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A compass for sustainable development

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1. Introduction

Environmental problems have multiplied and changed character during the past decades: from local to global, from distinct to diffuse, from short time delay between cause and effect to long time delay, and from relatively low complexity to high complexity [Holmberg & Karlsson 1992]. This enlargement of complexity and effects has increased the need for a compass to point us in the direction of sustainability.

A compass requires a sensitized needle that can respond to the pull or lure of magnetic north. The four principles we have developed are means of sensitizing our society — but what is the objective lure to which that heightened sensitivity responds, what is magnetic north? It is precisely the principle of sustainability, the moral insight that destroying the future capacity of the earth to support life is wrong. We take this moral principle as given. Our focus is on sensitizing the needle, not on explaining the existence of magnetic north. This ethical presupposition is widely, but not universally, shared. It deserves discussion in its own right, but that is not our present purpose.

To successfully implement sustainable development, professionals, experts and the general public need to be engaged. In order for diverse communities to function effectively together, we need to take advantage of the different competencies and skills we share and meld them into an integrated system of change. This requires shared mental models, much in the same way as when a hockey or soccer team is functioning as an intelligent organism rather than as a group of individuals. To merge the different skills of the goal-keeper, defenders and attackers into an effective whole, the players need to have exactly the same overall perception of what the game is about — a non-negotiable set of rules. In athletics the rules are fixed during a game or tournament but can be re-negotiated between seasons. We are at a point now where we need to re-negotiate the rules of our economic game so that they conform to the rules of the biophysical world which cannot be amended, changed or negotiated.

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With regard to environmental problems, we not only face the problem of creating and disseminating the set of rules for sustainable development. Unlike a hockey team, there is not a shared understanding of the basic reasons for the rules. Thus far, only a relatively small segment of society accepts sustainability as critical and compelling.

That so much of today's environmental debate is based on conflicting arguments is, in one sense, positive since different opinions are imperative for a free and open dialogue. However, much of the controversy is unnecessary and self-defeating, and therefore delays urgently required measures. The unnecessary part of today's environmental debate is linked to a number of factors such as misunderstanding, poor knowledge, resistance built on vested interests, psychological resistance linked to the traditional attitudes, and difficulty at arriving at an appropriate overview due to the change of character of environmental problems as described above. These problems place high demands for consensus on our mental models of sustainable development.

There must be a balance in society between investing in sharing of existing scientific knowledge, and investing in further extension of that knowledge. Our strong emphasis on public pedagogy reflects our belief that in present circumstances it is more important to extend basic knowledge of how the world works to everyone than for a few advanced specialists to master further details of their special discipline. The scientific background to our principles is not new — indeed they derive their force precisely from the most basic laws of science. All physicists know and accept them (first and second laws of thermodynamics and the principle of matter-conservation). But the voting public does not understand them, and often the scientists themselves fail to see how these laws set the context for sustainable development. Public pedagogy is therefore the foundation of our model. In a democracy, public policy cannot rise above the understanding of the average voter. Consequently, the distribution of knowledge is at least as critical for democracy as the distribution of income.

2. Critical requirements for a theoretical model of sustainability

a. The model must be based on a scientifically acceptable conception of the world.
b. The model must contain a scientifically supportable definition of sustainability.
c. The overall perspective must be applicable at different scales, and must see the economy as a subsystem of the ecosystem at each scale. Individuals must see how their actions aggregate from micro scales up to the macro scale, and thus understand their role in the overall move toward sustainability.
d. The micro-economical perspective should not require individuals to act against self interest. We may need some altruistic behaviour in the political task of setting up the rules of the game, but in the actual playing of the game we should not expect individuals to behave altruistically.
e. The model must be pedagogical and simple to disseminate so that it can support a public consensus necessary to be put into practice democratically.

f. The model must not engender unnecessary resistance or be adversarial.
g. The model must be able to get started without first requiring large scale societal changes. It should be implementable within today's economic reality. Business corporations, political parties and the public should be able to use the model directly.
h. It would be an advantage if the model could also be used as a starting point for developing "new economics" — as a way to recognize a new and larger pattern of scarcity to which old and basic economizing principles must be applied.

3. Previous models for sustainable development

Previous models satisfy few of these demands. Some of the requirements are satisfied, but many models fail requirement b), which means the rest fail automatically. Often the effects of marginal environmental measures are analyzed in today's perspective, without being linked to the overall principles for sustainability that must be met tomorrow. If the starting point is today's prices, today's infrastructure, today's sectorized fields of responsibility etc., there are large risks for such sub-optimized measures that later on prove to be "blind-alleys". There are many examples of this. Today's low prices (often subsidized) on non-renewable energy also implies that long-term investments still are made without reference to sustainability and the change of relative costs which will be inherent to it. Today's sectorized fields of responsibility within communities means that many possibilities for more efficient overall societal planning are missed. This concerns both energy efficiency (for instance the use of waste heat) and more efficient use of material (for instance re-use of products, recycling of nutrients on crop-land and forest's and recycling of metals).

