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Title:

Sustainable Management of Materials, Products and Services - Applying a Full Systems and Life Cycle Perspective

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Abstract

There is no such thing as a “sustainable” or “harmless” substance, material, product or service. From a sustainability perspective, the characteristics of practices must be evaluated in relation to the full social, ecological and economic impacts throughout the whole life cycle. Sustainable *management* of materials, products and services follows from the full context of sustainability. This is not captured by a traditional Life Cycle Assessment (LCA), neither is the strategic business perspective.

A framework for Sustainable Development has previously been presented built on Backcasting from four Basic Principles of sustainability. It is used here to elaborate guidelines for the sustainable management of materials, products and services. The presented framework helps to imagine a future where management complies with the four basic principles of social and ecological sustainability, followed by strategic measures and investments to arrive at that goal. Such strategies should build on a step-by-step approach, where each step provides the ground for the next, while bringing economic resources to the continuation of the process. The available possibilities are a combination of dematerialization and substitution/change of materials, products, services and social mindset. There is a dynamic relationship between the two – dematerializations support substitutions and substitutions will prompt dematerializationsThe opportunities are evaluated under each of the four basic principles by asking key questions. This paper lays the groundwork for a future study, where these guidelines will be developed into a model for strategic evaluation of materials, products and services applying a LCA methodology that is derived from a full sustainability perspective.

Keywords*:* Sustainable development; Sustainability; Systems thinking; Backcasting; Strategic Planning; System conditions; Life cycle assessment (LCA); Products; Services; The Natural Step (TNS)

1. Introduction

1.1 A troubled history

Freons were initially introduced as environmentally ideal compounds due to their non-toxic and non-bio-accumulative nature. However, they proved to be a classic example of good intentions yet unintended consequences – an analogy that characterizes much of the past two centuries of modern industrial materials development [1]. Eventually they became doomed on the market as their effects on the ozone layer emerged and radical international action to curb their production and use followed.

There are many more historic examples of "safe" materials that have been commercialised, followed by a late awakening and subsequent large costs to society and individual organizations to redress the damage. Examples include accumulation of compounds such as PCB, DDT, and Methyl mercury in biota, all causing biological impacts such as hampered fertility in mammals and birds. Other potentially worse examples of direct impacts on humans may also loom on the horizon – e.g. bromine organic anti-flammables in blood, endocrine disruption from plastic additives, antibiotic-resistant strains of microbes from antibiotics in biota, and hampered kidney function from cadmium in foods – to mention just a few.

On the principle level, society continues to repeat the same mistakes. The industrial history of such events reveals lessons that should be kept in mind for future planning.

Sometimes impacts occur through very complex interactions in the biosphere, and cannot generally be determined before hand. At best, a certain impact can be clearly related to a certain activity or process after it has occurred. However, this is sometimes scientifically difficult, and the delay from the discovery of impacts, through scientific analyses, to legislation may be very long. This *speaks in favour of developing basic and first-order principles by which practices can be evaluated and determined upstream in the cause and effect chain*. At this stage complexity and uncertainty are at their lowest, which allows the potential for designing unsustainable problems out of the system before they become complicated and irreversible downstream second-order effects that require expensive compensation.

1.2 Backcasting from Principles vs. Backcasting from Scenarios

We have previously presented a framework for sustainable development that takes the above points of view into account [2,3,4,5]. The framework is built on (i) Backcasting from (ii) Basic Principles of Sustainability.

(i) “Backcasting” is a planning procedure by which a successful planning outcome is imagined in the future, followed by the question: “what was it that we did today that allowed us to get there?”

(ii) The term "Basic Principles of Sustainability" denotes principles that:

(i) ...are based on a scientifically agreed upon view of the world,

(ii) ...are necessary to achieve sustainability,

(iii) ...are sufficient to cover all aspects of the sustainability concept,

(iv) ...are general enough to include all activities relevant to sustainability,

(v) ...are concrete enough to guide action and serve as directional aids in problem analysis and solutions; and

(vi) ...are mutually exclusive and collectively exhaustive in order to enable comprehension and structured analysis of the issues.

The methodology has been elaborated from “Backcasting from Scenarios” [6] – a planning methodology built on the envisioning of a simplified picture of success. A metaphor from games theory for this method of planning is jigsaws, by which a more or less specific picture guides the game and helps the player deal with its complexity. Although backcasting from scenarios is a methodology that may encourage people to be more strategic and cooperative towards shared visions, it also has associated disadvantages for sustainable development. First, it is difficult for large groups to agree on detailed descriptions of a successful sustainable outcome due to differences in values, etc. Second, technical development may change the conditions for planning. And finally, detailed descriptions of a sustainable enterprise or society may not be sustainable at all. Together, these factors can lead to i) confrontational planning exercises and delayed action, ii) a narrow view of the technical potential of optional pathways, and iii) uncertainty with regard to whether a scenario is ultimately sustainable or not. For example: “Are photovoltaics really sustainable – what do they contain and what is the ultimate resource potential for this technology?” In this light, it is clear that basic principles for sustainability are needed to scrutinize any scenario with regard to its ecological resource potential and the complexity of its social and economical system dynamics.

Backcasting directly from basic principles of sustainability, on the other hand, resembles *chess* more than jigsaws, where principles of success (principles of checkmate, or basic principles of sustainability) guide the game. This is a dynamic planning method whereby each move takes the current situation of the game into account while at the same time optimising the possibility of winning. In the case of chess, a large number of winning combinations (i.e., checkmate) exist. *In conclusion, rather than agreeing on detailed descriptions of a desirable distant future, it is easier to (i) agree on basic principles for success, (ii) agree on initial concrete steps that can serve as flexible stepping-stones in the right direction, and (iii) continuously re-evaluate transitions in this way.*

The basic principles of sustainability are elaborated as first-order mechanisms – upstream at the first level of approximation – for ecological and social unsustainability, followed by a “not” inserted in each principle. The principles have been put into a framework for sustainable development, where step by step actions are launched in a strategic way to serve as economically attractive stepping-stones towards compliance with the sustainability principles. The framework presented below is systematized as a manual for facilitating brainstorming sessions and team planning (section 2.3, “A-B-C-D”-methodology).

1.3 The 'Funnel' as a Metaphor for Declining Room to Manoeuvre

Backcasting from Sustainability Principles does not depend solely on altruistic motivations, nor on saving money and resources through increased "eco-efficiency". Business benefits from taking the full scope of sustainability into account also exist – in the short term as well as in the long term.

Unsustainable development can be perceived as society entering deeper and deeper into a funnel, leading to declining potential for quality of life and economic performance of individual organizations and society at large. Pollutants and gases inducing climate change are increasing while the productivity of ecosystems is decreasing – meaning larger inputs of resources such as pesticides and fertilizers for the same harvest or catch. Combined with an increase in global population and an ongoing deterioration of the social tissue due to growing gaps between rich and poor, this trend leads to a systematically long term declining per capita potential for resources and life quality, analogous to moving deeper and deeper into a funnel of declining resources [2,3].

