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The Environmental Performance Strategy Map: an integrated LCA approach to support the strategic decision-making process

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ABSTRACT

Life Cycle Assessment (LCA) is a well-known tool for analyzing environmental impacts on a wide perspective with reference to a product system and the related environmental and economic impacts. The need for a novel approach that complements environmental and financial considerations is addressed in this study with the introduction of a new graphical representation: the Environmental Performance Strategy Map. This graphical map allows one to combine the main environmental indicators (footprints) with the additional dimension of cost. The paper defines the Sustainable Environmental Performance Indicator as a single measure for sustainability of a given option. Comparison of different options for strategic decision-making purposes can be enhanced and facilitated by the use of this indicator.

1. Introduction

Life Cycle Assessment (LCA) involves the evaluation of specific elements of a product system to determine its environmental impact. The implementation varies depending on the adoption pattern and on the precision that needs to be achieved. The LCA is also called Life Cycle Analysis or the 'cradle-to-grave,' approach. It is composed of a conceptual framework and a set of tools that have been studied and developed in the last 30 years [1–3]. The core of the concept is the assessment of the impacts at each stage of the product life cycle.

The principles and framework for LCA include definition of the goals and scope, Life Cycle Inventory (LCI) analysis, Life Cycle Impact Assessment (LCIA), Life Cycle Interpretation phase and reporting have become well-documented and are now included in ISO standards [4–7].

Due to the constraints on resources and/or data availability, industrial companies usually perform analyses based on simplified LCA approaches or they simply apply the general principles of Life Cycle Thinking to certain aspects of the production system.

Life Cycle Thinking (LCT) requires a consideration of all environmental and toxicological impacts associated with the life cycle of a product. LCT is an approach that is used in different policies, from the US to the EU [8]. Because lowering the overall environmental impacts of production, usage and end-of-life management of products is critical for society to make progress toward more sustainable lifestyles, the research for ways to gauge the comparative sustainability of our actions is being intensified.

The importance of specific metrics to support policy-making and the decision-making process is paramount. In particular, Chapter 40 of Agenda 21 calls for research on indicators for sustainable development [9]. The challenge is to develop indicators that are not too generic or too broad. At the same time it should be possible to aggregate them into a meaningful, single indicator of performance, to be used for strategic decision-making. This could be particularly useful because it could provide the practitioner with a tool that balances different aspects and then provides qualitative inputs pertaining to the option that performs best from environmental and human health perspectives.

2. LCA: the general framework

The methodology for Life Cycle Analysis includes the phases described in Figs. 1 and 2. It should be noted that ISO 14040 neither does describe the LCA-related tools, in detail, nor does it specify which methodology should be used for each phase. It mainly provides a framework within which these elements can be developed and used.

2.1. Goals and scope definition

This is the first subjective phase of the application of LCA. At this stage it is necessary to identify the objectives of the analysis and the

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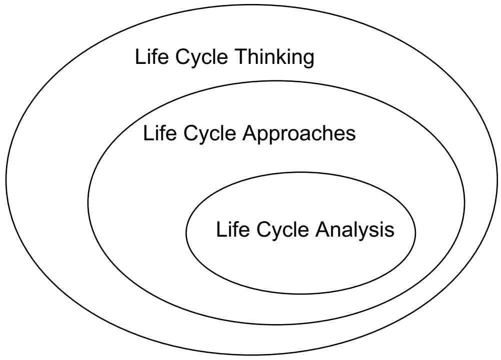

Fig. 1. Different application levels of life cycle methodologies.

system boundaries. This is to ensure that no relevant part of the system to be investigated is omitted. Given the subjective characteristics of this activity, it is necessary to be transparent with regards to all decisions and assumptions for this phase of the analysis. The goals and scope can be adjusted during the iterative process of the analysis.

2.2. Inventory analysis

The objective of the second phase is to perform mass and energy balances to quantify all the materials and energy inputs, as well as wastes and emissions from the system that cause the environmental burdens. The following main issues (as defined by ISO 14040:1997) should be considered during this phase: data collection, refining the system boundaries, calculation, validation of data, relating data to the specific system and allocation.