3.1 Internalization of environmental costs

Economic theory is general enough to account for pollution and depletion of finite resources. However, it is difficult to find methods to fully evaluate these aspects in monetary terms. In such efforts, attempts are made to evaluate the costs for marginal changes without reference or consideration to the overall conditions for sustainability. There are great risks associated with such procedures. Costs tend not to escalate until something dramatic occurs, which means that feedback comes too late. For example, a gallon of water is worth little today, but what will the last gallon of drinkable water be worth? This is a serious draw-back for margin-based valuation, considering that environmental problems often are systemic and non-marginal, characterized by a long time delay between activity and damage, non-linear interrelationships (for instance threshold-effects) and complex cause and effect chains. In this way, a highly uncertain variable (monetary evaluation of life-supporting system) is introduced into the definition that should be absolute and comprehensive. This dilemma can be solved by proceeding from the overall physical conditions for sustainability, since nature must survive independently of how it is economically evaluated. There is no guarantee that all environmental costs can ever be internalized in a way that prices alone will provide enough information to foster development toward sustainability. Therefore, monetary models must be complemented with models based on physical indicators that measure society's development towards or away from sustainability.

3.2 One-dimensional physical measures

Many scientists have realized the difficulty in trying to evaluate changes in the stock of natural capital in monetary terms. It has led to attempts to change the unit of value from monetary terms to something “closer to nature”. The most common attempts build on various units or “currencies” related to energy flows in both society and nature. However, such procedures have many weak points. First of all these scientists have generally observed the difficulty to audit the complex interrelationships in Nature with one single currency. For instance, accounting pollution of mercury in a lake in energy –, exergy –, or emergy – terms, would lead to an inappropriate and highly coloured description of reality. The world functions on the basis of many qualitative properties of matter that are simply not reducible to differing quantities of energy or exergy. As Georgescu-Roegen (1976) noted in reply to the modern versions of an energy theory of value: “matter matters too”.

Furthermore, efforts to apply various energy terms as an appropriate currency are based on the assumption that the lack of energy provides the overall restrictions for societal metabolism of resources. But the global use of energy only corresponds to around 1/13000 of the incoming energy from the sun. Thus, the bottle-neck for sustainable development is the complex pattern of all the material flows in society including the resource sinks for societies metabolic wastes [Holmberg 1995]. Those flows are generated not only by the energy-sources (for instance fossil coal leading to flows of carbon dioxide and polluting metals), but also by the other material flows that are linked to the energy flows (mining, production, packaging, distribution and consumption). Besides the material flows, surface area provide another limiting factor, both as space for human activity, and as the basic “net” for capturing solar energy that drives the material cycles by which dissipated quality of materials is reconstituted.

The amount of energy used in the Society is often perceived as a general marker for the amount of resources spent. “The less energy used — the more resource-saving and sustainable behavior”. However, this reasoning leads to a number of shortcomings. First, the rationale for saving resources is to stay within the boundaries of sustainability. Consequently, those still need to be defined (see System Conditions 1, 2 and 3 below). Furthermore, many people have access to such small amounts of resources that their basic human needs are not met. This is part of the problem, for instance through deforestation (see System Condition 4 below). Finally, many urgent measures for sustainability, for instance restoration of soils that have become infertile, require more resource-inputs than are applied today.

Although a physical perspective is needed, one-dimensional physical measures narrow perspectives and lead to an insufficient accounting of both impact and dependence of society on nature.

3.3 Multi-dimensional physical measures

The above reasoning leads to a need for evaluating society's impact on nature with more than one indicator. Most previous models have contained one or both of the following two characteristics: (1) Indicators have been applied late in the cause-effect chain. (2) Indicators have not proceeded from a comprehensive description of the overall physical conditions that must be met in a sustainable society.

