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Environmental indicators for business: a review of the literature and standardisation methods

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Abstract

This paper reviews the existing literature on environmental performance indicators as they relate to private sector organisations, followed by a basic classification of ways in which environmental data are being standardised for use in indicators. It was found that the majority of standardisation schemes for environmental information fall into one of five categories, namely standardised using economic criteria, physical impact categories (such as global warming potential), linear programming methods (such as productive efficiency), economic valuation methods or as part of business management review processes. The paper concludes that environmental data, once normalised, should be used in a diversity of indicators that are tailored to the information needs of the data users and that, as long as normalisation of data is kept separate from aggregation and standardisation, many different indicators can be developed based on a comparatively small dataset.

Keywords: Environmental performance; Aggregation; Standardisation; Productive efficiency; Management indicators; EMAS; ISO

1. Introduction

Decision-making and management of complex issues requires methods for representing these issues by simple units of measure. These are called indicators — condensed information for decision-making. The natural environment is a typical example of such a complex issue for which there is a need for appropriate indicators. It is obvious that the precise nature of the information required for decision-making varies with the type of decision to be made, the context of decision-making and the stakeholders involved. For instance, a private consumer may only want a simple signal that says whether a consumer product is "green" or not "green", while an engineer engaged in product design needs more complex information that can guide specific design strategies. Table 1 gives examples of the various functions that environmental indicators may have, in different contexts.

The choice and use of environmental indicators by companies depend also to some (perhaps large) extent on the type of firm, their sector, size, proximity to environmentally sensitive consumer markets, the time horizon involved, type and degree of external environmental regulation and the corporate culture of the organisation. In addition, the definition of "environmental indicator" is frequently ambiguous.

This paper discusses environmental indicators to compare environmental performances of business, to be used by business itself and external information users. Based on a European research project (MEPI — Measuring Environmental Performance in Industry), this paper reviews current approaches to developing indicators for corporate uses. After the Introduction, Section 2 briefly reviews definitions. Section 3 then gives an overview of the different indicators as found in the literature. From this overview we conclude that there is a notable need for standardisation and aggregation of environmental information for both external as well as internal users. Section 4 discusses five schemes by which environmen-

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Table 1
Different users and functions of environmental indicators inside and outside the firm

User/decision context	Function for the user
Corporate manager	To monitor a firm's "environmental" development in relation to strategic targets (derived from concern about future impacts of environmental developments)
	To identify most harmful wastes and emissions [38]
	To communicate corporate environmental performance/attitude to stakeholders (shareholders, environmental authorities, clients)
	Reference performance in preceding periods/years
Production plant manager	To identify opportunities for improvements of efficiency
	To convey information on the efforts to limit environmental impact of plant operations
Market manager	To identify new market opportunities
	To defend market positions; reference point competitors
Purchasing manager	Accountability; business-to-business relations
Environmental authorities (compliance situation)	To test compliance of firm with permits
Authorities (national)	In voluntary agreements; communicating a firm's effort to environmental improvement
	Useful for constructing databases that are helpful in developing and implementing a government's environmental policy
Investors and shareholders	Indicator for financial performance
	May indicate environmental liabilities that could affect a firm's financial performance
Consumers	To meet needs of green consumer

tal information can be standardised. Based on the review of the literature and the data standardisation methods, we propose a stepwise protocol to develop appropriate environmental indicators at the firm or site level. By implication, such indicators do not relate to environmental aspects of the type or origin of the purchased raw materials or energy, nor do they relate to environmental aspects of the use of the products.

It should be noted that the main reason for standardisation of data is the need to make (more or better) sense of environmental information. For instance, 1000 t of CO_2 emitted does not mean a lot without information about the context in which this emission took place — the history, the size of the system under operation, and many other factors. Generally, the conversion of standardised environmental information to indicators supports policy and assists the regulation of environmental impacts of organisations. In addition, there is the need for different standardisation schemes, as different stakeholders have different decision-making paradigms, and environmental information needs to be made appropriate to the context in which decisions are being made.

Generally, the requirements of environmental indicators are, first, that they can be formulated for any kind of indicator — i.e., they should be objective, understandable, significant (covering all relevant aspects), consistent with the objectives, responsive to stakeholder expectations, and allow for meaningful comparisons [2,7] at a reasonable cost. They should also be "workable", in the sense that the data required to implement them are really available in practice.