In this light, staying on the cutting edge of solutions towards sustainability at the opening of the resource funnel inherently means relatively smaller risks of being hit by its walls, and greater opportunity represented by their opening. Hitting the walls may appear as: i) increasing costs for resources, waste–management, taxes, and insurance premiums; ii) increasing cost for complying with new legislation; iii) loss of good reputation; iv) over-corrections when concrete negative impacts surface; and v) loss of market share to those who develop cutting edge solutions. A common counter-argument for pro-activity is that the timing for such negative events is difficult to determine. The logic, however, actually applies in reverse. The business risk associated with inherently unsustainable practices lies with those who are currently economically dependent on them. You cannot change an organization's dependency on energy systems, infrastructures, technologies, management routines, and image over night. What we do today influences our chances tomorrow. The funnel is a metaphor that is applied to sensitise the business community to the larger picture and bring about 'enlightened self-interest'.

The theme of this paper is to put the future vision of practices for any organization, municipality or nation, within the constraints determined by the basic principles of sustainability, and then to elaborate some commonsense conclusions and guidelines for the assessment and development of products and services throughout their life cycle.

In section 2, the overall approach is presented. It includes an abridged version of the previously presented framework and methodology for applying it, and overall conclusions on its implications that serve as input to section 3.

In section 3, the framework is discussed in detail in relation to the overall constraints and challenges of appropriate evaluation of business performance from a sustainability perspective. The discussion is built on experiences from applying the framework to a number of issues such as Sustainable Product Development [7] and LCA [8] and contains a general discussion on dematerialization and substitution/change. Two concrete examples from international industrial application of the framework for strategic decision-making are presented. These include the development of new production lines at Electrolux [9,10,11] and the management of tradeoffs regarding mercury in low-energy lamps at IKEA [12].

In section 4, the collective picture from the previous sections is used to discuss LCA. Traditional Life Cycle Assessments from the perspective of "choosing between negative impacts" can be completed by 'backcasting from principles' where "choosing between stepping-stones towards sustainability" is the objective rather than solely incremental reduction (i.e., designing out the tradeoffs in the long run).

Section 5 presents a conclusion and an outline of future research.

2. Approach

2.1 Elaboration of the principles of the framework

A framework for planning in complex systems should keep five essential hierarchal levels apart and not confuse them with each other [4] – (i) the System level, (ii) the Success level, (iii) the Strategic level, (iv) the Action level and (v) the Tools level. When this generic planning framework is applied to the challenge of sustainability, it says that there is a system called (i) "human society in the biosphere". In order to measure performance in this system, the "success level" (ii) is introduced, describing the principles of how human society in the biosphere could be sustainable and therefore successful at the basic principle level. When the goal or principles of success are known, it becomes possible to develop a strategic plan to reach that goal. This is why the "strategic level" (iii) follows. Once a strategy exists, it is possible to implement supporting concrete actions (iv). Finally we need tools (v) for on-line monitoring of our actions to make sure that those are in compliance with the strategy (iii).

Insert Figure 1 here

In order to avoid confusion, it is important to consider the dynamic and logical relationship between the levels. To this end, they should not be confused with each other. "Renewable energy", for instance, is often regarded as a principle for sustainability, belonging to the (ii) Success level, whereas it actually belongs to the (iv) Action level. Switching to renewable energy may lead to systematic deforestation and is therefore not in itself a principle for sustainability. However, if sustainably *managed*, renewable energy may comply with principles for sustainability.

At the heart of planning and cooperation is level (ii) – success. It should inform strategies, actions and the design of our tools. It occurs through backcasting from success principles, i.e., imagining a vision, and/or components of a vision, that comply with the principles and then proceeding by asking: "what shall we do now to optimise our chances of getting there?"

In order to arrive at a principle definition of (ii) success – in this case sustainability – we must know *enough* about the (i) system – in this case the biosphere, human societies and the interactions and flows of materials between the two. Since the concept of (ii) *sustainability* becomes relevant only as we understand the unsustainability inherent in the current activities of society, it is logical to design principles for sustainability as restrictions, i.e., principles that determine what human activities must *not* do in order to avoid destroying the (i) system. Freons (from now on called CFCs) were "harmless" yesterday, but which compounds will be harmful tomorrow? In what principle ways could we destroy the biosphere/society's ability to sustain us? This question is answered by looking *upstream* in cause-effect chains, where basic errors of societal design trigger the thousands of negative impacts occurring downstream.

Redesign within basic constraints of sustainability is the only way of tackling our current problems sufficiently upstream, and thereby avoiding new problems looming in the future. At this level, complexity is at its lowest, and the comprehension that follows from understanding this level makes it possible to ask the right questions and to structure all the details in a way that makes sense from a decision making point of view. With an added "not", such basic principles for destroying the system would be conditions for the whole system (Biosphere and Society) – "system conditions" [2,3,4].

The negative impacts related to unsustainability encountered today can – on the basic principle level – be divided into three separate mechanisms by which humans can destroy the biosphere and its ability to sustain society:

1. A systematic[1] increase in concentration of matter that is net-introduced into the biosphere from outside sources.
2. A systematic increase in concentration of matter that is produced within the biosphere.
3. A systematic degradation by physical means.

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[1] According to the Oxford English Dictionary the word "systematically" means: in a systematic manner; according to a system or organized plan; regularly or methodically. In this context systematically can be interpreted in two ways: (i) the deviation from the natural state must not systematically increase (increase more and more) due to the influence from society. (ii) the society must not be organized in such a way that it makes itself systematically dependent on activities that cause such (i) effects.

The system conditions specify how to avoid the destruction of the system ‘society within the biosphere’. Together, the first three basic principles provide a framework for ecological sustainability that implies a set of restrictions within which sustainable societal activities must be incorporated. Sustainability of society also depends on the maintenance and robust functioning of social systems – formal institutions as well as the informal structuring of civic society at large. This is required not only to sustain society itself, but also to comply with the first three ecological constraints. This requires a fourth basic condition.

Insert Box 1 here.

2.2. The implications of the System Conditions for planning

I. The societal influence on the biosphere due to accumulation of material from the Lithosphere (Earth's crust) is covered by the first principle [3]. The mechanism reflects a *net-input* of elements into the biosphere.

The balance of flows between the biosphere and the lithosphere must be such that *concentrations* of substances from the lithosphere do not systematically increase in the whole biosphere, or parts of it. Depending on the characteristics of the respective substances and the recipient, the critical concentrations (ecotoxic thresholds) differ and are generally not possible to foresee. This must be taken into account when considering flows and developing monitoring schemes.

II. The societal influence on the biosphere due to accumulation of substances *produced* in society is covered by the second principle. This mechanism differs functionally from the first, because production refers to the combining of elements into compounds, whereas system condition 1 reflects net-inputs of elements.