(1) The first characteristic refers to indicator systems describing damage in nature. Of course there is a need to monitor the changing state of nature. However, monitoring is insufficient if we want to steer society towards sustainability. Since environmental problems originate within society, it is important that we focus our interest early on the cause and effect chain – on societal metabolism and its influence on nature rather than the temporary state of nature that has so far resulted from that continuing influence. There are at least four reasons for this (Holmberg, 1995): (1) Deleterious effects have already occurred where we can measure them — the task must be to avoid them. (2) The causal factors are diluted and dispersed when they exist in nature, often making it difficult to detect them in due time. (3) Due to the complexity as well as various delay-mechanisms in the cause and effect chain, it may be difficult or impossible to link a deleterious effect in nature to a particular activity in society. (4) Indicator-systems late in the cause and effect chain miss all the potential environmental problems that have as yet not caused any detectable effects in nature. For instance, this is true for most of the metals and persistent unnatural compounds, that are accumulating today in society. Due to complexity and delay-mechanisms, indicator-systems late in the cause and effect chain have generally lead to such complicated and incomprehensible results that the experts applying them have lost overview and control. If we for instance apply emissions of CO_2 as an indicator for the impact of fossil fuels, we end up with two major problems. Firstly, the complexity of negative and positive feed-back loops that are related to the accumulation of CO_2 in the atmosphere leads to such complicated calculations that we lose control. This in turn may lead to such complicated disputes regarding the allowed threshold for accumulation of CO_2 in the atmosphere, that we tend to forget that a systematic accumulation is definitely non-sustainable. Secondly, the accumulation of CO_2 is but one of many molecules or elements that accumulate in nature due to the transformation of fossil fuels and other deposits in the Earth's crust to dispersed waste. In this respect, the accumulation of CO_2 could be regarded as an indicator for a net increase of other types of waste such as metals like cadmium or lead, or sulfurous acid rain.

(2) The second characteristic has generally led to the concept that marginal improvements in today's situation are comparable with one another. This excludes consideration of what alternative will best suit a development path focusing on

sustainability for the whole society. An example is arguments for burning of paper instead of recycling, with reference to the sometimes high transport costs inherent to recycling. But how do the calculations appear, when fuels have become renewable, transport distances shortened and transportation becomes more efficient — not only with regard to the technical efficiency of the various vehicles in use, but also with regard to the organizational point of view (for instance by collecting paper for recycling when the new one is delivered)?

In conclusion we need multi-dimensional measures proceeding from overall conditions for sustainability that put focus early in the cause and effect chain. There are few attempts along that line (e.g. Daly [1977,1990]; Page [1977]; Jacobs [1991]; IUCN, UNEP, WWF [1991]; Holdren et al. [1992]). We extend these contributions, with a more coherent effort which is aimed at public pedagogy as well as operational planning for sustainable development.

4. The "up-stream" societal problems we are dealing with

Society is influencing nature through an *exchange* of energy and matter. Matter is mined or drilled from the earth's crust and is delivered to the ecosphere. Molecules and compounds are produced in society — intentionally in production, as well as unintentionally in for instance sewage water or smoke from incineration processes – and delivered to the ecosphere. We are also *manipulating* natural systems through expansion of the technosphere and various other modes of exploitation [Holmberg & Karlsson 1992].

For example, natural ecosystems are replaced with monocultures to increase yield, but at the cost of loss of resilience and biodiversity. Another example is the flows of copper from the earth's crust to the ecosphere from mining. It has increased five times since 1945, and is today about 20 times larger than the corresponding natural flows [Holmberg et al 1994]. Likewise, the content of carbon dioxide in the atmosphere has increased by about 30 percent due to the burning of fossil fuels and deforestation [IPCC 1990]. Production of new compounds has literally exploded. In the present industrial society tens of thousands of chemicals are used regularly. There are, for example, over 70.000 chemicals on the U.S. TSCA (Toxic Substances Control Act) Inventory [Clements et al, 1994]. Many are produced in such volumes that the limits of the natural mechanisms by which they are turned into resources — or disposed of — are exceeded. This means that sedimentation processes, as well as biodegradation followed by re-entry into the cycles of nature, are exceeded leading to accumulation in the ecosphere. Some of the substances accumulate directly in nature, some accumulate in society until they eventually leak out into nature. For example, heavy metals are leaking from the stored accumulated metals of society, and they will continue to accumulate in nature even if we cease completely to mine them [Wallgren 1992; Holmberg et al. 1994]. The rate of manipulation and harvesting from the ecosystems is also extensive. The global fish catch has for instance increased 4.5 times since 1950 while all 17 major fishing areas in the world have either reached or exceeded their natural limits [Brown et al. 1994].

5. Model for sustainability

A model for sustainability that can function in practice provides a framework for society's activities, making societal metabolism compatible with the overall conditions in it's resource-base. Using a reverse perspective and proceeding backwards from this absolute framework for sustainability, the economical system must be adjusted by a step by step investment process towards compatibility with the natural system that supports it — i.e. towards sustainability. Individuals should be able to regard themselves as contributors to such a concrete plan. Our model is aiming at this, and has been constructed based upon the following reasoning:

<u>The precondition of our lives</u>
Humanity cannot tolerate continual degradation of the environment. We cannot, for instance, be sustained by an environment with ever lower pH values, ever increasing concentrations of heavy metals in the soils, ever increasing concentrations of CO_2 or CFC in the atmosphere, ever decreasing resource base for agricultural production, ever decreasing conditions for marine production etc. We may and do argue about what levels we can survive within, but no one argues that we can survive with continuous loss or degradation in living systems.