2. Concepts and definitions

There is some confusion with respect to concepts such as environmental indicator, environmental impact and physical indicator. In addition, the term "impact" has different connotations as well, because impact as in 'impact on' differs from 'impact of'. Also, different (policy) communities have different interpretations of the concept: usually the term impact describes changes in the environment (and socio-economic implications). The action or situation that causes the impact has different names. In the ISO community, there is the definition of *environmental aspect* as an element of an organisation's activities, products or services that can interact with the environment (ISO 14001, 1996). This includes emissions of a production facility and emissions that are the result of using the product. In discussions of indicators (for sustainable development) the term *environmental pressure* is often used [22,27]. Also the term *stressor* is used, implying the view of the environment as a system under stress. In the LCA community, the term *environmental intervention* is proposed, and defined as "exchange between the anthroposphere (the 'economy') and the environment including resource use, emissions to air, water or soil" (Ref. [17], p. 33).

Secondly, "*physical indicator*" and "*environmental indicator*" are often confused. In this paper, *physical indicators* are concerned with mass and energy flows so that their unit of measurement is either kg/year or J/year (or associated flow units). This concept is unambiguous and, for the focus of this paper, physical indicators typically cover the manufacturing process. A physical indicator is not normative: a number for a mass flow or energy flow in itself is neither good nor bad. It has to be evaluated and then it becomes an environmental indicator as well as an indicator of the evaluated impact of an activity. By contrast, an *environmental indicator* is concerned with the measurement and tracking of firm output to the physical environment. For example, energy consumption is a physical indicator, the sum of greenhouse gas emissions expressed in carbon equivalent is an environmental indicator.

In addition, an *environmental impact* is defined by ISO 14001 as "any change in the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's activities, products or services". This definition implies that this (marginal) change is expressed in physical terms and — whether adverse or beneficial — that the impact itself is not interpreted normatively. However, for environmental policy-making the relevant question will always be "Is a certain change in the environment good or bad? And how good or how bad?" Environmental indicators must be able to provide the appropriate information support to allow such a value judgement, ideally based on explicit value systems.

3. A review of existing classifications and initiatives

Environmental performance measurement (EPM) can be defined as the measurement of the interaction between business and the environment [4]. Issues and perspectives of EPM can be analysed at the level of individual environmental performance indicators, the level of the overall performance measurement system and at the level of the relationship of this system with the external environment.

The contentious and complex issues in identifying what changes in the environmental system can be attributed to be within the responsibility of a firm, and in normalisation and aggregation of data as well as the use of conversion/potency factors and the units of analysis, require conceptual precision. They are briefly described and discussed in Section 4.

An example for a classification at the level of individual indicators is presented by Loew and Kottmann [24]. They classify environmental indicators (EIs) — with some overlaps — according to environmental protection areas (energy, transport, emissions, waste, packaging, production, stock-keeping and water management), system boundaries (site/company, process or product) or levels of analysis/representation (level of material and energy flows, polluters, cost or effect level). This is an example for a classification at the level of individual indicators. On the polluter level, the cause of energy and material flows is represented. The level of materials and energy flows incorporates flow quantities that can be derived from site/company-, process- and product balances (which represent different forms of eco-balancing). EIs on the cost level can be derived from data on the materials and energy flow level if such flows cause costs, but to record such flow-induced costs and allocate them correctly to the polluter, environmental cost and performance accounting is necessary. Finally, on the effect level, effects of material and energy flows on for example climate, biosphere or atmosphere should be represented in an aggregated way. This requires a rarely achieved overlap-free classification in for instance environmental media (soil, water and air) or in life-cycle analysis (LCA) impact categories (global warming, acidification, ozone depletion, etc.).

An example for a classification at higher level, predominantly at the level of the overall performance measurement system, is given by Bennett and James [5] who describe three generations of environment-related performance measurement that correspond with groups of key indicators. First-generation indicators describe the business process, indicators on regulated emissions and wastes, and indicators for costly resources and compliance. Second-generation indicators reflect energy and materials usage/efficiency and significant emissions and wastes, as well as financial and implementation indicators. Third-generation EIs include relative indicators, eco-efficiency, stakeholder, environmental condition and products indicators, and the use of a balanced scorecard of these indicators. Fisksel [13] classifies environmental performance approaches functionally into performance-tracking, decision-making and external reporting approaches. This is closely related to the three generations proposed by James and Bennett where the main objective in the first generation is risk management, whereas the second generation is predominantly concerned with continuous improvement and can be related mainly to performance-tracking. The third generation has a broader set of internal and external objectives and broadly incorporates all three of Fisksel's categories.