As with metals (system condition 1), the complexity of qualitative differences amongst various compounds as regards degradability and ecotoxic thresholds requires subtle guidance as regards the respective flows and practices.

III. The societal influence on the biosphere by physical means is covered by the third principle. It covers destructive manipulation, displacement and harvesting of natural capital and natural flows within the biosphere.

Again, the complexity is high, and we need a subtle tackling of this complexity

IV. Social dynamics and the production of services for humans are covered by the fourth principle. The challenge is to contribute as much as possible to the meeting of human needs in society worldwide, over and above all the substitution/change and dematerialization measures taken in meeting the first three objectives. The term "human needs" is not only defined as basic physical needs such as food and fresh water, but also all constitutional needs that must be satisfied for humans to stay mentally and socially healthy– e.g., protection, affection, understanding, identity [13,14].

This basic understanding of the collective mechanisms behind the thousands of impacts related to unsustainability makes it possible to ask critical questions about the full scope of sustainability, and to focus upstream in cause-effect chains at the initial stages of planning and product development. In this way, problems can be designed out of the system, rather than to first allowing impacts to occur, studying the impacts and publishing results, comparing notes with other scientists, and only then beginning to design policy and laws in response. Backcasting from basic principles represents a complementary method by which to avoid sustainability related impacts, despite little or no knowledge. The effects on the ozone layer from CFCs could have remained an unknown and unnecessary piece of knowledge had CFCs been scrutinized through a lens of the four system conditions of sustainability before they were commercialised. CFCs are unsustainable in relation to System Condition 2, except when contained in tight technical loops (see box 1 above).

Taken together, the first three system conditions define an ecological framework for any sustainable society, and the fourth principle is the basic social condition, interacting with the other three in a dynamic way. If the purpose of society is to meet human needs worldwide now and in the future while conforming to the ecological constraints given by the first three principles, then the use of resources must be efficient enough. However, it will not be sufficient solely to strive for the dematerializations and substitutions/changes needed to comply with the first three system conditions. Social sustainability implies that we also need improved means of dealing with issues of 'equity' and 'fairness' from the perspective of *human needs* and population growth. It is an inefficient use of resources, from the perspective of humanity, if one billion people starve and lack access to safe drinking water, while at the same time another billion use valuable resources for low-value activities such as sitting in traffic jams. These issues could begin to be addressed by keeping the current and future basic needs of humanity in mind when decisions are made.

It follows from above, that backcasting from principles help us ask questions like "do we use persistent compounds that are foreign to nature?" or "do we pay social costs for the purchase of materials in the developing world?" It leads to a larger perspective and should have at least as high priority as "do we emit ecotoxic substances?" The latter question only covers those substances and activities that have already surfaced as problematic, whereas the first type of questions complete the picture on the basic principle level, helping to avoid problems, with new substances and practices, that would otherwise surface in the future. These issues are more thoroughly covered in section 3.3.

2.3. A Manual to Apply the Framework

As a first step for an organization that wants to take sustainability as the starting point for planning, the system conditions must be "translated" into objectives that are relevant to the individual organization (the System Conditions are basic principles for the whole biosphere). For an organization that does not want to be a problem in the system, a logically and ethically relevant way of translation would be to add 'our contribution' to the phrasing of the system conditions:

The ultimate sustainability objectives of our organization are to:

1. …eliminate our contribution to systematic increases in concentrations of substances from the Earth's crust.

2. … eliminate our contribution to systematic increases in concentrations of substances produced by society.

3. … eliminate our contribution to systematic physical degradation of nature.

4. …eliminate our contribution to the undermining of human's ability to meet their needs worldwide

Each individual organization must draw its own conclusions from these basic principles as regards problems, solutions, goals and sub-goals. The four-step manual below provides a systematic way of guiding this intellectual process, "A-B-C-D" [3]:

(A) Awareness: The framework – including the system conditions, the step-by-step approach to comply with them, and the business motivation for doing so in a strategic manner–is shared as a mental model for community building amongst the planning participants (i.e., "playing the game Sustainable Development by the same rules");

(B) Baseline: An assessment of "today" is conducted by listing all current flows and practices that are problematic from a sustainability perspective, as well as considering all the current assets such as technique and competence and resources and alliances that are in place to deal with the problems;

(C) Visioning: Solutions and visions for "tomorrow" are created and listed by applying the system conditions to trigger creativity and scrutinizing the suggested solutions; and,

(D) Setting and Managing Priorities: Priorities from the C-list are made, and smart early moves and concrete programs for change, i.e., action planning, are launched.

The latter point – D – provides the framework with its strategic component. Suggestions from the C-list are prioritised for early launch to serve as stepping-stones for further improvements (similar to when moves in chess are scrutinized as regards their potential as stepping stones to eventually complying with principles of checkmate) by searching for measures that respond "yes" to the following three questions:

(i) *Does this measure proceed in the right direction with respect to all system conditions?* Sometimes a measure represents a trade-off that proceeds in the right direction with respect to one of the system conditions while working against others. Asking this question helps illuminate the full picture, and lead to complementary measures that may be needed to take all system conditions into account.

(ii) *Does this measure provide a stepping-stone for future improvements?* It is important that investments, particularly when they are large and tie resources for relatively long time periods, can be further elaborated or completed in line with the system conditions in order to avoid dead ends. An example would be investing heavily in a technology that will reduce the environmental impact, but without being capable of later adapting to complete compliance with the system conditions.

(iii) Is this measure likely to produce a sufficient return on investment to further enable continuation of the process?

Measures that answer "yes" to all three questions provide the strategic element of the methodology. Each suggested investment is scrutinized for its potential to (i) reduce impacts, (ii) serve as a flexible platform, and (iii) bring financial resources to further development.

3. The framework applied to the sustainable management of, materials, products and services.

This section discusses the essential issues when Backcasting from System Conditions of Sustainability is applied to the management of materials, products and services more in depth. These include: (3.1) the dynamic interrelationship between dematerializations and substitutions (trans-materializations); and (3.2) complexity and how to make priorities on the detailed level within the constraints provided by the framework. Two concrete examples from industry are also provided to put the issues in context (3.3).

3.1. The dynamics of dematerializations and substitutions/changes

Each of the system conditions represents a basic principle for sustainability. To comply with them in the future requires combined dematerializations and substitutions/changes [5]. This means that when society is sustainable, minerals and metals (S.C 1), chemicals (S.C 2), and unintentionally produced compounds such as dioxins or nitrogen compounds from over-intensive farming (S.C 2) are not systematically increasing in concentration in the biosphere, *i.e., all compounds have ceased to systematically increase, not only the ones that are currently causing identified impacts*.

Furthermore, renewable food and fibre from ecosystems are not over-harvested and/or purchased from poorly managed ecosystems or from companies that are not restoring ecosystems after strip mining. Transportation infrastructure is also not growing systematically at the expense of productive ecosystems (S.C 3).