<u>Basic science</u>
* Matter and energy cannot be created or destroyed. (According to the first law of thermodynamics and the principle of matter conservation.) Mass number, i.e., the number of nuclear particles is conserved. If we disregard from nuclear reactions that are relatively unusual on the Earth's surface, this law also holds in a stronger form: the number of atoms/ions of a certain nuclide (a certain isotope of a certain chemical element) is covered as well as the total number of electrons. This law has to be slightly adjusted to account for the nuclear reactions that do take place. This can be done rather easily, but does not effect this discussion.

* Matter and energy tend to disperse. (According to the second law of thermodynamics.) This means that sooner or later, matter that is introduced into society will be released out into natural systems.

* Material quality can be characterized by the concentration and structure of matter. Concentration can be calculated by the concept of exergy. To calculate structure we need information theory to develop more sophisticated measures. We never consume energy or matter — only its exergy, purity and structure.

* Net increase in material quality on Earth is produced by sun-driven processes. Photosynthesis is the only large-scale net producer of material quality. According to the second law of thermodynamics, disorder increases in all closed systems. Consequently, an exergy flow from outside the ecosphere is needed to increase its order. The exergy flow from the sun is far greater than the exergy flows inherent in gravity in the solar

system (creating for instance tidal flows) or the exergy flows from radioactive decay inside the Earth (creating geothermal heat).

The cyclic principle

Basic science and the precondition of our lives lead to the cyclic principle. This means that waste must not systematically accumulate in Nature, and that reconstitution of material quality must be at least as large as its dissipation. Consequently, matter must be processed in cycles, i.e. the societal metabolism must be integrated into the cycles of Nature. This avoids a systematic shift in environmental parameters and enables the continuing diversity of nature and human activity. From the cyclic principle, four conditions for the maintenance of quality in the whole system can be deduced. A more thorough discussion of the four system Conditions is given in (Holmberg 1995 and Holmberg et al 1996).

Figure 1

Figure 1. For its photosynthesis, the green cell A uses exergy from the Sun to concentrate and structure dispersed matter into resources, such as carbohydrates. These exergy-rich resources are then also used to maintain the animal cell B. The animals together with the decomposers discharge these resources into carbon dioxide, water and nutrients that can again be used as building blocks and be recharged into exergy-rich structures by the green cell. Thus, the matter goes around in huge cycles, partially in the form of exergy-rich structures and partially in the form of dispersed matter. The energy is converted in many steps. The final form is low-temperature heat which is radiated into space. The exergy from the Sun also maintains the great water cycle, in which water is lifted to high altitudes, and thus charged with gravitational exergy that is gradually lost when the water is running back to the sea. There is also a continuous weathering of substances from the lithosphere which is balanced by sedimentation back to the lithosphere. The pre-industrial society used resources mainly from the ecosphere and

returned the "waste" to the ecosphere, where it was recharged into new resources, by processes that used exergy from the Sun. These charging processes have exceeded or at least kept pace with the societal discharging processes until recently. The industrial society has increased the use of substances from the lithosphere (1) and its emissions of artificial substances (2). It has also increased its manipulation of the ecosphere (3). These trends imply that resources are systematically depleted; substances are systematically accumulating in the ecosphere and the long-term productivity capacity and diversity are systematically deteriorated. Furthermore, the societal transformations of natural resources into services to humanity are afflicted with low efficiency and injustices (4) [Holmberg 1995].

Since there is probably no limit to the number of possible designs of sustainable societies, the definition must be searched for on the principle level — any sustainable society would meet such principles. Since "sustainability" was a non-relevant expression until "non-sustainability" started to exist due to human activities, it is logical to design the System Conditions as restrictions, i.e. principles that determine on the overall level what human activities must not do to the environment.

When a substance is accumulating in a system, it can only be due to one or more of the following mechanisms:

1. The substance is accumulating in the system, because the matter, that is the origin of the substance, is brought into the system from outside at a higher rate than it is removed (net-input).
2. The substance is accumulating in the system, because it is produced there at a higher rate than it is assimilated.
3. The substance is accumulating in the system, because the ability of the system do assimilate the substance is reduced.