Examples of recent initiatives on environmental indicators (which represent the interests of a variety of company stakeholders in various combinations) are:

- Association of Chartered Certified Accountants (ACCA) Report on Environment-Related Performance Measurement [4];
- Global Reporting Initiative [8];
- EU Eco-Management and Audit Scheme [11];
- ISO 14031 — Environmental Performance Evaluation [30];
- Guide to Corporate Environmental Indicators by the German Federal Environmental Agency [6];
- WBCSD Report on Eco-efficiency Metrics;
- National Round Table on the Environment and the Economy [26];

- EEA Working Paper on Eco-efficiency Indicators [14]; and
- World Resources Institute (WRI) Report [10].

Each approach has its different strengths and weaknesses with regard to several criteria such as performance measurement or performance management, applicability within an environmental management system or reliability of data collection. Some of these initiatives, such as EMAS, ISO, by the WBCSD or the German Federal Environmental Agency, are aimed more towards internally oriented performance management whereas others are focused on external performance measurement (WRI, NRTEE, EEA, CERES, ACCA). Overall, the current practice of using environmental indicators in business shows little standardisation and there is use of many different environmental indicators that only rarely attempt to measure overall eco-efficiency and almost never address overall sustainability [36]. With regard to applicability within an environmental management system, EMAS and ISO-based environmental indicators are best-suited, since they originate either directly from the standard (EMAS) or from a linked standard (ISO, which is linked to ISO 14031 on Environmental Performance Evaluation). For indicators based on these initiatives, reliable firm-level data are often readily available, but guidelines regarding the suggested use of indicators are mainly voluntarily and rather general.

By contrast, initiatives concerned with externally oriented performance measurement and more homogeneous use of environmental performance indicators point to

- the need for more standardisation [10,5,8];
- measurement of sustainability [36] and eco-efficiency [37];
- life-cycle thinking [5]; and
- a narrower but deeper analysis of core areas of environmental performance [5].

Following this criticism, firms should aim to develop physical indicators in broad resource categories that reflect the requirements of sustainable development, especially eco-efficiency, but can also be calculated on the basis of available data on more disaggregated indicators currently used in firms and industrial sectors.

It should also be noted that all approaches outlined above deal with environmental aspect indicators, rather than measures that indicate or identify changes in the environmental quality of the system concerned. This is largely due to the non-availability of environmental impact data that can be attributed with sufficient rigour to individual organisations' environmental resource use behaviour, as well as the complexities of such attribution in a complex and self-adaptive ecosystem. However, in the choice between environmental aspects and environmental quality indicators, the contribution of a firm to changes in environmental quality is arguably more relevant. So it can be argued that companies focus on measuring (and reporting) what they can measure rather than what users of such information ideally would like to know. The most pronounced manifestation of this unfortunate trend is the exclusion of *environmental impact indicators* (there called *environmental condition indicators*) as relevant indicators in ISO 14040, and it highlights that firms publish data they have available rather than what external stakeholders would like to see.

In addition, many indicator systems display a redundancy of indicators in that several variables show intrinsic multicollinearity.[1] For example, collecting fossil-fuel *input* and CO_2 *output* for a conventional power station is merely an indication of its relative efficiency and production volume, which suggests to focus on one indicator alone. In other words, if the input—output conversion shows little diversity between production sites, gathering input as well as output data is costly and unnecessary. However, the problem remains to identify that indicator which is best suited to represent the group of interrelated indicators.

Finally, the majority of environmental information is only being used to compare organisations over time, with little comparability offered between organisations. The current lack of standardisation (both in data gathering/measurement and conversion) and in aggregation across business or functional units, as well as the relative youth of the environmental indicator field itself, are the main reasons for this.

