cover aspects such as stakeholder inclusion; preservation of cultural values and benefits to communities surrounding a company’s operation; consistency of employment conditions and health and safety standards for all operations regardless of their location (intragenerational equity); and leaving the environment in a condition likely to be acceptable to future generations and not creating problems, such as toxic or radioactive wastes, for which solutions are not known (intergenerational equity). The “Sustainable Development Progress Metrics recommended for use in the Process Industries” developed by the Institution of Chemical Engineers (IChemE 2002) follows this approach, including social indicators which aim to reflect “the company’s attitude to treatment of its employees, suppliers, contractors and customers and also its impacts on society at large”. More contentiously, the IChemE indicators include the disparity of income and benefits between the company’s direct employees.

However, none of these indicators addresses the social value of the products or services which a company provides. To take an obvious if extreme example, a company producing “weapons of mass destruction” might operate in a way which appears to be benign in terms of these social indicators, but that would not justify the company’s activities. To take a less extreme example, if I were to buy a gun<sup>2</sup> and shoot a colleague, it would be no consolation to his family to know that its manufacturer operates to sound ethical standards; equally, it would be of little interest that I used “environmentally friendly” lead-free bullets with low values of  $\emptyset_{i,j}$ .

Therefore some attention must be paid to social indicators applicable to products and services. This is a relatively unexplored area. The following discussion is a very preliminary account of a possible approach. The discussion of social benefits will be strictly at an anthropocentric level<sup>3</sup>, trying to relate social benefits of products and services to satisfying human needs. Starting at the

<sup>2</sup>It may be noted that the purchase, the funeral expenses and other resultant transactions would represent positive contributions to GDP—a caution against using conventional short-term economic indicators.

<sup>3</sup>However, it may be noted that Banner (1999) has argued that the distinction between anthropocentric and ecocentric environmental concerns is false.

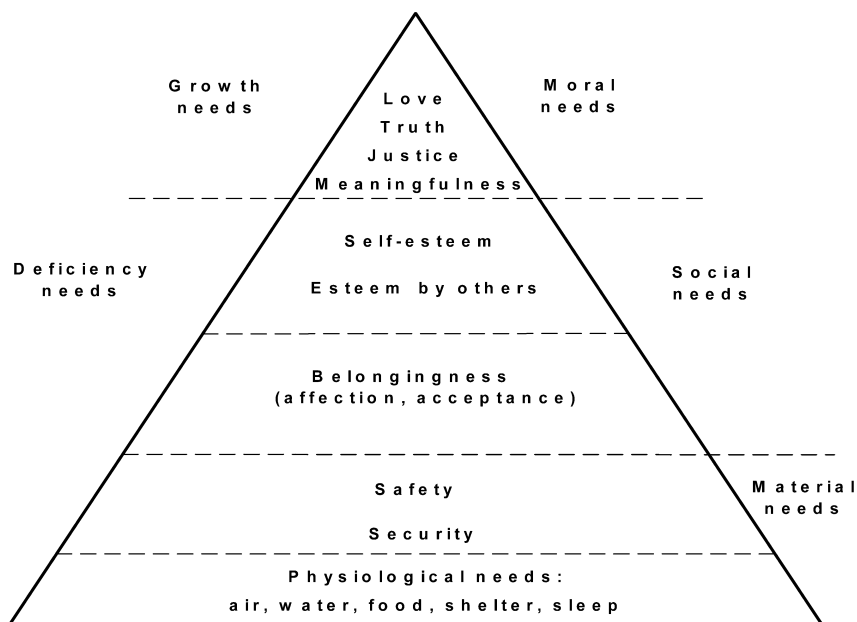


Fig. 3. Maslow's "hierarchy of human needs"

category level, two attempts to categorise human needs are widely used. Perhaps the best known is that due to Maslow (1954), who articulated the hierarchy of human needs summarised in Fig. 3. The common interpretation is that higher level needs remain latent until the lower level needs are satisfied (although there is some question as to whether Maslow himself intended this interpretation; see Jackson 1996). An alternative categorisation, much discussed in the development literature, is due to Max-Neef and others (1991). Max-Neef identified a set—strictly not a hierarchy—of needs summarised in Table 2. Each of the nine needs is envisaged as applying in each of four “existential” categories—being, having, doing and interacting—leading to a matrix of 36 categories of fundamental needs. In addition, Max-Neef suggested a tenth need, transcendence, which might correspond to Maslow’s “growth needs” (see Fig. 1).