Based on this logic, and the previous description of basic science and understanding of the cyclic functioning of our system, the System Conditions were elaborated:

System condition # 1: *Substances from the lithosphere must not systematically increase in the ecosphere.*

This means: In the sustainable society, fossil fuels, metals and other minerals must not be extracted and dispersed at a faster pace than their slow redeposit and reintegration into the Earth's crust.

Reason: The balance of flows must be such that concentrations of substances from the lithosphere do not systematically increase in the whole ecosphere, or in parts of it such as the atmosphere or ecosystems etc. Besides the upstream influence on this balance through the amounts of mining and choices of mined minerals, the balance can be influenced by the quality of final deposits, and the societal competence to technically safe-guard the flows through recycling etc. If the concentrations of substances in the ecosphere systematically increases, they will eventually reach limits — often unknown — beyond which irreversible changes occur.

In practical terms this means, in relation to today's situation: radically decreased use of fossil fuels, and mining - particularly of scarce elements that are accumulating already today like cadmium.

Does your organization, municipality or country systematically decrease its economical dependence on lithospheric metals, fuels and other minerals? Since life reacts on concentrations rather than amounts, it is essential what metals we use. The natural concentration of aluminum is around one million times larger than the natural concentration of mercury. This means that the societal flow of aluminum can be about one million times greater than the societal flow of mercury if we allow ourselves to increase the concentration of the two metals in Nature to a certain level.

System condition # 2: *Substances produced by society must not systematically increase in the ecosphere.*

This means: In the sustainable society, substances must not be produced and dispersed at a faster pace than they can be broken down and be integrated into the cycles of nature or be deposited into the Earth's crust.

Reason: The balance of flows must be such that concentrations of substances produced by the society do not systematically increase in the whole ecosphere, or in parts of it such as the atmosphere or ecosystems etc. Besides the upstream influence on this balance through productions volumes and characteristics of what is produced, such as degradability of the produced substances, the balance can be influenced by the quality of final deposits, and the societal competence to technically safe-guard the flows through recycling, incineration etc. If the concentrations of substances in the ecosphere systematically increases, they will eventually reach limits — often unknown — beyond which irreversible changes occur.

In practical terms this means, in relation to today's situation: Decreased production of natural substances that are accumulating systematically, and a phase out of persistent unnatural substances.

Does your organization, municipality or country systematically decrease its economical dependence on persistent unnatural substances?

System condition # 3: *The physical basis for the productivity and diversity of Nature must not be systematically deteriorated.*

This means: In the sustainable society, we cannot harvest or manipulate the ecosystem in such a way that productive capacity and diversity systematically deteriorate.

Reason: Our health and prosperity depend on the capacity of nature to re-concentrate and restructure wastes into resources. Thus, the resource basis for (i) productivity in the ecosphere such as fertile areas, thickness and quality of soils, availability of fresh water, and (ii) biodiversity is not systematically deteriorated by overharvesting, mismanagement or displacement.

In practical terms this means, in relation to today's situation: Sweeping changes in our use of productive land in, for instance, agriculture, forestry, fishing and planning of societies.

Does your organization, municipality or country systematically decrease it's economical dependence on activities which encroach on productive parts of Nature, e.g. long road transports or other deleterious exploitation of green surfaces, over-fishing etc.?

System condition # 4: *Fair and efficient use of resources with respect to meeting human needs.*

This means: In the sustainable society, basic human needs must be met with the most resource-efficient methods possible, and their satisfaction must take precedence over luxury consumption.

Reason: If the societal ambition is to meet human needs everywhere today and in the future, while conforming to the restrictions with regard to available resources given by the first three System Conditions, then the use of resources must be efficient. If we are more efficient, technically, in organization and socially, more services with the possibility of meeting more human needs can be provided for a given level of influence on nature.

In practical terms this means, in relation to today's situation: Increased technical and organizational efficiency throughout the whole world, including a more resource-efficient lifestyle particularly in the wealthy sectors of society. Furthermore, it implies improved means of dealing with population growth.

Does your organization, municipality or country systematically decrease its economical dependence on using an unnecessary large amount of resources in relation to added human value?

The four System Conditions provide a descriptive framework for a sustainable society. Participants on all levels – households, corporations, local authorities, nations – can systematically direct their activities to fit into this frame by requiring all secondary goals to function as natural steps in the process of achieving these four conditions of sustainability. In a program for development (see fig. 2), small measures can be perceived and understood within the larger goal. In this way sustainability (the four System Conditions) as well as sustainable development (the program) become working definitions which can be conceptually and physically applied on all levels of a system.

Together with a strategic program, the four System Conditions provide a concrete model — a compass — pointing the direction to sustainable development.