4. Standardisation and aggregation

4.1. Basic concepts

The field of environmental indicators, though relatively young, is already highly diversified with approaches based on LCA, economics, management accounting, ecology and a physical gate-to-gate analysis. The literature and practice review above has shown that little comparability exists currently and environmental data are often displayed without known standardisation or conversion factors, with limited information as to what the data refer to or include. This makes comparisons and full understanding difficult for external users. To increase transparency of performance and to increase credibility, we suggest that all environmental data be normalised after which step the data can be standardised and/or aggregated towards specific indicators to suit particular information needs (Fig. 1). This sequence should improve comparability of data (through

[1] Collinearity (or multicollinearity) is the undesirable situation where the correlations among several independent variables are strong.

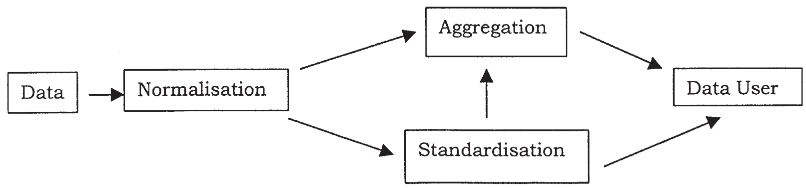

Fig. 1. Stepwise approach to development of environmental indicators.

standardisation), as well as reduce data complexity and increase the usability and suitability of data (aggregation). This sequence also allows the targeting of information to specific stakeholders by using different standardisation bases or methods.

Standardisation refers here to efforts to increase the comparability of environmental data, between years (longitudinal), sites, functional units, products or resource uses. The most common activity to standardise is normalisation, which transforms data into compatible or comparable forms. Normalisation ensures that data are converted to units or to a form compatible with a chosen standard or baseline, or that they have common units. Typically, normalised data allow more meaningful comparison across different seasons, production volumes, product prices or physical characteristics, such as water or air temperature or other variables.

By contrast, aggregation transforms data into different forms or formats to allow a better understanding or interpretation of the data by different groups or for different purposes. Aggregated physical indicators serve as summary indicators and give an overview of total resource use, emissions and waste without being relative to production. Higher aggregation allows the presentation of larger production units into an overall picture, thus allowing for the interaction and interdependency of environmental effects. However, greater data aggregation also implies less relevance for local or highly specific environmental issues. We suggest that data aggregation is guided by the subsidiarity principle, namely that data are to be aggregated to the lowest level of the organisational hierarchy where the decision can be made appropriately. We also suggest, as a general guidance, that indicators should be as simple as possible and only as complex as necessary.

A special type of data aggregation uses potency factors, such as ozone depletion potential or global warming potential. Conversion or potency factors become relevant in intra-impact assessment that aims to aggregate emissions of different physical/chemical nature into physical indicators for pressures on various environmental endpoints. Common measurement units for physical EIs are physical, chemical and biological units. Attempts to aggregate several indicators will typically result in dimensionless measures [33], outlined below.

4.2. Economic standardisation (business activity indicators)

A particular category of indicators are economic indicators, which link the information provided by physical and impact indicators with relevant information on the activity of the production or business units under investigation. Economic, financial and/or monetary quantities can be used to scale the information contained in other kinds of indicator, i.e., physical and/or environmental, or even impact indicators. Thus these indicators are typically in the form of ratios, with the numerator containing the physical information and the denominator holding the economic or financial information:

$$\text{Indicator}=\frac{\text{Physical and/or environmental quantity}}{\text{Economic and/or fincanical quantity}}.$$

The quantities that can be used at the denominator should reflect adequately the size and/or the activity of the production unit; Table 2 provides a (non-exhaustive) list of possible quantities.

Physical production is well suited when one unique physical production output, e.g., tons of pulp in the pulp and paper sector or kWh in the electricity sector, is dominant in its use. This allows easier comparison between plants or companies within the same sector. Turnover or sales are often promoted in studies on the measurement of environmental performance, because they are simple and readily available in most situations. However, when considering production chains, there may be problems of double accounting and therefore a misleading picture may emerge. Looking at environmental performance within a sector, a better measurement may therefore be the shipment value [25].

The number of employees may be another proxy for the manufacturing activity; it is readily available and does not entail the problems linked with financial quantities [2,31]. There may be additional problems using that quantity, due, e.g., to different labour intensities in different sectors and/or different countries. Finally, total investments may be taken as a substitute to either turnover or value added.