Finally, all practices are put in the largest possible perspective as means to provide services for meeting human needs on the global scale (S.C 4). In relation to their ultimate utility, materials are not wasted and/or made inaccessible by other means to people in less affluent areas of the society. Nor does their extraction, manufacturing, transportation, warehousing and marketing contribute to social behaviour or abuses which undermine people's capacity to live a fulfilling life.

From an industrial perspective, this requires measures like:

(a) *Dematerializations* by means of higher resource productivity and less waste. Dematerializations, such as recycling or improvements of design that allow higher material performance per unit of utility, are helpful in avoiding accumulation of waste (S.C 1 and S.C 2) and reducing the pressure on productive ecosystems (S.C 3). Increasing resource productivity and reducing waste is also a way of ensuring enough resources for people on the global scale (S.C 4).

(b) *Substitutions/changes*. Many currently used materials and management routines are so problematic from a sustainability perspective that it would be too expensive to safeguard them within the constraints provided by the system conditions. Consequently, dematerializations are not enough to reach sustainability, and substitutions in their widest possible meaning are also necessary. These include decision-makers exchanging narrow rationales for meeting market needs, to a wider perspective considering all aspects of our cultural mindset when it comes to meeting human needs such as our social system and health impacts of supply chains and end-use of products in society (S.C 4). Other examples of mandatory substitutions/changes are some heavy metals that are very scarce in natural ecosystems, e.g. cadmium [10,11,15] (S.C 1), chemicals that are relatively persistent and foreign to nature such as certain plasticisers [16] (S.C 2), and materials such as wood from poorly managed ecosystems or from a strip mine that does not restore natural systems after decommissioning [12] (S.C 3). Such flows should not only be dematerialised (which is necessary during a transition period) but in the end be phased out or substituted by other materials and practices. Such new materials should be selected and/or developed in a way that maximizes the benefits for a global society and presents such opportunities for future generations that will be easier to adapt within the constraints of the system conditions. In turn, this means that the flows of certain replacement materials may not be dematerialised, but in fact *increased* to arrive at a sustainable society. Materials that are scarce and foreign to nature may be essential for sustainability and consequently need to be *increased* in a sustainable way, i.e., safeguarded by extraordinary societal means and 'closed-loop' processes. Examples include scarce metals in thoroughly recycled photovoltaic cells.

It follows that the terms *Dematerialization* and *Substitution/Change* are not only important themselves; they are also interrelated in a dynamic way and this should be utilized for planning. The less degradable a scarce material is in natural systems, the more its flows must be safeguarded and/or reduced i.e. 'dematerialised' within the technosphere, since leakages that can be assimilated in natural cycles are smaller. For scarce metals, assimilation occurs slowly as sedimentation and biomineralisation. For chemicals that are relatively persistent and foreign to nature, such as PCB or CFCs, assimilation also occurs as degradation, but very slowly. Similarly, the more of a substance an organization uses, the higher the risk that increasing concentrations pose a threat, and the more the flows of materials must therefore be safeguarded and/or reduced, or otherwise substituted.

Economic relationships between dematerialisations and substitutions/changes also exist. When profound dematerializations are insufficient – perhaps because materials are so relatively non-degradable and/or thresholds in natural systems are already surpassed (e.g., CFCs or PCBs) – we need to substitute. Such may initially be relatively expensive because production volumes of substitutes are often relatively small. Furthermore, they often require investment in new infrastructure. An example is the development of substitutes for CFCs in refrigerants, as well as new refrigerators that accept new coolants [10]. To make the *substitutions/changes* affordable, the implementation of new technologies is often supported or made possible through various kinds of *dematerializations*, i.e., higher resource productivity and less waste within the new production lines and products [5,7]. On the other hand, the infrastructure required to successfully dematerialise or close the loop may be more complicated and/or expensive than a simple substitution/change. One example of this would be when the infrastructure for recycling a metal to prevent its accumulation in the biosphere is more expensive than designing a biodegradable product the flows of which do not exceed ecosystem thresholds and consequently do not require a closed-loop system. Dematerializations should here be taken in the widest possible perspective and include not only leaner products, but also recycling and new business models including leasing. This means that there is a dynamic relationship between the two: *Dematerializations support certain substitutions/changes, substitutions/changes will prompt certain dematerializations* and substitutions/changes may eliminate some needs for dematerialisation.

Beyond these simple examples of the complexity and subtlety of tradeoffs between dematerialisations and substitutions/changes lies a critical point. As organizations first begin their journey, they often grasp for a variety of low-hanging fruit, looking for "early wins". While this approach is celebrated, either as an engagement or progress advancement, it must be kept in mind that the history of materials development is littered with stories of unintended consequences despite good intentions, i.e., the opposite of flexible stepping-stones. This underlines the need for patience and an integrated assessment of the effects of various combinations of dematerialisation and substitution/changes along the entire life-cycle from cradle to grave of a product or service – in other words, relentless focus on "success" through eliminating contribution to violations of the system conditions. Decisions in isolation without this broad perspective are dangerous, and threaten to solve one problem while creating another. The two examples below illustrate this complexity.

3.2. Two concrete examples from industry

Electrolux

An example from business is the way in which Electrolux phased out CFCs [9]. Introducing HCFCs would have meant an improvement in relation to CFC's ozone destruction potential. However, Backcasting from the System Conditions led to the following questions: can we trust that HCFC will be used large scale in the future, and if not, would HCFCs be able to serve as a flexible platform for the future development of other substances that would be less problematic from the System Conditions' point of view? The questions led to a completely different strategy towards sustainable use of hydrocarbons, using R134a as a flexible platform or stepping stone towards compliance with the system conditions, mainly the second system condition [10]. Though R134a has a relatively low degradability and does not fit the long-term goal in itself, it could be used as an incremental step in new types of white goods. The new version of white goods were therefore designed as a flexible platform in preparation for the next generation of degradable hydrocarbons that Electrolux was planning to develop. Electrolux was first in launching an entire family of freon-free refrigerators and freezers, resulting in increased market shares in several important markets. They also presented a new overall business strategy based on the system conditions [11]. It came to encompass a subtle balance of strategically chosen *dematerializations* and *substitutions/changes* under each system condition for a number of product families.

IKEA

Another example of systematic planning of this type is the methodology by which IKEA introduced their brand of low-energy lamps (CFL) on the market.[2] The tradeoffs between wasting energy on the one hand and increasing pollution with mercury on the other, have different dimensions and cannot be compared with each other by scientific means. The problem was dealt with through backcasting: in the future, lamps would be energy efficient, contribute to no increasing concentrations of mercury *or any other pollutant*, make perfect business sense for IKEA, yet still be affordable for the customer.. How could IKEA produce a flexible platform to arrive at this point? The story is presented by the head of environmental affairs at that time, Russel Johnsson [12]:

> "Replacing an incandescent lamp with a CFL will give considerable savings in energy consumption and electricity costs (roughly a factor of 5) and a considerable increase in product life (factor 8-10). But the high price has been an obstacle for the private households to dare to prove these facts to themselves in practice. The typical price level in Sweden at the time was 120 SEK (15 USD) for a 11 W CFL (corresponding to 60 W incandescent lamp). The reason for the high price has evidently been that the lamp manufacturing giants have large production facilities for incandescent lamps and do not want to compete with themselves by marketing CFLs at low prices. The problem is even more complex, since CFLs have a higher mercury content than incandescent lamps."