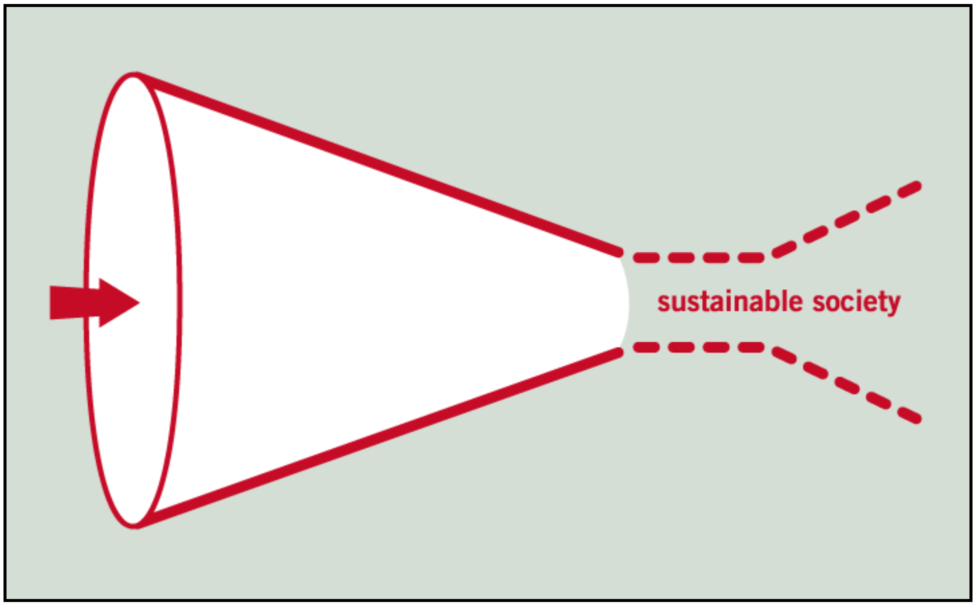

Figure 2

F**igure.2** Since we are today violating the four System Conditions, waste is steadily accumulating and resources are steadily diminishing. This means that the resource-potential for health and economy is systematically decreasing. At the same time, the Earth's population is rapidly increasing. Non-sustainable development can be visualized as entering deeper and deeper into a funnel, in which the room to maneuver becomes narrower and narrower. For the company, municipality, or country wanting to make skillful investments the crucial factor is to direct its investments towards the center of the narrowing funnel, rather than into the wall. In reality, this means that the intelligent investor makes himself less and less economically dependent on being part of continued violation of the System Conditions. The laws of nature supersede man-made laws. Hence it will be inevitable to suffer economically — and to eventually be hurt by the market — if the economical course is not altered inline with the System Conditions. The walls of the funnel will superimpose themselves more and more into daily economic reality in the following ways: environmentally concerned customers, stricter legislation, higher costs and fees for resources as well as pollution, and tougher competition from competitors who invest themselves skillfully towards the opening of the funnel, i.e. to meet the four System Conditions. Failure to meet the four conditions leads not only to hitting the funnel wall in the short run, but also to further constriction of the funnel itself in the long run.

6. **Checking the model in relation to the list of requirements in section 2.**

a. *The model must be based on a scientifically acceptable conception of the world.*

Our model proceeds from the overall conditions for a sustained resource base in the whole ecosphere. The basis for the model proceeds from well-established laws of nature, and the fact that humanity must exist within a limited environment.

b. *The model must contain a scientifically supportable definition of sustainability.*
A general rule is that we must avoid divergences from the natural state that are large relative to natural fluctuations. Due to complexity and delay-mechanisms in the cause-effect chain, it is difficult to foresee what levels are dangerous. Our definition therefore underlines that we must at least avoid systematically increasing the divergences. Thus, our model provides a minimum requirement for sustainability that is, nevertheless, far away from today's situation. By making it possible to focus upstream, where complexity in the cause-effect chain is relatively low, it avoids the requirement of knowing all the complex potential effects downstream. The conditions focus on underlying mechanisms rather than effects in nature, thus "indebtedness", through delayed damage also becomes accounted for. The System Conditions are complementary, i.e. they don't overlap. Furthermore, violation of the System Conditions contain all environmental problems that are relevant to sustainability.

c. *The overall perspective must be applicable at different scales, and must see the economy as a subsystem of the ecosystem at each scale. Individuals must see how their actions aggregate from micro scales up to the macro scale, and thus understand their role in the overall move toward sustainability.*
Since the model proceeds from the whole system i.e. the ecosphere — instead of being based on the economy and its technical cycles — the goal-set provides an absolute frame of reference rather than a sum of varying details. The global scale is really the simplest, because we can abstract from trade. At smaller geographic units we must allow for trade between units, but that changes none of the basic principles. Today, the flows of matter and energy in the whole civilization have far exceeded the restrictions defined by each System Condition. This means, that for the whole civilization to become sustainable, all participants should systematically phase out their direct or indirect demands on mining of scarce metals and fossil fuels (System Condition 1), persistent compounds that are foreign to nature (System Condition 2), deteriorating exploitation of productivity and biodiversity of nature (System Condition 3) and seek ever more sophisticated and resource-saving methods to meet human needs (System Condition 4).