Value added is often advocated because it supposedly reflects the contribution of manufacturing activity to the global welfare, as measured for instance by the national

Table 2
Possible denominators of environmental indicators defined as ratios

Denominator	Units	Availability	Drawbacks
Output (less input use)	Physical	Good	Comparison across sectors; product diversity; relative weights to outputs and inputs
Turnover or sales	Financial	Good	May be over-rated
Shipment value	Financial	Variable	Difficult to compare, price-dependent
Value added	Financial	Fair or difficult	Problems of definition
Operating profit	Financial	Good	Highly fluctuating, depends on corporate decisions outside the system boundaries
Number of employees	Number	Good	Differences in labour intensities across sectors
Total investments	Financial	Good	Reflects only a part of the activity

gross domestic product (GDP). However, while its definition at a macroeconomic level does not pose particular problems, definitions at the corporate level may vary, depending upon the assumptions adopted and the socio-economic and industrial context under consideration [18]. Economic value added used at corporate level refers to above "normal" return on capital, which is not easily observable and usually not reported by firms.

However, a particular problem regarding economic standardisation across sectors or nations is the different degree of internalisation of environmental costs by the price mechanism. Firms in an economy with few environmental taxes will be economically favoured compared with firms operating in economies with "green taxes". Indicators normalising with value added or profit would thus favour firms in economies with a low degree of internalisation.

Globally, it is surprising to see the large multiplicity of data and measurement units that are used to describe business activities. Therefore, methods are needed to integrate various parameters from different levels of analysis; the most frequently used of which are linear programming-based methods (such as data envelope analysis and the productive efficiency method outlined below), or, generally, multicriteria analysis.

4.3. Physical aggregation: impact categories and indicators

In policy-making, the issue of changes in the environment is conceptualised as an ensemble of environmental problems that can be addressed more or less mutually independently. The impact of an emission (environmental pressure) relates then to different environmental fields (e.g., climate change, waste production). Following the practice in LCA [29] of products, we call these fields *impact categories*. In the ISO terminology one speaks of "environmental categories" (ISO 14042).

The concept of "an environmental problem or impact category" is a social construct, and listings of environmental problems differ with the contexts within which impact categories have been identified. For instance, Table 3, first column, lists impact categories that are often used in product LCA and the second column shows impact categories as they are perceived in the European context of environmental (quality) policy-making. These indicators refer to environmental condition in countries, and not to impacts of firms. The third column lists impact categories as used in corporate environmental policy. This list shows that, from a firm management point of view, there can be several dimensions that are relevant for constructing indicators for corporate environmental policy-making.

An environmental impact may be the result of different environmental pressures. For instance, the change in the condition of the ozone layer is the result of the emissions of different substances. Similarly, the acidity of soils and surface water can be changed by different pollutants. In those cases there are possibilities to normalise the impacts of these environmental pressures (e.g., emissions) with respect to their impacts (e.g., impacts per kg emission). From the above, we suggest that agreement should be sought to establish a list of relevant impact categories that can be used as a guiding matrix for corporate environmental indicators.

4.4. Productive efficiency indicators

A further class of aggregate indicators is derived from the productive efficiency framework. This methodology is based on quantities and information that are readily available, i.e., physical and economic/financial quantities. A detailed discussion of the approach can be found in Tyteca [33,34].

Essentially, the principles of the method are based on the premise that a production unit that produces more output with the same level of inputs, or releases less undesirable outputs (i.e., pollutants) for a given level of output production, is more efficient. Based on that standpoint, for a given set of similar observed production units, the method then constructs a so-called production frontier, such that observations lying on the frontier are declared "efficient" while observations lying inside the

Table 3
Topics in environmental policies in different decision contexts

Product policy (LCA community, SETAC) [35]	EU environmental quality policy [12,23]	Corporate environmental policy indicators (Brophy, 1995 in Ref. [1])
Depletion and competition of abiotic resources	Air pollution	Waste minimisation, reduce consumption of non-renewable resources, energy efficient
Depletion and competition of biotic resources	Biodiversity loss	Shared responsibility
Depletion and competition of land	Climate change	Environmental training
Global warming	Marine environment and coastal zones	Targets and objectives set beyond minimum compliance
Depletion of stratospheric ozone	Ozone layer depletion	Public disclosure
Human toxicological impacts	Resource depletion	Sustainable development
Ecotoxicological impacts	Dispersion of toxic substances	Habitat conservation
Photo-oxidant formation	Urban environmental problems	Research and development
Acidification	Waste	BS7750, EMAS
Eutrophication	Water pollution and water resources	World-wide standard
Odour		Compensation for environmental damage
Radiation casualties		Legislative compliance, liability on environmental issues
Noise		

frontier are declared “non-efficient”, implying that the latter have productivity slacks and that they can improve either their output production or their release of undesirable outputs.