A crucial distinction is also drawn between *satisfiers* which meet needs and *violators* which reduce or destroy the possibility of satisfying needs. “Weapons of mass destruction” are usually seen as violators. Inter- and intra-generational equity fit readily into the framework of human needs: in view of the growing evidence for the role of social inequality in reducing levels of public health (see e.g. Wilkinson 2000), it might also be argued that social inequality can be interpreted as a violator. *Singular satisfiers* satisfy one need without inhibiting satisfaction of others; *synergic satisfiers* help to satisfy more than one need; *inhibiting satisfiers* satisfy one need at the expense of one or more of the other needs; *pseudo-satisfiers* bring a false and temporary sense of satisfaction. For examples, see Jackson (1996).

Investigation of products as satisfiers and violators provides a possible link from needs as categories, through aspects to indicators. Following the idea that indicators have to be developed from a common set of categories on a case-by-case basis, a very preliminary exploration is made here of possible ways to establish social indicators, using specific sectors as exemplars.

**Process sector**

The Responsible Care initiative goes at least some way towards ensuring that products are used beneficially and responsibly. However, one of the characteristics of the process industries is that their products are generally used as inputs to final products (building components, manufactured goods etc.) rather than being the final products themselves. Given the close regulation of process plant throughout the industrialised world, it is increasingly recognised that the principal environmental impacts arise from chemical products rather than chemical production (RCEP 2003). Therefore the environmental impacts affect people who do not receive direct benefit from the industry or from use of products; the impacts are then solely violators.

Given the range of possible uses, many of which are unknown to chemical producers, it is difficult for companies in the process sector to answer the question “What human needs do your products satisfy?” Nevertheless, the sector is increasingly being required to answer this question, in effect addressing the balance between social benefits and environmental impacts. The OECD (2000;2002) is developing a “Framework for incorporating socio-economic analysis (SEA) in chemical risk management decision-making” as a structured way to estimate the balance between the benefits of a chemical product against the risks it poses to human health and the environment. The OECD argues that the indicators which emerge from the process should be expressed as monetary values, so that the process becomes a form of cost/benefit analysis.

Table 2. Max-Neef’s “fundamental human needs”

Material needs	Subsistence	Protection
Non-material needs	Affection Participation Idleness Freedom	Understanding Identity Creativity (Transcendence)

Other groups advocate a participatory approach to balancing risks and social benefits but with less emphasis than the OECD on monetary valuation and cost/benefit analysis. The Royal Commission on Environmental Pollution (1998;2003) stresses that environmental issues and policy choices of this kind invariably raise questions of value (as distinct from economic preference) which need to be integrated into each critical stage of decision-making, including the “framing” of the problem under consideration (which amounts to defining the categories and aspects of concern). All these approaches imply that formulation of social indicators needs to be an extensive and carefully structured process of public engagement, analogous to the kind of debate which has taken place in many European countries over the commercial use of genetically modified organisms. One likely outcome is that many more chemical products than at present will be licensed for use only in applications with high recognised social benefit, satisfying genuine needs.

### **Petroleum and petrochemicals**

Additional considerations apply to the petroleum and petrochemicals sector: in common with some but not all of the process industries, it uses a non-renewable resource—fossil hydrocarbons. Long-term use of this resource is constrained, although by the capacity of the biosphere to accommodate the emissions rather than by the availability of the resource itself (RCEP 2000). The Shell Group, for example, has developed a Sustainable Development Management Framework which includes the aspects “engage and work with stakeholders” and “maximise benefits to the community” (see Cunningham et al. 2002), recognising the need for public engagement outlined above for the process sector. In terms of the categories discussed above, these aspects refer to both material and social or non-material needs because the intention is to support personal and community development rather than just providing employment as a route to satisfying material needs. As in the IChemE (2002) indicators, the Shell approach recognises the broader social responsibilities of the company, even though the environmental and economic indicators refer only to the company’s own operations.

The general approach to defining indicators must also cover both products and projects. Cunningham et al. (2002) report two case studies to explore the development of indicators: for a specific product—biodiesel [rapeseed methyl ester (RME)]—and for a specific project—development of a natural gas resource in Sakhalin (an area of Eastern Russia with rather special social and environmental characteristics). Biodiesel is of particular interest as an attempt to shift from non-renewable to renewable fuels, and contribute to the social goal of helping to stabilise rural populations. Sakhalin is a stark example of a case where a finite resource needs to be developed in a way which permanently enhances a community which is depressed both socially and economically. Table 3 summarises preliminary aspects and indicators of social benefit. The value of these indicators is currently being tested. They are attempts to quantify categories and aspects which are really qualitative, but the category—aspect—indicator

framework helps to ensure that the indicators are significant, not merely reported because they can be measured.

### **Electronics**

Like other manufactured items, electronic goods are final products. Unlike the process sector, it is therefore possible to examine the social impact of the product itself, by asking whether it satisfies any category of human need. The specific example of mobile telephones will be considered here. Mobile telephones can be regarded as synergistic satisfiers, meeting needs which include safety, security and acceptance for Maslow; or protection, identity and participation for Max-Neef. (Their role as violators of some needs, for example by use on crowded vehicles, is recognised by some manufacturers who have promoted codes of practice or guides to courtesy in using mobile telephones.) The fact that they require limited fixed infrastructure gives them a particular role as satisfiers in developing countries.

