On Physics and Education for Sustainable Development

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Abstract

Physics offers an important additional insight to the understanding of sustainable development that needs further attention, particularly with regard to higher education for sustainable development. The use of energy and other resources in the society and the consequences of this use on the environment can be described and better understood by applying the concept of exergy and exergy based methods. The concept of exergy is introduced and applied to the use of physical resources in the society and introduced as an excellent ecological indicator. This brings new insight to the conditions for a sustainable development that is further elaborated in this presentation. The importance of introducing this new knowledge into present higher education for sustainable development is argued for. However, difficulties and obstacles from the higher educational establishment are also presented. This may relate to a problem of changing paradigm, since higher education is presently mainly engaged in the education of an unsustainable development.

Keywords: education, sustainable development, physics, exergy.

Introduction

Sustainable development is more and more becoming an educational problem in the society and the UN has declared 2004–2014 the *Decade of Education for Sustainable Development*. Recent warnings from the IPCC (Intergovernmental Panel on Climate Change) all but confirm an ever increasing climate crisis (IPCC 2007) due to human activities, e.g. the release of carbon dioxide into the atmosphere from the use of fossil fuels. The increasing lack of understanding and action reveals a need for knowledge with more of a holistic view of the situation. Present fragmented approaches generated by the traditional educational system lack this and rather lead to further confusion. The division of knowledge into disciplines and further into even more specialized areas leads to a common lack of general knowledge and understanding of the problem among many students. This I have experienced many times during my over thirty years of teaching the subject at university and high-school levels. Instead more of a holistic approach must be adopted and applied according to the presentation below. These concepts must be incorporated into traditional knowledge and be further elaborated within the educational system. All related and relevant areas from both natural and social sciences must be treated simultaneously together with a focus on moral issues to gain understanding of the problems. My own experience of this is a strong positive feedback from the students and parts of the educational establishment, e.g., the UNESCO project *Encyclopedia of Life Support Systems* (EOLSS). However, sometimes there is also a strong skepticism among the academic establishment for this that also has to be dealt with. Thus, traditional boarders between different disciplines must be removed and more of interdisciplinary studies and activities must be applied at both high school and university levels. More problem oriented approaches and a focus on moral issues are also to be encouraged. This in turn implies educational and pedagogical challenges in order to create

prosperous knowledge and understanding for the development towards a sustainable or rather vital society. My hope is that this study will encourage and contribute to this process.

The aim of this study

In this study I will focus on an alternative approach to describe and understand the conditions that are essential to sustainability. This approach is based on well established scientific knowledge; however, the field of application might be new to many readers. Basic physical concepts, models and perspectives are exposed. Thus, I address in particular teachers and students that want to gain insight into and meet arguments on education for sustainable development. It is my hope that this presentation will be a useful complement to traditional knowledge in the field and that it will contribute to the development of the education towards sustainable development.

The purpose is twofold to point out weaknesses of traditional often fragmented knowledge and to offer suitable knowledge for the interested reader on knowledge towards sustainable development. In addition possible ways to meet this situation in present educational system as well as possible reactions will also be elaborated. We must not forget that the aim of most education so far is on developing means and methods to exploit and deplete resources that imply an environmental destruction, i.e. a truly unsustainable practice.

Let us start by introducing the basic physical conditions that present science regard as the conditions we all have to rely on.

Physics and Nature

In order for things to happen, i.e. motion to occur, there must be a driving force: something that can create action. A force is created by a difference in space of some kind, i.e. a contrast. This is a physical quantity such as temperature, pressure, concentration or tension. When this force, due to this contrast, is acting, it also "eats up" its source of power. Thus, gradually, as the force acts its source of power is destroyed.

Exergy is the physical concept of contrast, which quantifies its power of action. Exergy is defined as work, i.e. ordered motion, or ability to perform work. Exergy is related to the concept of time accordingly. If exergy is destroyed then time appears. Exergy destruction is an irreversible process, which creates a motion in a specific direction, i.e. in the direction of time. We may say that this defines the arrow of time.

Energy and matter cannot be created, destroyed, produced or consumed. In fact, this defines energy, i.e., something that is always conserved or the First Law of Thermodynamics. The famous relation of Einstein $E=mc^2$ states that matter is just a form of energy. Energy can only be converted into different forms. In the real world this occurs by the consumption of contrast, i.e., exergy. Locally, exergy may increase, but this can only occur at the expense of an even greater deterioration of exergy elsewhere. The total amount of exergy must always decrease as a consequence of the existence of time and the law of Nature or the Second Law of Thermodynamics.

In Fig. 1 we see how energy flows through a system. The motive force of the flow of energy through the system is the exergy or the level of order. Energy is falling from a state of high order in the inflow into low order in the outflow. This is also expressed as a destruction of exergy (Wall 1977 & 1986).