The method is an aggregation method in the sense that all relevant information taken into account (i.e., production inputs and outputs, pollutants, financial quantities) is aggregated using self-defined weighting coefficients to produce an aggregate quantity, conventionally taken as 1 for units that are efficient and less than 1 for non-efficient units. For each producing unit, the method (based on linear programming techniques) seeks a weight combination that will yield the maximum value of the efficiency. If the unit is efficient, that value will be 1; if no weight combination exists such that efficiency takes the value 1, the unit is non-efficient. The production frontier may be paralleled with the concept of best available technology, since points lying on the frontier reflect best practice, relative to the observed dataset.

The advantages of productive efficiency methods include standardisation, flexibility (since various ratio alternatives can be formulated right away), robustness of the associated linear programming methods, and “objectivity”, because the weights are self-defined. However, we should also be aware of a potential drawback of productive efficiency — i.e., the high sensitivity of the results with respect to the number of factors and units considered. One should therefore be aware that a given result can only be considered with reference to the associated dataset. However, this is no longer a drawback if we recall that best practice, or best available technology, is always a relative concept that depends heavily on what actually exists. In general, the higher the number of observations, and/or the lower the number of variables, the better the discriminating power of productive efficiency methods. Productive efficiency methods such as those described can provide us with aggregate environmental indicators that can be termed “economic”, because they are grounded in a theory that is basically economic.

4.5. Impact assessment and economic valuation

Many impact assessments involve an often subjective evaluation of the impact; economics offers a methodology to avoid such subjectivity, because, at least conceptually, it attempts to apply societal judgement as it is revealed by market prices. In practice, this methodology is difficult to follow since there is no market for the type of economic goods (e.g., environmental quality) that impacts ‘constitute’.

Activities that cause environmental concerns are also often beneficial to individuals. From a welfare economics perspective, a firm’s activities pose an (environmental) problem if the valued concerns are larger than the valued benefits (optimal welfare is defined here as a Pareto optimum). In a world which is ideal according to neo-classical economics, concerns and benefits are priced by the market mechanism and in such a world there is no problem from a societal point of view (individuals may still have problems). Coase [9] argued famously that, from the perspective of economic efficiency, it does not matter if we tax the polluter or compensate the pollution victim and that, accordingly, we should identify the alternative that has least transaction cost and most social benefit.

However, in the real world there are concerns that environmental resources are not adequately priced — the famous externalities of economic activities (e.g., safety in transport, environmental externalities). Taking this view, the impact categories that are chosen should relate to environmental externalities.

The most frequent method based on the economic valuation of environmental impacts is known as the "value added–value lost" method. It uses the following definitions [18]:

Cost of environmental effects=
Environmental costs relating to the
processing or treatment of emissions+
costs of residual effects,

Cost of residual effects
=Residual effects expressed in monetary terms,

Environmental expenditure=Payments to third parties
+environmental taxes−environmental grants,

Value lost=Costs of the environmental
effects caused by a company's
operations, less the company's
expenditure on mitigating these effects

and

Net value added=Value added−value lost.

The value lost may be taken as an overall assessment of the environmental burden of a company, provided all relevant information on the use of resources and the discharge of waste and pollutants is available, and provided appropriate cost equivalents have been quantified using adequate methods. However, in situations where the emphasis is on comparison, a more meaningful environmental indicator would be a ratio defined as

Environmental Indicator=value lost/value added.

There are various methods with which these quantities may be evaluated (see, e.g., [32,15]). However, the effort required for data collection and economic assessment is still high and may turn out to be prohibitive in many practical situations.

As an alternative to methods based on financial evaluation, we suggest to group information on emissions of stressors, using types of environmental impacts caused by pollution as a criterion for aggregation. This step includes assigning the data on environmental interventions (emissions, environment pressures and stressors) to impact categories. In both SETAC LCA circles [17] and ISO proposals, this step is already known as classification. The calculation of the physical indicators is carried out by multiplying emissions with a factor. Such factor is called a characterisation factor [35], potency factor [38] or equivalency factor [16]. Udo de Haes [35] distinguishes three broad groups of impact categories, namely (1) resources and related impact categories; (2) human and eco-toxicity; and (3) non-toxic pollution.