2.3. Impact assessment

The third phase is based on the aggregation of the environmental impacts quantified in the inventory analysis into a limited set of recognizable impact categories (e.g. global warming, ozone depletion, acidification). This phase comprises the following steps: classification, characterisation, normalization and weighting.

The second step in this phase is mainly a quantitative step: *characterisation*. In this step it is necessary to assign the relative contribution of each input and output to the selected impact categories [10]. The next step in this phase is *normalization* [11]. The goal of normalization is to establish a common reference to enable comparison of different environmental impacts.

Quantitative results of the characterisation of impact categories are not always comparable and an additional step is necessary:

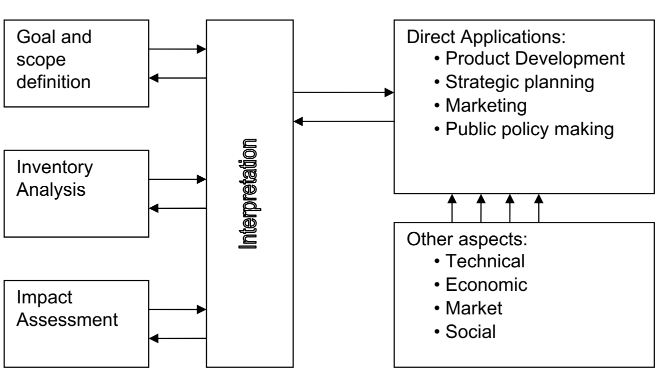

Fig. 2. Phases and applications of LCA adapted from ISO 14040:1997 [4].

weighting [12]. This activity aims at comparing the impact categories against each other. This makes it possible to rank and possibly to define the relative importance of the different results. Weighting can be a quantitative or a qualitative activity, which is not always based on science, but often on social or political considerations.

2.4. Interpretation

This is the last phase as indicated by ISO 14040:1997. Interpretation is a systematic procedure to evaluate the information from the inventory analysis and impact assessment of the product system and to draw conclusions from all of the foregoing results of the study [3].

3. Limitations of LCA approaches

Even though LCA is a powerful tool to assess the environmental impacts of products/services, some important limitations have been identified in recent years [13–15]. The main limitations are related to the LCA methodological approach, especially data quality and collection, definition of the system, time boundaries, and process modelling. The *quality* and *availability of data* influence the results significantly. The *time aspect* is often critical in including or excluding some effects of the systems under analysis. The LCA study should consider environmental impacts on the longest possible timeframe, possibly an infinite one. The holistic approach of LCA, one of its main strengths, is also a cause of complexity. In most LCA studies assumptions are made and the *system boundaries* are modified in order to leave out some elements. Results of the LCA are often used for process optimisation. The applicability depends greatly on the *model of the process* that has been adopted at the beginning of the study, which is frequently too simplified.

Finally, the great amount of detailed data required in completing a full LCA, which also takes full costs into consideration, can discourage some practitioners from using LCA as a decision-making support tool.

4. From environmental assessment to strategic environmental maps

The ecological footprint analysis approach is a way to compare human demand with our planet's capacity to regenerate; it is a way to measure human burdens on the ecosystem. Usually it represents the amount of biologically productive land and sea area needed to regenerate the resources consumed and to absorb the corresponding wastes. Different footprints have been developed, to consider the impact of different resources. In a broader view the ecological footprint is related to the method of LCA, which is typically used for products and services, but is also applicable for production plants and regions. One of the LCA advantages is that it better covers the whole range of impacts, and it may also provide an accounting of the upstream impacts.

Nevertheless, one of the most important limitations in the application of LCA as an input for strategic decision-making from an environmental perspective is the limited inclusion of cost and investment considerations. A new approach is required in order to integrate financial, environmental, resource and toxicological considerations into a single analysis. The core of the concept is to calculate some specific sustainability indicators, based on LCA. This can help one define the relevant contributions to support strategic decision-making. The 'cradle-to-grave' approach can help to assure that all environmental and human consequences are taken into account. These must be further balanced against financial and resource consumption considerations.