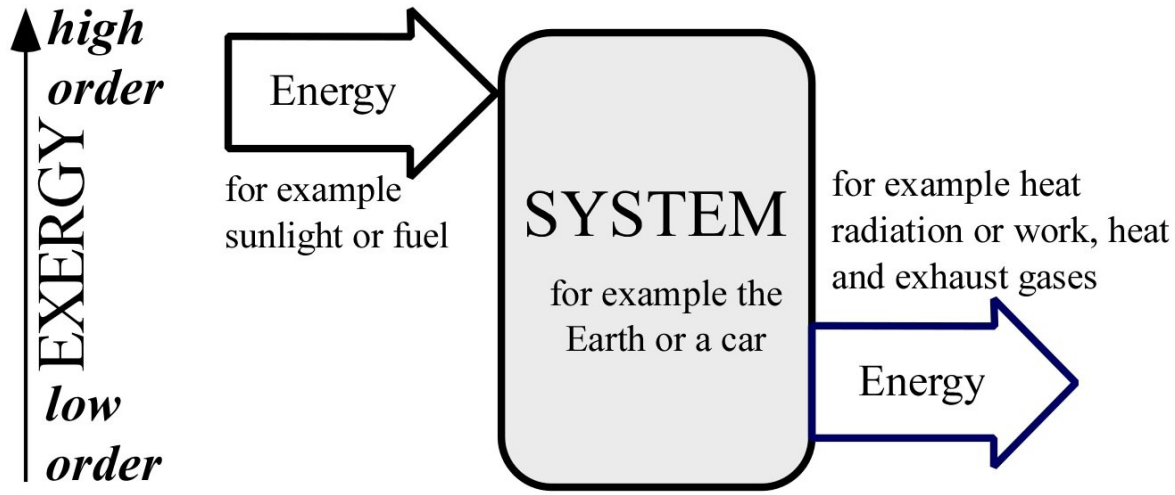

Fig. 1 The flow of energy through a system.

Energy only serves as a carrier of exergy, which is partly consumed when it flows through a system. The moon offers us moonlight and a car is a mean of transport, however, the systems remain in principal unchanged, i.e., a steady state system.

If exergy is stored in the system we may have a viable state, i.e. life may develop. The existence and evolution of life imply that some exergy from the sun must be stored on Earth. Exergy feed life.

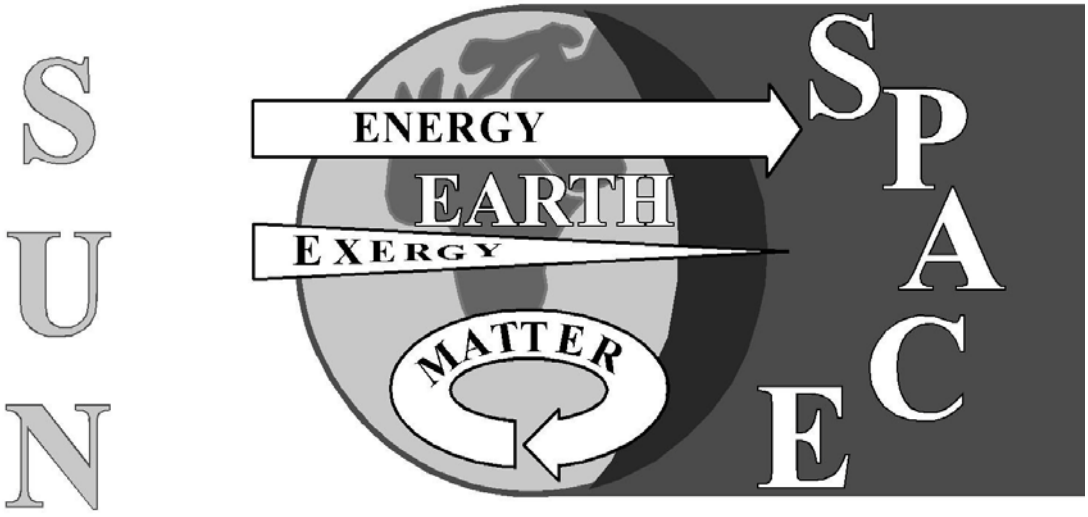

Fig. 2 The Sun-Earth-Space system.

The source of exergy on Earth is secured from the contrast between the sun and space, see Fig. 2. The exergy on Earth exists through the conversion of energy from sunlight into heat radiation, which flows from Earth back into space. Due to this, all flows of energy and matter are carried forward through systems on Earth's surface, and life can evolve. Thus, the storage and build up of exergy on Earth is a fundamental condition of sustainable development.