Some studies have applied a broader approach, with the indicators 'energy consumption' or 'tonnes of materials consumption'. These are aggregate measures. However, these indicators should preferably not be used in combination with impact categories discussed above to avoid double counting.

4.6. Management indicators

Management indicators (MIs) do not per se belong to the categories of standardised or aggregate indicators of physical environmental performance. However, they are mentioned here because they yield complementary information that often explains the environmental performance as quantified by the physical, economic or impact indicators. MIs provide information on the organisation's capability and efforts in managing matters such as training, legal requirements, resource allocation, documentation and corrective action, which have or can have an influence on the organisation's environmental performance. These MIs should assist evaluation of efforts undertaken by management and actions to improve environmental performance. Two broad classes can be identified, which (caricaturally) are referred to as "qualitative, subjective" and "quantitative, objective".

The first class of MIs corresponds to those described in the Business Environment Barometer (e.g., [3]). They are designed for the measurement of perceptions, attitudes and strategies towards the environment. They also need global surveys to allow for the assessment of the influence of various factors on perceptions and attitudes, or for cross-sectoral comparisons. Since there is no standardisation as to what is a "good" or "bad" attitude or perception, even if we translate such information on Likert scales, there may be little relationship between these and physical or impact indicators, especially if we want to compare results from different surveys.

The second broad class of management indicators have the same goals as the previous ones — i.e., assess the efforts made, but here the information is based on quantified, verifiable information. For instance, the European Green Table [11] highlights examples of MIs as:

- environmental investments;
- running costs pertaining to environmental protection (fees, personnel expenses, fines, energy, maintenance);
- number of employees with specific environmental tasks;
- number of reported incidents; and
- degree of compliance with regulation.

Some of the categories may be hard to distinguish and/or assess. As a traditional example, what is the part of total investments that is devoted to the environment? This may be easy to answer in the case of end-of-pipe treatment investments, but much harder in the case of new (cleaner) production technologies. There is also the problem of distinguishing between recurrent and capital investment and, in the latter category, between investment that replaces, upgrades on environmental grounds, replaces on purely environmental grounds or upgrades, which fundamentally alters the production system.

5. Conclusions

As the above literature review and the review of standardisation schemes have shown, many diverse and diverging approaches to environmental indicators exist for the firm level. These are unlikely to be amalgamated into a single set of indicators — certainly not in the near future. In addition, it is questionable whether such an approach is as desirable as it appears at first glance, given the great diversity of applications, industries and stakeholders. As James March famously observed: "The World has an uncomfortable way of not permitting itself to be fitted into clean classifications". However, it is still possible to point at standardised or aggregate indicators that prove popular in practice, or have been proposed in the reviewed literature. It is the main point of this paper that, to allow meaningful data use and cost-effective data collection and storage, environmental data should be normalised and, in a separate step, aggregated or standardised to firm indicators that are suitable for the information needs of many different stakeholders.

5.1. Suggested indicators

Table 4 gives an account of the essential results of this paper as they relate to standardisation or aggregation. The operational uses, based on data availability, are generally good or fair, except for category 4, where very large amounts of information is required to assess the costs of emission treatment or processing, as well as the financial equivalents of environmental impacts.

Clearly, physical EIs themselves are not sufficient for environmental performance measurement but have to be combined with environmental condition indicators (e.g., sustainability, receptor or proxy environmental condition indicators) and management performance indicators (synonym: economic indicators focusing on the business unit under review). These groups of indicators can be related to each other based on the OECD pressure–state–response model [10].

In order to identify improvements for processes and products, the EIs for all environmental protection areas for one specific product or process can be combined in an analysis. According to Loew and Kottmann [24], an ideal environmental information system should predominantly consist of EIs at the polluter level and materials and energy flow level, as these are usually perfectly sufficient to identify existing optimisation potentials. However, for tactical and strategic planning decisions, a mix of EIs on the effect level and of EIs on the materials and energy flow level seems to be most appropriate.