It is suggested therefore, to evaluate all options against the following categories:

- Carbon footprint;
- Water footprint;
- Energy footprint (land, renewables, non-renewables);
- Emission footprint (emissions to air, water and soil, waste materials);
- Work environment footprint (work environment and toxicological impacts).

Costs should also be considered as an additional category, possibly representing the crucial relation that they have with all the other categories.

To represent these relations and to compare options from an environmental and, more generally, a business perspective, a new graphical representation needs to be introduced: the '*Environmental Performance Strategy Map*,' (EPSM). The objective of this representation is to build upon the strengths of ecological footprint analysis tools and Life Cycle Analyses tools, to provide a single indicator for each option. The practitioner can make use of this indicator to support the decision-making processes toward the best option from sustainability and environmental perspectives.

The first step in building the EPSM correctly is to calculate the impacts of the option under analysis for all the above-mentioned footprints. The integrations of these elements and the cost perspectives will provide a single indicator to assign to each option. The comparison among different options, with different characteristics and ratios of advantages and disadvantages, can be facilitated by a graphical representation. The best option, from an environmental and financial perspective, can then be selected based on this approach.

5. What footprints?

Different methods have been developed in the last years to correlate environmental sustainability of specific activities with land and water areas required to supply this activity with resources and to absorb its wastes [16,17]. This is usually referred to as the ecological footprint.

Some initial objections to the original method in terms of how energy is accounted for [18], as well as the difficulty in using the tool in the decision-making process [19], have been overcome by the development of specific indicators (SPI [20] and DAI [21]). In particular the Sustainable Process Index (SPI) considers the area as a basic measure: the more area a process requires, the more its burden from an ecological point of view. The SPI method is based on the comparison of natural flows with the mass and energy flows generated by a technological process. The calculation of an SPI is based upon computation of the total area required (A_{tot}):

$$A_{tot} = A_R + A_E + A_I + A_S + A_P \quad (1)$$

where A_R is the area required to produce the raw materials (given as the sum of the areas to provide renewable raw materials, fossil raw materials and non-renewable raw materials), A_E is the area needed to produce process energy, A_I is the area required for the process installations (equipment/plant), A_S is the area required for support staff and A_P is the area required for the accommodation of products and by-products [20].

A model that proposes the combination of ecological footprinting with economic considerations is proposed in the ecological value added system [22]. This is based on an input–output system and upon the ecosystem pricing concept, introduced via energy values and the ecological footprint. The balance between carbon sinks and emissions defines the sustainability target for this model.

In order to provide a more comprehensive analysis of the interaction of the environmental burdens and financial costs, the Environmental Performance Strategy Map is based on the combination of the following five footprints.

5.1. Carbon footprint

With environmental issues high on the business and political agenda, different definitions of the individual contribution to carbon dioxide emissions have been proposed [23]. Usually, they are referred to as carbon footprint. In response to public attention, different tools have been developed to calculate the value of the carbon footprint, in relation to a product or process [24]. Even though these tools are useful in increasing public awareness, they often lack transparency and might provide conflicting results.

For the purpose of building the Environmental Performance Strategy Map, this paper refers to a land based definition, where the carbon footprint estimates the land area required to sequester atmospheric fossil CO_2 emissions through afforestation [16]. This area is calculated as [17]:

$$CF = M_{CO_2} \cdot \frac{1 - F_{CO_2}}{S_{CO_2}} \cdot EF \quad (2)$$

where CF is the footprint of indirect land occupation by fossil fuel and cement related CO_2 emissions ($m^2\,y$), M_{CO_2} is the product specific emission of CO_2 (kg CO_2), F_{CO_2} is the fraction of CO_2 absorbed by the oceans, S_{CO_2} is the sequestration rate of CO_2 by biomass (kg $CO_2\,m^{-2}\,y^{-1}$) and EF is the equivalence factor for forests.