Perhaps because the social benefit of the product has not been seriously questioned, some companies in the mobile telecommunications sector have started to address the question themselves. Social and environmental aspects of their business are being explored through systematic engagement with their own employees (e.g. Oxley Green et al. 2002) as a preliminary to engagement with a broader set of stakeholders including customers and suppliers. The process of identifying categories of social impact and proceeding through aspects to develop specific indicators then becomes, as for the other sectors discussed above, an open process to introduce corporate social responsibility into product development. This represents a notably innovative approach to the use of sustainability metrics.

### **Fast-moving consumer goods**

Two examples will be considered briefly of products in the fast-moving consumer goods (FMCG) sector. The first is domestic laundry detergent, usually considered necessary<sup>4</sup> to deliver the function “supply of clean clothes”. This service is unusual in lying at the intersection of several supply chains (including detergent, machine, water, energy and fabric) with limited communication between the supply chains (Ransome and Clift 2002). However, it is universally regarded as a satisfier of needs: physiological and social for Maslow; material and non-material for Max-Neef. Companies in the FMCG sector are accustomed to stakeholder engagement in the form of consumer focus groups. Systematic work is now in progress to establish the environmental concerns of stakeholders, starting with company employees (Clarke et al. 2002). Much as for mobile telecommunications, the objective is to use structured social processes to elicit the categories and aspects of public concern, and hence to develop performance indicators which can be used to guide innovation and future product development. Whether this approach can also be

<sup>4</sup>Washing clothes by hand may require less energy input, but avoiding this chore arguably satisfies needs such as Max-Neef’s “idleness”. Washing in unconfined conditions such as streams is arguably undesirable on environmental grounds.

**Table 3.** Examples of Indicators developed by Shell Group

Aspect	Indicators	
	Product—biodiesel (RME)	Project—natural gas exploitation
Engage and work with stakeholders	Acceptability of fuel to consumer. Effect of fuel on engine performance.	Plan for stakeholder dialogue in place. Frequency of meetings between company and local community.
Maximise benefits to the community	Level of employment generated. Amount of RME required not secured locally <sup>a</sup> .	Number of employees recruited within a 50 km radius. Percentage of suppliers from the local area (radius 50 km).

<sup>a</sup>Note that this indicator is to be interpreted negatively or inversely

used to inform communication between the intersecting supply chains remains to be investigated.

Other fast-moving consumer goods, such as cosmetics or hair styling aids, arguably meet none of the basic needs identified by Max-Neef or Maslow. At best, they might be regarded as pseudo-satisfiers for Maslow's "self-esteem" (which is consistent with the singularly repugnant advertising slogan "Because I'm worth it"). If purchase and use of such products has no identifiable social value, there might still be an argument that they are sustainable if purchase by the end user creates activity along a supply chain which helps to satisfy the needs of others, most obviously by employment which is rewarding in both the economic and personal senses. This would require the curve describing the supply chain (cf. Fig. 2) to be concave rather than convex, providing VA to the primary resource industries. We have yet to find a product for which this is the case ...

### Conclusions

Indicators for the direction of sustainable development need to represent all three dimensions: techno-economic, ecological and social. Aggregation across the dimensions, for example expressing ecological indicators in monetary form, is unnecessary and undesirable. However, normalised parameters which combine different dimensions can be informative. Indicators of economic and environmental performance are well established for products and services, and can be combined to identify activities which are significantly less sustainable than the average of human economic activities. They can also be used to reveal unsustainability in supply chains. Social indicators applicable to products and services are also needed, but are not generally available. To be valid, they need the kind of public acceptance which can only be achieved through well-structured participatory decision processes.

For indicators to be used effectively, it must be recognised that they will identify some economic activities which are so unsustainable that they must be discontinued. Industrial sectors which recognise the importance of equity but not the existence of constraints on human activities will be in the position of trying to ensure that everyone on the Titanic has access to a deck chair.