[2] CFL lamps are energy efficient but do contain mercury. This means that they are not sustainable in their present form but future development may make it possible to substitute the mercury.

The trade-off problem here was between higher use of mercury (System Condition 1), lower expenditure of energy (mainly System Conditions 1 and 2), and higher costs for the lamps, thereby lowering their availability to the public (System Condition 4). A more creative methodology than trying to estimate if the impacts outweighed the benefits was to start the planning procedure from a point where the tradeoffs did not exist – i.e., backcasting from the System Conditions to find a strategy to comply with them. In short, the following moves resulted:

1. A producer who could provide an adequate combination of the listed criteria to serve as a platform was identified. A reliable CFL with max. 3 mg Hg (mercury)/lamp – comparable to the European Union environmental labelling system of max 10 mg on the global market (i.e. a reduction to one third of previous levels or a factor 3) for such lamps – was then selected as the standard. A Chinese manufacturer, outstanding both from product design and production technology points of view met those requirements at the same time as they were price-competitive.
2. The producer and their competitors were notified that as long as they were ahead of the competitors on price, energy expenditure and mercury content, they would continue to do business with IKEA.
3. IKEA also visited the supplier's R&D department and discussed possibilities for further reducing the mercury content and other potential environmental improvements. The site visit was documented on video and edited video cassettes were later distributed to all Swedish stores.

4. Customers were informed about the serious environmental dangers with mercury and offered the option to take back (free of charge) all their used light sources containing mercury to IKEA stores. A contract with a major recycling company (RagnSells) to take care of all such returned light sources with mercury including all those generated in stores, warehouses and offices was then signed. 98-99 % of the mercury was recovered by a specialist company in Germany. Together with the Swedish Society for Nature Conservation (SSNC) a thorough review was also conducted of the recycling company and documented on video as well.

As a result of this campaign, the private household sales of CFLs in Sweden increased considerably forcing the competition to decrease their prices while IKEA's CFL sales increased. Russel Johnsson concludes [12]:

"We think that our campaign has been good for everybody – for the customers and for the country (we need to save energy in order to close down nuclear reactors) – except the manufacturers and importers of incandescent lamps. We calculated that, if every Swedish household replaced 20 pieces of 60W incandescent lamps with 11W CFLs, the resulting yearly energy savings would equal the production of one of the Swedish nuclear reactors".

3.3. The complexity of making detailed priorities

It follows, that the four system conditions can be used as a checklist to discover flows and management routines that are critical from a sustainability perspective. Critical aspects are listed, including questions where more information is needed (areas of uncertainty are also listed as “critical” aspects until answers exist), for instance, whether a substance is persistent and foreign to nature or not. Solutions are developed based on combinations of dematerializations and substitutions/changes for each critical flow, with the ultimate sustainability objective of eliminating the organization’s contribution to violations of the system conditions. When new products are planned, this way of thinking can inform all stages of a traditional product design cycle – from investigation of needs, through principle product, prototype, production and marketing [7]. Together with ten small to medium-size companies, we are currently developing this planning method into a concrete tool for sustainable product development. An essential aspect of this study is to identify hierarchies of relevant questions under each system condition (see section 4).

Sometimes many different measures that fit the presented framework exist, i.e., can serve as strategic stepping-stones towards compliance with the System Conditions while bringing resources to the continuation of the process. How can we make priorities on an even more detailed level amongst them? *Are we able to create checklists or manuals to support decisions beyond the overall framework with its guidelines for dematerializations and substitutions/changes throughout the life-cycle of materials?* Given that complete compliance with the system conditions is the ultimate goal, on what grounds can tradeoffs during the transition be managed, and how are uncertainties as regards compliance with the principles dealt with?

When we prioritize between various strategic options for sustainable development that all fit with the presented framework (providing flexible platforms towards compliance with the system conditions while bringing resources to the continuation of the process) many categories of criteria are simultaneously in play that represent grey areas, and make each situation unique. To elucidate this, a few obvious and important categories of such criteria are listed:

1. Certainty of current data and information. This category varies between no knowledge about risks, or even about the very existence of a material or compound (meaning that there is zero influence on decisions), to certainty, where the categories below are allowed to determine the outcome of planning. Between those extremes, a grey-zone influences decisions in a relative manner. The precautionary principle was created to deal with this uncertainty, and is further informed by categories 2 and 3 below.
2. Seriousness. This category directly communicates with the first. Regardless of how certain our knowledge is about a specific problem, we still have to assess its seriousness before we can decide on actions. Full knowledge of serious social and/or ecological impacts provides one extreme, whereas full knowledge of completely benign impacts provides the other. Between those, we have the grey area again, this time expressed as “degree of potential danger”. The greater the seriousness of the considered impacts, the smaller the certainty needs to be to provide a rationale for undertaking proactive measures.
3. Urgency. The combined result of the first two categories is now integrated into the temporal perspective. The extremes are, on one hand, certain information on serious impacts that will occur soon, and on the other hand, vague information on

very benign effects that might occur in the distant future. A multidimensional grey volume now exists (see figure 2).

Insert Figure 2 here.

4. The individual player's relative contribution to the problem. This category reflects the moral dilemma. The greater an organization's contribution to a problem is, the greater are the ethical demands to take action. For natural reasons, this contribution is often determined somewhere in a grey area (uncertainty here should not be used to dodge responsibility. We are dependent on the system 'Society in the Biosphere', and should be held accountable for the impacts we are inflicting on it – see the 'Funnel' metaphor and the 'Enlightened self-interest' sections in the Introduction). Yet another grey area dimension is now added.
5. The efficacy of possible solutions. This category can be subdivided into two interrelated categories:
   - Technical Potential: An organization may or may not have access to effective means to deal with a problem. The potential for providing a substantial contribution to solving a problem is therefore a driver for activity; however, reality is again a grey area.
   - Economic Potential: Even if effective measures exist, it is not certain that effective contributions to solving the problem are attractive or even possible from an economic point of view. The extremes are net-income from the measures on one hand (where no other drivers need to exist), vs., on the other

hand, pure costs that are so large that the measures are not within the realm of a realistic budget.