This footprint unit of measure is expressed in m^2.

5.2. Water footprint

The concept of water footprint is a relatively new one; it is related to the concept of virtual water [25,26]. Virtual water is the amount of water required to produce a service or a product. In analogy with ecological and carbon footprints, this indicator is designed to summarize the contribution of a product or activity to the deterioration of the environment. The focus is on the consumption of the limited resource, water. While the ecological footprint is designed to calculate the area needed to sustain specific human activities, the water footprint looks at the volume of water. With two different methods (top-down or bottom-up) the water footprint measures the amount of water related to human consumption and takes into consideration blue and green water, as well as the production of polluted grey water [27]. For instance, in the case of crops, we can define the green virtual water content as a ratio between the effective rainfall and the crop yield. Analogously, the blue virtual water content is the ratio between the effective amount of irrigated water and the crop yield. The total virtual water content is given by the sum of these two elements.

In this paper the Environmental Performance Strategy Map is used to represent an overall indication of the comparative sustainability of different options from a strategic decision-making point of view. The water footprint of an activity consists therefore, of two components: the direct water used (for producing/manufacturing or for supporting activities) and the indirect water use (that propagates throughout the supply chain). This footprint unit of measure is L/m^2.

5.3. Energy footprint

The energy supply footprint [28] takes into account different energy supplies as related to different demand categories, such as

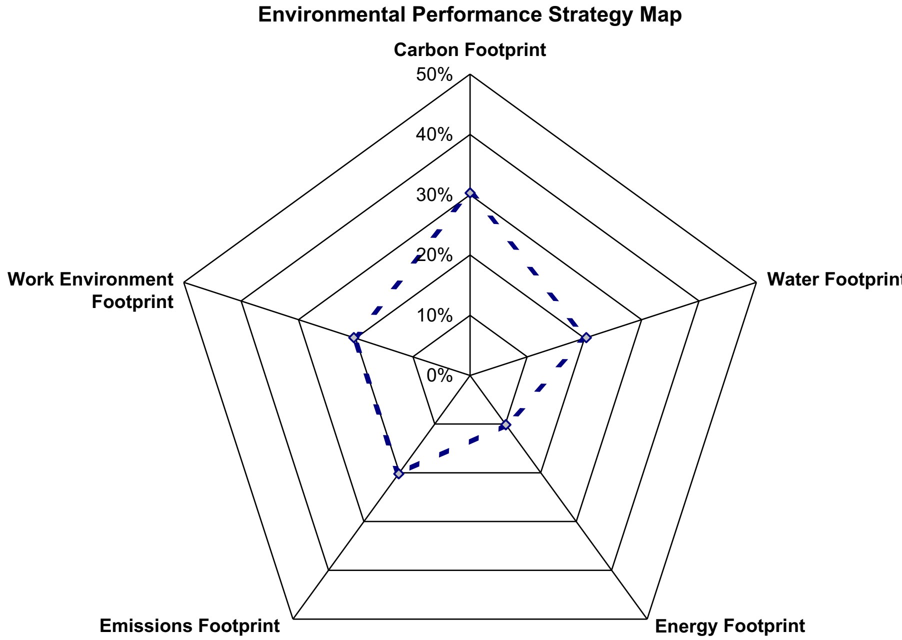

Fig. 3. Plotting the footprints in the EPSM.

heating and hot water production, process energy, electricity and traffic. The footprint is calculated by multiplying the final energy use of different energy carriers with their land need indices and adding these results to the footprint of the whole energy supply. This footprint unit of measure is m^2. It is important to notice that the energy footprint, as defined in Ref. [28], includes some CO_2 contributions from burning processes. However, it does not include all other CO_2 contributions and that is why it is important to make use of the carbon footprint as defined in Section 5.1.