Meeting these conditions ultimately implies a limit on the total throughput of natural resources. Since total resource use is the product of per capita resource use times population, it further implies that each of these two factors is ultimately limited, and that there is a choice regarding which factor to emphasize most in a given context. In Northern countries with low population growth we expect the emphasis to be on restraining per capita consumption of resources, while in Southern countries with low per capita resource consumption and high demographic growth we expect the focus to be on slowing population growth (System Condition 4).

d. *The micro-economic perspective should not require individuals to act against self interest.*
The world is living outside the framework for sustainability. If firms and other institutions are contributing to this, their activities will perish in the long run. If they, in spite of this, proceed to launch investment programs that increase their economical dependence on being part of violations of the System Conditions, they will lose their money sooner or later — but only after doing much damage although the investment may prove profitable in the short run. The time-axis in the activity program of the model makes it possible to relate short-range goals (measures) to what we know about the long-range goal (meeting the four System Conditions), making it possible to avoid a situation where the subgoals undermine the continuation of economical development. In this way we can avoid investing in alternatives that will commit us to a path that will have enormous environmental impacts in the future, even though their present impact may be low. "Left-over" matter must not systematically accumulate anywhere in the ecosphere. With this insight, LCA (life cycle analysis) and environmental auditing are excellent tools. Without this insight however, such tools may even be hazardous, because they may lead to a false sense of control.

e. *The model must be pedagogical and simple to disseminate so that it can support a public consensus necessary to be put into practice democratically.*
The rational for the model is to stimulate informed democratic decisions in politics and industry through the creation of public understanding of scientific matters in the simplest possible way, but without ending up in reductionism. The model describes overall principles for the relation of the subsystem (economy) to the total system (nature and society). The overall principles could be named "trunk and branches", and all concrete parts and details could be named "leaves". Once the trunk and the branches are clearly understood, any participant within his or her respective field of expertise can put on the "leaves" — undertake the measures implied by the principles. We have found that it is easier to create consensus and pro-activity by focusing on the "trunk and branches" for several reasons:

* Knowing overall principles makes it easier to think upstream in cause-effect chains.
* It is easier to obtain overview and consensus concerning overall principles than details, due to relatively lower complexity.
* Disputes that are based on various set of values are easier to resolve.
* For a leader group in politics or industry, overall principles are generally more necessary, more engaging and easier to reach consensus on, than details. While, for instance, life-cycle analyses and environmental auditing are tools for the experts to monitor subgoals on the path of change, the model provides a possibility for the leader team, which is often isolated from the department for environment, to get a personal engagement. The leaders can then be part of the same "team" as the environmental department, and use their language. (This generally does not only lead to an improvement of the long-sited economical strategy, but also to a better budget for the department of environment.)

f. *The model must not engender unnecessary resistance or be adversarial.*
The applicability at various geographic scales, the reliance on self-interest, and the accessible pedagogy all combine to give the model a bridge-building function. People who are competent in their particular fields of expertise generally have knowledge about details within their competence, but generally lack an overview concerning overall scientific principles. By leaving the interpretations amongst the “leaves” to themselves, it stimulates engagement and respect rather than defense mechanisms.

g. *The model must be able to get started without first requiring large scale societal changes. It should be implementable within today’s economic reality. Business corporations, political parties and the public should be able to use the model directly.*
The time-axis of the action plan then functions as a psychological “shock-absorber” – for the uninitiated, it is surprising, even disturbing, to see the gap between the standards required for sustainability and today's situation. But all thousand-mile journeys commence with one step. Through the step-wise strategy, you can also avoid “converting the best action at a given time into the enemy of the good”. A very common problem for proactive organizations is that various measures that are launched to “save the environment” are perceived as insufficient and sometimes more immoral than doing nothing at all. However, linking them to a framework of sustainability, allows a more positive attitude towards relatively small steps in the right direction.

h. *It would be an advantage if the model could also be used as a starting point for developing “new economics” — as a way to recognize a new and larger pattern of scarcity to which old and basic economizing principles must be applied.*
It is difficult to translate natural resources into monetary terms. However, that must not stop us from systematically integrating societal development into natural frameworks. According to economical theory [Hueting, 1980; El Serafy, 1992; Daly and Cobb, 1989; Mäler 1991], one should use as measure for national welfare net-national product corrected for changes in the state of natural resources and environmental quality — specifically for liquidation and depreciation of natural capital.