### References

Azapagic A, Perdan S (2000) Indicators of sustainable development for industry: a general framework. *Trans Inst Chem Eng* 73B:243–261

- Banner M (1999) Why and how (not) to value the environment. In: Christian ethics and contemporary moral problems. Cambridge University Press, London, Chapter 5
- Behmanesh N, Roque JA, Allen D (1993) An analysis of normalized measures of pollution prevention. *Pollut Prev Rev*, Spring:161–166
- Biswas G, Clift R, Davis G, Ehrenfeld J, Förster R, Jolliet O, Knoepfel I, Luterbacher U, Russell D, Hunkeler D (1998) Ecometrics: identification, categorisation, and life cycle validation. *Int J LCA* 3:184–190
- Clarke L, Clift R, Wehrmeyer W, King H, McKeown P (2002) Addressing employees' concerns to facilitate environmentally conscious decision making innovation. In: 10th International Conference of the Greening of Industry Network, Göteborg, June
- Clayton AHJ, Radcliffe NJ (1996) Sustainability—a systems approach. Earthscan, London
- Clift R (1998) Engineering for the environment: the new model engineer and her role. *Trans Inst Chem Eng* 76B:151–160
- Clift R (2000) Contribution to forum on sustainability. *Clean Prod Process* 2:67
- Clift R (2001) Clean technology and industrial ecology. In: Harrison RM (ed) *Pollution: causes, effects and control*, 4th edn. Royal Society of Chemistry, London, Chapter 16 (pp 411–444)
- Clift R, Wright L (2000) Relationships between environmental impacts and added value along the supply chain. *Technol Forecast Soc Change* 65:281–295
- Cunningham B, Wehrmeyer W, Clift R, Brewer L (2002) Integrating social concerns into the decision-making process associated with the petroleum industry. In: 10th International Conference of the Greening of Industry Network, Göteborg, June
- DETR (1999a) A better quality of life. UK Department of Environment, Transport and Rural Affairs, The Stationery Office, London
- DETR (1999b) Monitoring progress: indicators for the strategy for sustainable development in the United Kingdom. UK Department of Environment, Transport and Rural Affairs, The Stationery Office, London
- ECTEL (1997) End-of-life management of cellular phones: an industry perspective and response. ECTEL Cellular Phones Takeback Working Group, London
- ICHEME (2002) The sustainability metrics—sustainable development progress metrics recommended for use in the process industries. Institution of Chemical Engineers, Rugby
- Jackson T (1996) *Material concerns—pollution, profit and quality of life*. Routledge, London
- Jackson T, Clift R (1998) Where's the profit in industrial ecology? *J Ind Ecol* 2:3–5
- Lehni M (1999) Measuring eco-efficiency with cross-comparable indicators. WBCSD, Geneva
- Maslow A (1954) *Motivation and personality*. Harper and Row, New York
- Max-Neef M, Elizade A, Hopenhayn M (1991) *Human scale development—conception, application and further reflections*. Apex Press, New York
- McLaren J, Parkinson SD, Jackson T (2000) Modelling material cascades—frameworks for the environmental assessment of recycling systems. *Resour Conserv Recycling* 31:83–104
- OECD (2000) Framework for integrating socio-economic analysis in chemical risk management decision-making. Report ENV/JM/MONO (2000)5. Organisation for Economic and Cultural Development, Paris

- OECD (2002) Technical guidance document on the use of socio-economic analysis in chemical risk management decision-making. Report ENV/JM/MONO (2002)10. Organisation for Economic and Cultural Development, Paris
- Oxley Green AS, Wright L, Burningham K, Clift R (2002) Assessing the environmental views and concerns of Nokia employees as part of stakeholder participation. In: 10th International Conference of the Greening of Industry Network, Göteborg, June
- Ransome T, Clift R (2002) The supply, use and waste management of domestic clothes washing. In: Wrisberg N, Udo de Haes HA (eds) Analytical tools for environmental design and management in a systems perspective. Kluwer, Dordrecht, Appendix C (pp 205–230)
- RCEP (1998) Setting environmental standards. 21st Report of the Royal Commission on Environmental Pollution. The Stationery Office, London
- RCEP (2000) Energy: the changing climate. 22nd report of the Royal Commission on Environmental Pollution. The Stationery Office, London
- RCEP (2003) Chemicals in products. 24th Report of the Royal Commission on Environmental Pollution. The Stationery Office, London
- Reid D (1995) Sustainable development—an introductory guide. Earthscan, London
- Saling P (2002) Realising more sustainable products and processes in different fields of business by application of the eco-efficiency analysis. In: NATO Advanced Research Workshop, Maribor. Clean technol Environ Policy, in press
- Taylor AP, Postlethwaite D (1996) Overall business impact assessment (OBIA). In: 4th LCA Case Studies Symposium. SETAC-Europe, Brussels, pp 181–187
- WCED (1987) World Commission on Environment and Development: our common future. Report of the Brundtland Commission. Oxford University Press, London
- Wilkinson R (2000) Mind the gap—hierarchies, health and human evolution. Weidenfeld & Nicolson, London
- Wright M, Allen D, Clift R, Sas H (1997) Measuring corporate environmental performance: the ICI environmental burden system. *J Ind Ecol* 1:117–127
- Zakotnik I, Radej B (2002) Environment as a factor of national competitiveness in manufacturing. In: NATO Advanced Research Workshop, Maribor. Clean technol Environ Policy, in press