5.2. A four-step procedure for the development of indicators

Simplified, environmental aspects can be understood as outputs and environmental impacts as changes resulting from outputs. If environmental protection is seen as a social, public or national concern, then impacts rather than aspects matter [36]. Therefore the conceptual idea is that organisationally measurable and attributable data from firms, which reflect (at least) the major environmental *aspects* of a firm, should be transformed into at least indicative or surrogate information on environmental *impacts*, grouped in impact categories or scaled using science-based potency factors or other alternative methods (e.g., asking for public assessment, given the nature of environmental problems as a social construct).

The central challenge in developing indicators is to generate and disseminate information about the environmental behaviour of the decision-making unit that is meaningful, accurate and relevant for the information user, and cost-effective. There are no universal ways to achieve this, as each set of indicators should be specific to the organisational context and the information requirements of the user. However, to harmonise the indicator development and information dissemination efforts, we propose harmonisation and, ipso facto, collaboration on the development of indicators as well as a separation between data gathering and normalisation and the use of data as inputs for indicators. Therefore, the process of developing appropriate indicators has these core elements:

1. The collection of (time-series) data on firms/facilities about physical indicators, economic/business/management and environmental indicators. The results of this step are economic or environmental or social variables that are describing the system under review.
2. The establishment of the database with environmental indicators, requiring the later use of potency factors (e.g., greenhouse gas warming potentials) for aggregating emission data. The result of this step is an electronic storage of normalised data. This normalisation refers to the physical units in which the data are stored as well as the uniformity of measurement, often described in the data collection protocol. It thus pre-

Table 4
Summary of candidate standardised and/or aggregate indicators and data requirements

Category	Possible indicators	Data requirements
Business activity indicators	Physical production	Physical quantities of inputs used and outputs produced
	Financial quantities	Value added, turnover, sales, shipment values, total investment
	Operating profit	Revenues, cost of sales, selling and administrative expenses
	Number of employees	Total; engaged in production; wages
Environmental impact indicators	Contribution to greenhouse effect	Annual emissions and effluents (tons/year)
	Surface water pollution	Potency factors
Productive efficiency indicators	Various, depending on emphasis on inputs and/or emissions and/or impacts	Any kind as requested (same as in environmental and impact indicators): physical quantities of inputs used (including, e.g., number of employees, capital, energy, raw materials, (non-)renewable resources) and outputs produced; levels of emissions and waste production; environmental impacts; financial quantities
Monetary aggregate indicators	Value lost and net value added	Environmental costs relating to the processing or treatment of emissions; residual effects; payments to third parties, environmental taxes, environmental grants; expenditures to mitigate environmental effects; cost equivalents of environmental impacts
Management (effort) indicators	Various (explanatory factors)	Environmental investments; running costs pertaining to environmental protection (fees, personnel expenses, fines, energy, maintenance); number of employees with specific environmental tasks; number of reported incidents; degree of compliance with regulation

vents, for example, energy data collected in GJ as well as BTUs, therms and kWh. It also ensures that, in the case of a company with several sites, all sites measure energy at the same point and to the same criteria.

3. Where appropriate and feasible, to aggregate environmental indicators (by category) into a single indicator for environmental impacts (possibly with public assessment). The result of this step is an integration of different environmental time series to describe environmental performance at the appropriate level — be this for the site, a company, several companies of the same area or sector, nationally or globally.
4. Combine these data into performance indicators, using any of the above standardisation schemes as denominator or normalising factor.

This then allows an analysis of differences in environmental performances of different firms or over time. Table 5 provides an illustrative example.

The proposed methodology allows flexibility in the way data are standardised and tailored towards specific data users and their requirements, without actually preventing the data from being used for other purposes as well. By separating data normalisation from subsequent stages in the data manipulation from “raw” data to environmental information, including aggregation or standardisation, the indicator generation is also separated from the data collection. It is hoped that such a “pooling” of normalised data can further facilitate a cost-effective use of environmental information for a variety of purposes and users. If, in due course, the standardisation procedures themselves become standardised, which is especially necessary in the economic valuation and the management indicator schemes as outlined above, the dataset should be available.

Table 5
An illustrative example of the analysis of differences in environmental performances of different firms or the same firm over time

Step		Example
1	Data collection	Energy consumption data
2	Establishment of database	Normalise data into common unit of measure (J), normalise for different processes, ensure normalisation of collection protocol, etc.
3	Aggregation	Aggregate to tons of carbon equivalent/greenhouse warming potential
4	Standardisation	Carbon equivalent per turnover, etc.

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