Prices that guide should not be current market-prices but rather the prices that include the cost of maintaining environmental sustainability. In this respect, the model can function as a starting point. Then the “price of nature” would be what it costs to not systematically destroy it according to system conditions no 1, 2 and 3. Thus “putting prices on nature” would be perceived as the *ex post* increase in market prices resulting from the additional investments necessary to implement the four system conditions, rather than as *ex ante* attempts to calculate full cost prices on the basis of contingent valuation or some other dubious methodology. Whatever prices result in the market, once the market is constrained by the four system conditions, are the prices that internalize the previously external cost of non-sustainability.

7. Practical application

The model has demonstrated its own applicability. It is spreading among corporations and municipalities in and outside of Sweden that learn to apply it in an autonomous way. It has proven efficient, not only to convince others about the need to change, but also as a planning model for concrete economical practice. Furthermore, it has lead to education programs at several universities.

Participants that want to apply the model should be made aware of the difference between the definition of the System Conditions for sustainability on the one hand, and the consequences regarding "permitted" flows of matter within each System Condition on the other. The total sustainable flows of matter within each System Condition still remain to be calculated. However, one doesn't have to await detailed analyses on those issues to apply the model. Sometimes the "permitted" flows per capita are so close to zero, i.e. concerning the use of cadmium (System Condition 1), that the lack of concrete data is no problem for strategic planning. And when the "total permitted" flows are much higher, for instance concerning emissions of N_2O (System Condition 2), the relevant questions can at least be raised: "Is it possible that we — in our business corporation or municipality — are investing ourselves into a dependence of N_2O emissions that exceeds our "permitted" share of the total assimilation capacity of N_2O?" And even more intriguing: "If today's total emissions of N_2O causes accumulation of this gas in the atmosphere, what is the proof that the margins to very severe problems related to further accumulation of N_2O give us a secure life-span for this investment?" In this way, the model allows that the requirements for proof are shifted from the public to the participants and their investments. Clear and intellectually solid definitions are helpful, even if they do not immediately lead you to very concrete consequences regarding figures and measures. And conversely: The lack of very precise figures does not justify models that are insufficiently defined.

We can identify three levels of complexity in the risk assessment following accumulation of waste:

I. Accumulation of waste occurs when emissions are higher than the assimilation capacity of the recipient environment.

II. The relative increase in concentration from the accumulation is the emitted amounts minus the amounts that are assimilated, divided by the base-line amounts in the recipient. Damage is often correlated to the relative increase in concentration. Moving focus upstream, the potential magnitude of these concentrations can be estimated already before the compounds have reached nature. This enables priorities in society's preventative measures to be adopted well before the mechanisms for destruction in nature are explicitly known or identified. Our first three System Conditions deal with this level.

III. For the same relative increases in concentration, the magnitudes of deleterious effects vary with different compounds and different levels and sites in the ecosphere. This complex problem is layered on top of level II.

Problems inherent in the assessment of the effects on level III, do not justify neglect of levels I and II. In fact, any problem concerning the difficulties to assess complexity — or trusting data — on levels I and II is severely magnified on level III. Furthermore, it is considerations on levels I and II that make it possible to avoid future damage that is hitherto unknown. Consequently, measures should be performed on all levels. In spite of this, reality often shows us that most work is performed on levels III *instead* of levels I and II. This is to grasp the leaves rather than the trunk.

Defining the frame of the goal as a guidance for today's measures provides a superior approach in planning to gain control relative to traditional forecasting. Such a strategy is referred to as "back-casting" [Robinson 1990], and is particularly useful when [Dreborg and Steen 1995]:
* The problem to be studied is complex.
* There is a need for major change.
* Dominant trends are part of the problem.
* The problem to a great extent is a matter of externalities.
* The scope is wide enough and the time horizon long enough to leave considerable room for deliberate choice.

The model discussed in this paper has been applied for strategic planning in 60 Swedish corporations, and has created investments of more than a billion USD. The model is applicable in corporations of any field of activity, for instance manufacturers like Electrolux or JM Construction, trading companies like IKEA or Hemköp and service-companies like Swedish McDonald's or Scandic Hotels. The model has also been systematically applied by 60 Swedish municipal authorities. An organization in Sweden, The Natural Step Foundation, has been developed to spread the model. Similar "Natural Steps" organizations are now being launched in other countries such as USA, UK, Canada, Netherlands and Australia.

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