5.4. Emissions footprint

To identify the real environmental burden we define as emission's footprint the quantity of emissions of the process under investigation in water, soil and air – are converted to area requirements. The conversion of emissions is calculated according to the principle that anthropogenic mass flows must not alter the quality of local compartments [29]. Maximum flows are defined based on the natural, existing quality of the compartment and their replenishment rate per unit area. For emissions to soil, the replenishment rate is given by the decomposition of biomass to humus (measured by the production of compost by biomass). For ground water this is the seepage rate (given by local precipitation). Emissions to the compartment air are treated slightly differently, as there is no natural replenishment rate for this compartment. Here the natural exchange of substances between forests and air per unit area (which is known for most airborne substances) is taken as a base of comparison between natural and anthropogenic flows [29]. Different emissions to air are not weighted, as only the largest dissipation areas are to be considered. Lower area consumptions' emissions may be dissipated without violating the principle that anthropogenic mass flows must not alter the quality of local compartments.

This footprint unit of measure is m^2.

5.5. Work environment footprint

For the purpose of building the EPSM, the work environment footprint is the work environment LCA as proposed by Ref. [30]. This method, based on the collection of good statistics, is designed to calculate the number of reported lost days of work per weight unit of product at the sector level. The following impact categories are included in the assessment [30]:

- Fatal accidents;
- Total number of accidents;
- CNS function disorder;
- Hearing damages;
- Cancer;
- Musculo-skeletal disorders;

Table 1
Normalization target factors.

	Target	Source
Carbon footprint	Max area available (m^2)	Problem definition
Water footprint	Average water required for a specific category of product or service (m^3)	UN Statistical Office <unstats.un.org/unsd/ENVIRONMENT/waterresources.htm>
Energy footprint	Max area available (m^2)	Problem definition
Emission footprint	Max area available (m^2)	Problem definition
Work environment footprint	Total number of accidents and work-related diseases per product group in the specific country or area (accidents/person)	National Statistical Office, e.g.<epp.eurostat.ec.europa.eu/portal/page?_pageid = 1073,46587259&_dad = portal&_schema-PORTAL&p_product_code = KS-BP-02-002-3A>
Cost	Max budget available for EHS management (€)	Problem definition

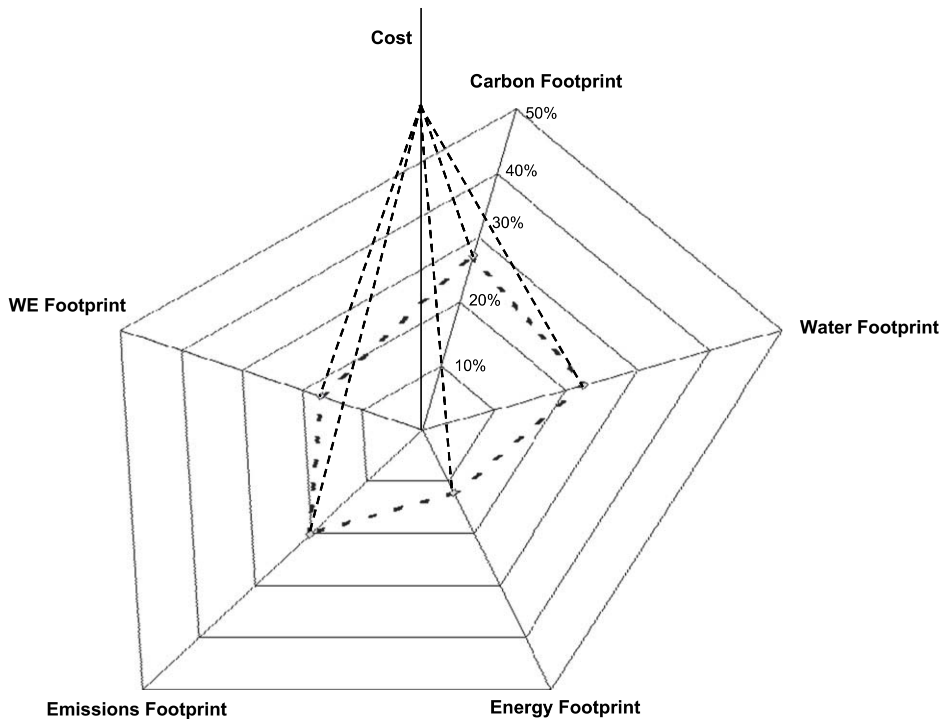

Fig. 4. Cost, the additional dimension in the Environmental Performance Strategy Map.