6. Market Visibility. This category naturally varies between high and low visibility respectively. It also implies a complex ethical dimension. If negative impacts are considered and measures are not undertaken because the chance of getting caught is low, this is an unethical and ultimately flawed decision. The same applies to "green-washing" without any greater engagement in the real cause. If, on the other hand, high visibility of actions is allowed to influence decisions for marketing/publicity reasons, it may lead to benefits for marketing and the creation of role models and leaders within society.
7. Clustered risks. The list above is complex enough, yet it deals with the risks of only one identifiable material. In reality, sustainability-related risks that are linked to individual materials and products present themselves as clustered risks along the entire life cycle – from resource extraction to end-use and disposal of products.

The conclusion is clear: it is difficult to create comprehensible, user-friendly detailed checklists or manuals for the management of complex systems like the one described above. Problems are generally multidimensional, and each dimension presents itself as a grey area. However, from other complex systems, such as chess, experience gives us a few guidelines for managing complexity:

- Once basic rules are clear, the individual's potential to deal with tradeoffs and to optimise chances in multidimensional and complex situations grows,

- One essential way to develop the potential of an individual to become a professional is to practice . Experience has a tendency to pay off (e.g., it is difficult to program computers to beat the best chess players), and
- Beyond a certain level of specificity, checklists may confuse more than help decision makers.

The overall recommendation from this would be to (i) make basic principles for success very clear upfront, (ii) develop smart overall strategies and guidelines for how to approach compliance with these principles (i.e., to apply a framework for decisions as a shared mental model among team members), then (iii) get on with the learning, i.e., “playing the game” and getting experienced in seeing the big picture goals and selecting stepping-stones in that direction.

The presented business cases from Electrolux and IKEA support this idea. These case studies present relatively advanced levels of competence in tackling the myriad of business and sustainability aspects to use the presented framework so that business moves comply with the principles of sustainability. This level of competence requires experience in ‘playing the game’, and a dense dialogue between experts on the framework and experts in the respective business area. How could this knowledge feed into a method of assessing products and developing new products from a full systems life-cycle perspective, by which this level of performance could be more systematized?

4. Life Cycle Assessments (LCA) from a Sustainability Perspective

4.1 The relevance of LCA

Industrial processes involve a whole series of events from the extraction of raw materials through transport, production, use of products, recycling and eventually to disposal of the product itself. The picture gets even more complicated when socio-economic aspects – such as the distribution of resources, wealth, social impacts and strategic business rationales – are included in the picture.

The term Life Cycle Assessment (LCA) denotes the sound objective of evaluating impacts of materials, products and services from the "cradle" (resource extraction), through transport, production, and use, to the "grave" (deposit of waste). A typical LCA includes: setting the goal and scope, conducting an inventory (LCI), performing an impact assessment (LCIA) and interpreting the results in the hopes of suggesting ways to reduce impacts. Obviously this leads to a more comprehensive view of the full impact than if only the material, product or service itself is evaluated. The most commonly applied forms of LCA focus on a selected number of ecological impacts that accompany products from the cradle to the grave – e.g., "emissions of greenhouse gases, acidification and eutrophication" – in order to compare different alternative, products with respect to their respective impacts. LCA has also been used to compare the environmental effects of materials and services. The purpose ranges from marketing one product over another, to trying to foresee the total impacts of alternative investments. However, it is important to realize that the term LCA in itself does not say *how* the evaluation is done, or for what *purpose.*

Many authors have discussed the complexity of, and difficulties related to, the assessment of sustainability impacts from industrial activities. Efforts have been made to streamline LCA to make the results easier to interpret [17,18,19]. However, a recent EU survey of available environmental evaluation tools concludes that there are many approaches for simplified LCAs but they are not always clearly and consistently defined. This therefore translates into inconsistencies when they are used [20]. The situation becomes even worse due to the lack of a generally accepted framework for discussing impacts from a sustainability perspective [21]. A systems view is needed to tackle the problems from a large enough perspective [22].

An appealing applicability of LCA is to support business in striving for *sustainable development.* However, a Swedish study on the implementation of environmental management systems in Swedish companies concluded that only 10% of corporations have allowed the results from LCAs to influence the measures taken [23]. The study did not explain this, but it is possible to suggest some presumptive reasons for the relatively low use of LCA by decision makers in business:

- The results from LCA, performed by scientists to evaluate a scientific question, may be too complex to interpret from a business perspective.
- Efforts to aggregate information from different categories of impacts into simplistic figures for decision makers may be perceived as flawed.

- The impact-perspective may be too narrow, i.e., missing important aspects of sustainability such as social aspects, unsustainable management routines of ecosystems, and unsustainable emissions of compounds with yet undiscovered impacts.
- The commonly applied LCA methods generally lack the strategic business perspective altogether.

In conclusion, it is possible that the relatively low impact of LCA on business decisions is not only related to a relatively low *use* of the method by decision makers in business, but also to a relatively low *relevance* of traditional LCA for such purposes. LCA as currently practiced is neither complete from the sustainability perspective, nor is it sustainability-oriented, nor is it practical from a user-friendly perspective.

4.2. Desired features of a Strategic LCA

Table 1 displays how a model for "Strategic LCA" would complete the various forms of traditional LCA currently applied:

Insert Table 1 here.

Considering the above, we suggest that a need exists for a "Strategic LCA" that consistently connects current LCA methodology to a full sustainability perspective and strategic business perspective as discussed in sections 1-3. This approach would have the following characteristics:

1) Coverage of <u>the full context of sustainability</u>

To cover the full context of sustainability requires that the four steps in a traditional LCA reflect the following:

i) *Goal/Scope*

A traditional LCI/LCA does not address all relevant aspects of sustainability. The focus typically is the efficient use of current materials, without recognizing that some materials should ultimately not be used at all given the costly investments required to safeguard flows within the constraints of the presented framework. Furthermore, traditional LCA tends to disregard issues not yet known to harm the environment, and it does not include the potentially disruptive social effects of the studied system. Other "blind spots" could include indirect impacts that come from the infrastructure supporting the material, product or service under study and how ecosystems such as forests, agriculture and fisheries are managed. It is critical, therefore, that the scope of analysis be explicit in considering the full scope of sustainability issues i.e. environmental, social and economic aspects

ii) *Inventory Analysis*

The environmental aspects studied in a traditional LCI/LCA typically cover a narrow sector of sustainability. Moving to a simplified "Screening LCA" further reduces the information entering the study. In contrast, a strategic LCA would capture the relevant sustainability aspects of the studied system since the analysis would start from the top with essentially no other system boundaries but the ones that apply for the whole biosphere and proceeding from the sustainability constraints of this system by asking about 'contributions' to the violations of those constraints. 'Hot spots' may later need more specific studies to be mapped out in more detail, and to give more information on priorities.

iii) *Impact Assessment*

Normally a LCI focuses on substances that are known to be harmful and/or substances whose effects are already quantified. The resulting list is then used to assess the potential environmental impact and guide the choice of material, product or service. A full LCA normally uses the LCI as input, divides the consumption and emissions into categories, and assigns quantitative indices according to their perceived threat to the environment. This results in one or several environmental impact indices that are presented to the decision-maker. However, in order for the impact assessment to be relevant from a sustainability point of view, it must take into account the full context of sustainability in assessing current and potential future impacts, rather than simply trying to aggregate impact measurements and create a simplistic view of today´s reality.

iv) *Results Interpretation and Improvement Assessment*

Results interpretation and improvement assessment must focus on the full scope of options available given the full context of impacts identified above. In a systematic way, it must also deal with the complex tradeoffs and prioritisation exercises that are an inevitable part of choosing options. Although ISO 14040 refers to this component as an "interpretation" stage [24], we propose a larger meaning, implying that an improvement assessment in relation to full social, ecological and economic sustainability must also take place at this stage.