- Airway diseases (allergic and non-allergic);
- Skin diseases;
- Psycho-social diseases.

This footprint unit of measure is the number of lost days of work/person.

6. Building the map

Once the contribution of each factor of the specific footprints has been calculated, it is possible to build the EPSM. The basic concept is to map the footprint on a specific spider-web plot, to identify a meaningful combination (Fig. 3). In order to have comparable measures, the results of each footprint are normalized, resulting in a scale from 0 to 100. What we propose using is a deviation-from-target methodology, where for each of the footprints, the authors of this paper define a maximum target and express each value as a percentage of the distance to that target. The objective is to lower, as much as possible, in percentage points, the contributions of each footprint to the overall combined indicator. The targets specified in Table 1 are either based on maximum available resources or are drawn from scientific consensus or regulatory requirements.

Each option has an area assigned that represents a combination of all footprints. In order to specify the cost and financial impacts we introduce an additional dimension (Fig. 4). This is the cost of the option under analysis. The cost is considered as an additional dimension because it is not used for comparative reasons. The indicator takes into account the total financial investment required for each options.

The volume of each pyramid represents the overall environmental and financial impact of the option under consideration. The authors of this paper define this index as the Sustainable Environmental Performance Indicator (SEPI). Finally it is possible to plot all options under consideration in a specific EPSM. The map therefore, enables comparison of different options for strategic decision-making purposes, based on a single Sustainable Environmental Performance Indicator.

To illustrate the use of the environmental strategy map, a demonstrative example of a plant in a Nordic country producing fertilizers and pesticides is presented. For confidentiality reasons, names and sensitive data are hidden. The company develops and markets plant protection products for controlling weeds and fungal diseases. It employees 850 people. It is located in a municipality in the northern part of Jutland (Denmark). The company budget for EHS management is €500,000. The following data (Table 2) characterises the production process.

Applying the method described in previous paragraphs, the different footprints are calculated (Table 3). To calculate the percentages of deviation from the targets, the values from Table 4 were used. These values are derived from Table 1.

The deviation-from-target values are used for the environmental strategic map (Fig. 3). The SEPI value from the area of the polygon is equal to 819.50. In this case for the cost we only consider

Table 2
Consumption and emission values of production process – single plant (2007).

Total consumptions		
Water consumption	m^3	49,749,000
Energy consumption		
Natural gas	MJ	809,000
Electricity	MJ	165,000
Heating oil	MJ	5100
Emissions		
Water	t	765
Air	t	94
Soil	t	94,550
CO_2	t	52,000
Work environment		
Absence from work due to accidents		4
Absence from work due to accidents (per worker)		0.004

Table 3
Calculation of footprints and deviation from the targets.