2) Practical

Traditional LCA begins with a Life Cycle Inventory (LCI) during which resource consumption and emissions from the studied system (a material, product or service) are quantified and summarized. As previously mentioned, these life cycle investigations require great effort and offer complex results that take time to interpret, making them impractical for managers. Many attempts have also been made to compensate for this by introducing simpler approaches such as "screening LCA", where the focus is on a qualitative study of larger flows, which involve less time spent on data gathering and simpler results. Still, it becomes more difficult to choose between alternatives if the result is not quantitative and the resulting simplicity is accompanied by a loss of information on both qualitative and quantitative aspects of the studied systems.

For these reasons, a strategic LCA would start with a qualitative overview of sustainability aspects and then move into selective quantitative studies focusing on data gaps. The data would not be aggregated into indexes that inherently mean a loss of information entering the study. Since the different components making up those indexes may require different business strategies, such losses of information make it difficult for traditional LCA to be useful and practical for decision makers.

4.3. Strategic LCA in Depth

A methodology for "Strategic LCA" that builds on a sustainability perspective has previously been suggested [12]. It uses the A-B-C-D analysis to guide the process (which is similar to the four steps of a traditional LCA), and is based on basic principles for sustainability (i.e., the system conditions) as the guiding norm for goal and scope definition, inventory analysis, impact assessment, and improvement assessment of LCA. Further, it sets out ultimate organizational objectives based on the system conditions, and summarizes the spectrum of action under the twin mechanisms of dematerialization and substitution/change. Decisions are then made using the three criteria mentioned earlier (i.e., flexible stepping-stones, sufficient return on investment, and progress across all four system conditions) to scrutinize actions. The authors also state that this perspective would open up a more strategic approach to LCA, but do not elaborate this idea, nor deal with the issue of complexity.

As outlined in section 3.3, further work has also elaborated on the three basic decision-making criteria such that they take into account issues such as: certainty of current data and information; seriousness; urgency; an individual organization's contribution; the efficacy of solutions; market visibility; and other clustered risks. These considerations represent an attempt to deal with the complexity encountered during strategic sustainability planning.

Finally, an LCA where the perspective is sustainability rather than randomly chosen impacts would build on questions under each system condition, and take a full life cycle perspective. Further efforts in this area have also been made to develop a set of hierarchical questions for application to the strategic development of materials, products and services in a model that integrates the presented A-B-C-D structure with a traditional model for integrated product development [11]. Product development teams from ten small to medium-sized enterprises (SMEs) were exposed to the hierarchically structured questions under each system condition and under each stage of product development. This methodology allows a generic approach that can be applied for any product category. Examples of the questions under each system condition include:

I…*"eliminate our contribution to systematic increases in concentrations of substances from the Earth's crust"*.

Relevant questions include:

"Does our organisation/project/ process/product systematically decrease its economic dependence on fossil fuels? Is our organization/project/process/product economically dependent on matter from the lithosphere? Can the same human service be delivered by less resource demanding means? Are any of the lithospheric materials, or their break-down products, currently increasing in concentration anywhere in the biosphere? Regardless of whether we have data on accumulation or not, are the materials abundant in nature (for instance aluminium, titanium, iron) or scarce (for instance copper, zinc, cadmium) [15]? If we are dependant on scarce elements, are there alternative methods by which we could phase them out, or is complete safeguarding of the substances inherently a more realistic alternative for the future? Are resources containing mined materials conserved throughout the life cycle or are materials used in a dissipative way? Are they recycled on a maintained quality level?

II…*" "eliminate our contribution to systematic increases in concentrations of substances produced by society"*.

Relevant questions include:

"Is the organisation/project/process/product today economically dependent on dissipative use of substances that are either produced on purpose, or unintentionally as pollutants? Are those substances, or their break-down products, currently increasing in concentration anywhere in the biosphere? Regardless of whether we have data on accumulation or not, are any of the substances persistent and foreign to nature? If so, are there alternative methods by which we could phase out our dependency on such compounds, or is complete safeguarding of the substances inherently a cheaper alternative for the future? Are resources containing chemicals conserved throughout the life cycle or are materials used in a dissipative way? Are they recycled on a maintained quality level?"

III… *"eliminate our contribution to systematic degradation of nature by physical means"*.

Relevant questions include:

"Is the organisation/project/process/product today economically dependent on activities that mismanage productive parts of the biosphere, or infrastructure that are unnecessarily area-consuming such as large road networks? What are the long-term possibilities with respect to meeting the same human needs by less area-consuming and/or less biodiversity-damaging alternatives? Are resources from productive ecosystems conserved throughout the life cycle or are materials used in a dissipative way? Are they recycled on a maintained quality level?"

IV*…"eliminate our contribution to the systematic undermining of people's ability to meet their needs worldwide".*

Relevant questions are:

"What human need is addressed through this material choice? In what way is the organisation/project/ process/product today economically dependent on using a large amount of resources in relation to added human value? Can this need be addressed in other ways, e.g., substituting products for services? Are social costs paid for throughout the value –chain and also among suppliers from developing countries? Are human rights violated in any region or site where we have a direct or indirect influence? Can this influence in any way be turned into long term opportunities to meet the same human needs by smarter and more sophisticated methods? Are resources conserved and recycled throughout the life cycle to increase the chances for economical availability over large enough global spatial and temporal perspectives? Do our activities directly or indirectly support regimes or social organisations whose activities undermine the health and well-being of others? Will our actions damage the cultural diversity of society? Are we helping or hindering other people to act in a sustainable way?

The preceding discussion provides an overview of what currently exists as part of the framework for Strategic LCA. Each piece is based on a framework for sustainability applied in the context of LCA. This approach may have a number of advantages that lead to a more practical and complete LCA methodology (summarised in Table 2).

Insert Table 2 here.

5 Conclusions and Future Research on "Strategic LCA"

The theme of this paper is to put the future vision of management – for any organisation, municipality or nation – within the constraints determined by a full life cycle perspective of sustainability, and then to elaborate commonsense conclusions and guidelines for the development of strategic pathways towards that point. “Backcasting from Basic Principles of Sustainability” is a framework that covers relevant aspects of how to plan ahead in the complex system “societies within the biosphere”.

The components outlined above as part of a “Strategic LCA” are theoretically robust and based on backcasting from basic principles for sustainability. They provide basic guidelines to assist organisations in asking the right questions and structuring their analyses to ensure that essential critical aspects of sustainability are not left out.

The guidelines thus far, however, are only a beginning. Most organisations typically require further support and guidance to help them analyse complex tradeoffs and choose the best options. Experts applying the guidelines to create templates of several products could help organisations better: i) structure quantitative data; and ii) analyse and make decisions based on the tradeoffs associated with multiple attributes of various technology pathways (i.e., the tradeoffs between environmental, social and economic goals that often exist).

In a forthcoming study, we will evaluate this possibility further. It builds on the fact that *experts* who are well experienced in applying the framework can produce such *templates* for various kinds of product categories. The templates will contain the overall picture of critical flows and practices for a certain product category, as well as possible solutions, all seen from the full scope of sustainability. These templates, describing the respective product categories *in general* can then be applied as benchmarks by product development teams trying to fill the sustainability gaps in strategically smart ways. This methodology will introduce a new way of dealing with complexity, at the same time as it will build on dialogue. Product development teams can also criticise the templates, by which they will be continuously refined as they are used. The methodology will also be simple enough to apply to small and medium-sized enterprises (SMEs).

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Vitae

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Box 1: The natural Step System Conditions for a Sustainability

In the sustainable society, nature is not subject to systematically increasing…

I …concentrations of substances extracted from the Earth's crust,
II …concentrations of substances produced by society,
III …degradation by physical means

and, in that society. . .

IV…people are not subject to conditions that systematically undermine their capacity to meet their needs.

Figure 1. The five-level-model for planning in the complex system – Society in the ecosphere

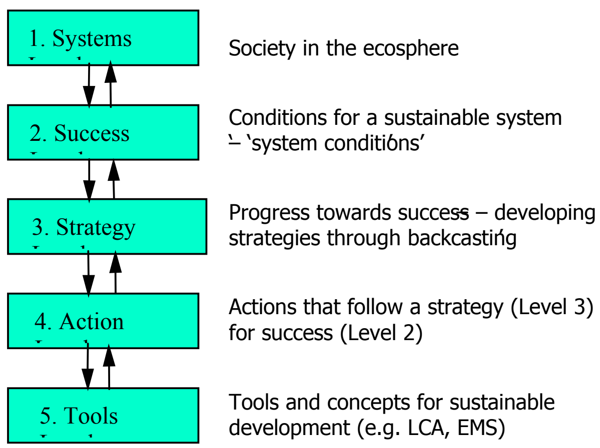

Figure 2. The grey volume between the categories of certainty, seriousness and urgency.

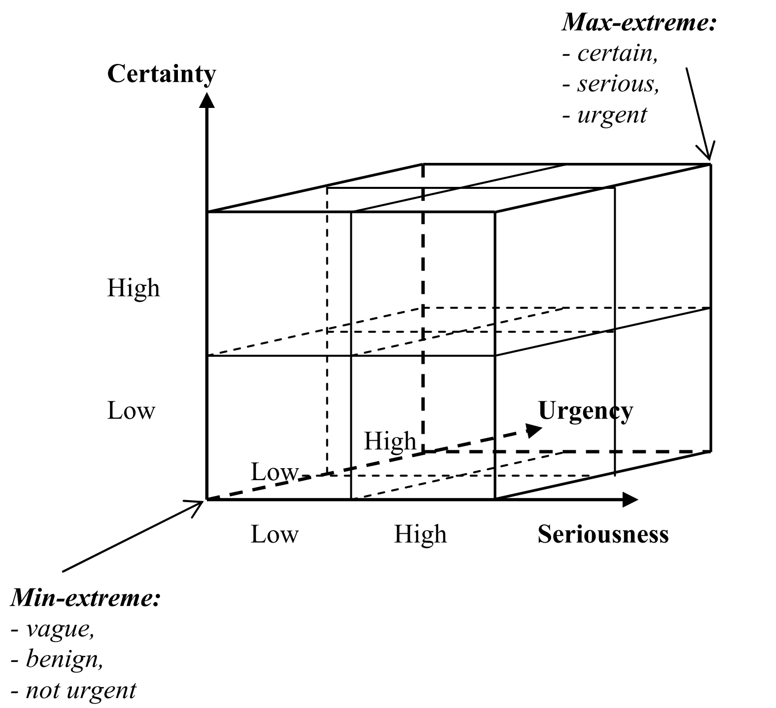

Table 1: *Comparison between different life-cycle related sustainability assessment approaches.*

Approach	**Description**	**Data type**	**Sustainability Issues covered**	**Objective**
Screening LCA and similar approaches	Often a group effort to sketch lifecycle environmental aspects or impacts.	Mainly Qualitative	Depends on participants. Focus is on known problems.	To give decision-makers an understandable yet simplified picture of material, product or service environmental load.
Life Cycle Inventory (LCI)	A mass balance for materials known to flow between a chosen system and the environment.	Quantitative	Depends on participants. Resource consumption and emissions of known pollutants with reference to the chosen scope.	To facilitate a choice of material, product or service with lowest resource consumption and emissions of known pollutants with reference to the chosen scope.
Full Life Cycle Assessment (LCA)	Weighted Summary of environmental load from a chosen system.	Quantitative	Depends on participants. Resource consumption and emissions of known pollutants with reference to the chosen scope.	To facilitate a choice of material, product or service with lowest environmental load values with reference to the chosen scope.
"Strategic LCA"	Back-casting from conditions for sustainability.	First qualitative then quantitative, if needed.	Potential environmental, social and economic problems and potential opportunities from a full systems perspective	To identify pathways towards sustainability.

***Table 2**: How a framework for sustainability makes the stages of a traditional LCA more practical and complete.*

LCA Stage	Steps in the A-B-C-D analysis	Completeness and Practicality
Overall process	**A-B-C-D**	Provides a structured A-B-C-D process and hierarchical set of questions from which one can "backcast from basic principles".
Scope/goal definition	**A**	Relates analysis to the system conditions as a starting point so that scope is not limited to impacts that are certain and/or known.
Inventory analysis	**B**	Relates inventory aspects along the entire life cycle directly to the four system conditions, ensuring that all flows and practices that are critical from a sustainability perspective are taken into account.
Impact assessment	**B**	Relates impacts along the life cycle directly to each system condition as a simple frame for the assessment.
Interpretation and Improvement assessment		
(i) Option generation	**C**	Provides overall strategic organisational objectives based on the four system conditions covering the full context of sustainability, and categorises the spectrum of improvements into two distinct and useful mechanisms for option generation - dematerialisation and substitution/change - and applies them to each system condition.
(ii) Option analysis	**D**	Provides a hierarchical set of questions (that are particularly useful at this stage) to ensure the full context of sustainability is taken into account.
(iii) Option choice	**D**	Provides three simple yet complete criteria to guide decision choices, reflecting the technical, sustainability and economic dimensions.