Carbon footprint	CO_2 52,500 t × (replenishment rate) 2.70 m^2/t	= 141,750,000 m^2
Normalized carbon footprint	141,750,000 m^2/(total water resources, municipality) 244,897,959 t	= 30.29%
Water footprint	= (water) 49,749,000 t	
Normalized water footprint	49,749,000 t/(total water resources, municipality) 244,897,959 t	= 20.31%
Energy footprint		
Natural gas (MJ)	809,000 MJ × (replenishment rate) 20 m^2/MJ	= 16,180,000 m^2
Electricity (MJ)	165,000 MJ × (replenishment rate) 153 m^2/MJ	= 25,245,000 m^2
Heating oil (MJ)	5100 MJ × (replenishment rate) 1178 m^2/MJ	= 6,007,800 m^2
Normalized energy footprint	47,43,800 m^2/(total area available, municipality) 468,000,000 m^2	= 10.14%
Emissions footprint		
Water (COD, nitrogen, phosphorus)	76,500 t × (replenishment rate) 1.00 m^2/t	= 76,500 m^2
Air (SO_2, particles, CO_x)	9400 t × (replenishment rate) 7634 m^2/t	= 71,759,600 m^2
Soil (spillage in the soil)	9,455,000 t × (replenishment rate) 2.38 m^2/t	= 22,512,355 m^2
	Total emissions footprint	141,750,000 m^2
Normalized emissions footprint	141,750,000 m^2/(total area available, municipality) 468,000,000 m^2	= 20.16%
Work environment footprint		
Absence from work due to accidents or health conditions	3.8	
Absence from work (per worker)	3.8/(number of employees) 850	= 0.0045
Normalized work environment footprint	0.0045/(average days of absence per worker national average) 0.022	= 20.32%

the value proposed for the investment and not a specific target. We can make this assumption because there are no additional options to be considered. Thus, the volume of the pyramid we obtained (Fig. 4) represents the space of all possible solutions.

7. The Sustainable Environmental Performance Indicator and policy-making

Considering the interrelations and the complexity of environmental issues, decision-making in this field is very difficult. This is particularly true if it is not supported by analytical tools and reliable metrics. The Sustainable Environmental Performance Indicator, demonstrated in this study, does not aim at being the single metric that policy makers should rely on to encompass all environmental and financial issues, it is instead a useful tool that can help them in the decision-making processes and could be adopted to compare different options and their comparative impacts on societies and on the ecosystems upon which they are totally dependent. In particular with its "deviation-from-target approach", SEPI provides a way to measure the effectiveness of environmental policies against performance targets. In this sense, the targets proposed in Table 1 can easily be adjusted to reflect local communities, counties or national reference targets. SEPI can be a valuable tool to investigate different options to a given environmental problem. For instance, if we mandate the reduction of the water consumption by 20%, this is reflected in a drop of SEPI by 7% points. In this fashion we can simulate the different options and propose the one with the highest possibility of reduction of the environmental burden.

Table 4
Maximum target values in the given geographical area (North Jutland, DK).

Total budget available	€	500,000
Total site	m^2	100,000
Total area available (municipality)	m^2	468,000,000
Total water resources (municipality)	m^3	244,897,959
Average accidents per worker (national average)		0.022

8. Conclusions

In the present study, the basic methodology, the main developments and limitations of Life Cycle Assessment have been reviewed. In particular the limitations in the use of LCA as a tool for strategic decision-making, allowed us to introduce the Environmental Performance Strategy Map as a possible solution. This particular graphical representation was designed to provide a single indicator – the Sustainable Environmental Performance Indicator – to overcome the use of footprints as mere communication and awareness tools. The introduction of the financial aspect complements the environmental and work environment considerations, in order to provide a more holistic answer to the sustainability of specific options. In particular SEPI can be successfully applied to provide an overall indicator of the environmental performance of existing applications or can be used as a supporting tool in comparing competing options in a strategic decision-making process. This approach has been demonstrated with a specific case to illustrate the main steps needed to find the balance between cost and environmental impacts. This offers potential balancing and minimising environmental impacts as energy/carbon footprint, water, emissions, working environment and quantifying them into one indicator.

9. Further studies

The SEPI is an important step in the debate on defining the appropriate metrics and methodologies for evaluating environmental performance. Specific case studies in the field will provide the opportunity to further refine and validate the SEPI as a useful tool in strategic decision-making. It is important to point out the difficulties in converting some of the footprints to area requirements. In general, it is relatively easy to express as an area, processes that are area based such as agricultural process. However, converting to an area, processes that are not primarily area based such as a chemical process can prove to be problematic. Another important development could be addressing the long term human health and ecosystem degradation costs. Identifying best practices and costs associated with them, as well as establishing target values are necessary next steps. This should be the basis for a comparison with current costs and practices. Further developments of this tool should address these problems.

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