Life in Nature relates to three fundamental sub-processes: production, consumption, and decomposition. These maintain the circulation of essential material substances by using the incoming solar exergy in a sustainable and evolutionary way, see Fig. 3.

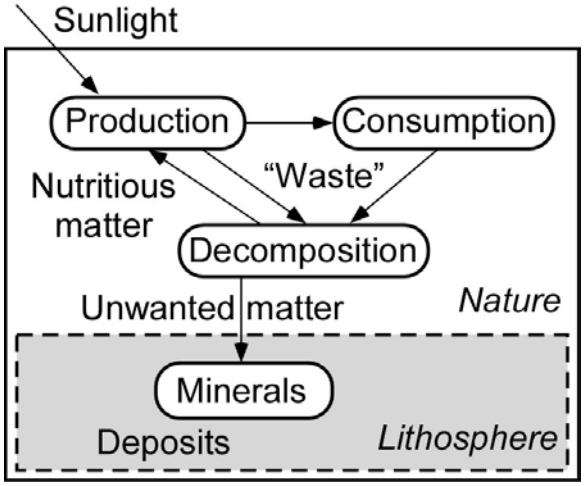

Fig. 3 The circulation of matter in nature is powered by sunlight.

Green plants, which represent the production process, convert exergy from sunlight into the exergy-rich substances of biomass, via photosynthesis. The exergy as biomass then passes through different food chains in the ecosystems. At every trophic level exergy is consumed and decomposition organisms dominate the last level in this food chain. There is no waste, however a removal of "unwanted" substances. Nature operates a unique machinery of development on Earth by capturing and sealing certain substances into deposits of minerals in Earth's crust. A fraction of the exergy from the sun-space contrast is stored as an increase of the exergy capital on Earth. This appears as a net-flow of "unwanted" substances from the biosphere into the lithosphere as well as a redistribution of other substances in the environment, e.g. oxygen to the atmosphere. Thus, the exergy capital on Earth is increasing, which is a key element in nature's process of reshaping the physical conditions on Earth in order to maintain the evolution of life.

Physics and Society

Present industrial society, is built on an unsustainable resource use, see Fig. 4. Fossil fuels and metals that originate from deposits of minerals in the lithosphere are unsealed and spread in the environment, which is exactly the opposite of what is done by Nature. This is obviously not sustainable, at least not for a very long time. Resource depletion and environmental destruction are two consequences of the use of these deposits. In a closed system "nothing disappears and everything disperses" which state that these substances will unavoidably end up in the environment.

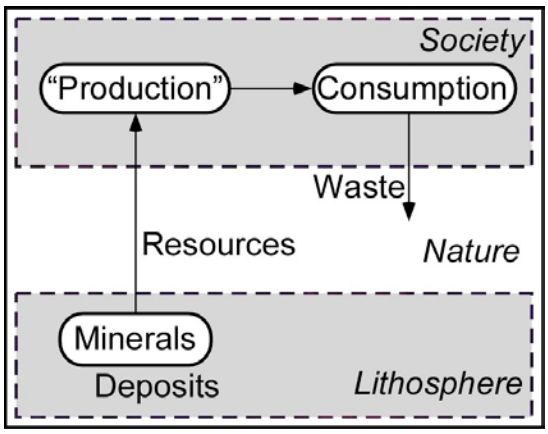

Fig. 4 Society depletes nature's capital and returns waste.

In Fig. 5, we see how the resource use in the society is maintained. The greater part of the exergy requirements are utilized from the terrestrial exergy stocks, i.e. funds and deposits. Only a very small part of the exergy flow from the sun is used directly. Through society we see an almost continuous exergy loss. Some exergy flows, such as flows of metals, initially increase their exergy in the manufacturing state when passing through society. However, other flows decrease their exergy all the more. A tank, which contains the funds and the deposits, indicates the limited amount of exergy stocks or exergy capital on Earth. As long as the levels are kept stable, i.e. the output of resources does not exceed the feed from the sun and the biological processes, we may have a sustainable situation. However, if the level is dropping, i.e. the exergy capital is depleting then we have an unsustainable situation and also the unwanted substances will gradually contaminate the environment. Thus, environmental pollution is an inevitable consequence of the use of deposits. The depletion of resources may not be the most serious problem that mankind face, but rather the emission of toxic and unwanted substances into the environment. The concern for an eventual lack of non-renewable resources as “peak oil” must be combined by a similar concern for the environmental impact and its consequences from the emission of these substances. Presently, only nature offers the machinery to put these substances back into the lithosphere (Fig. 3) in a sustainable manner. The present damage may take nature millions of years to repair, and in the meantime there will be a serious impact on the living conditions for all present forms of life as will be further explained below.

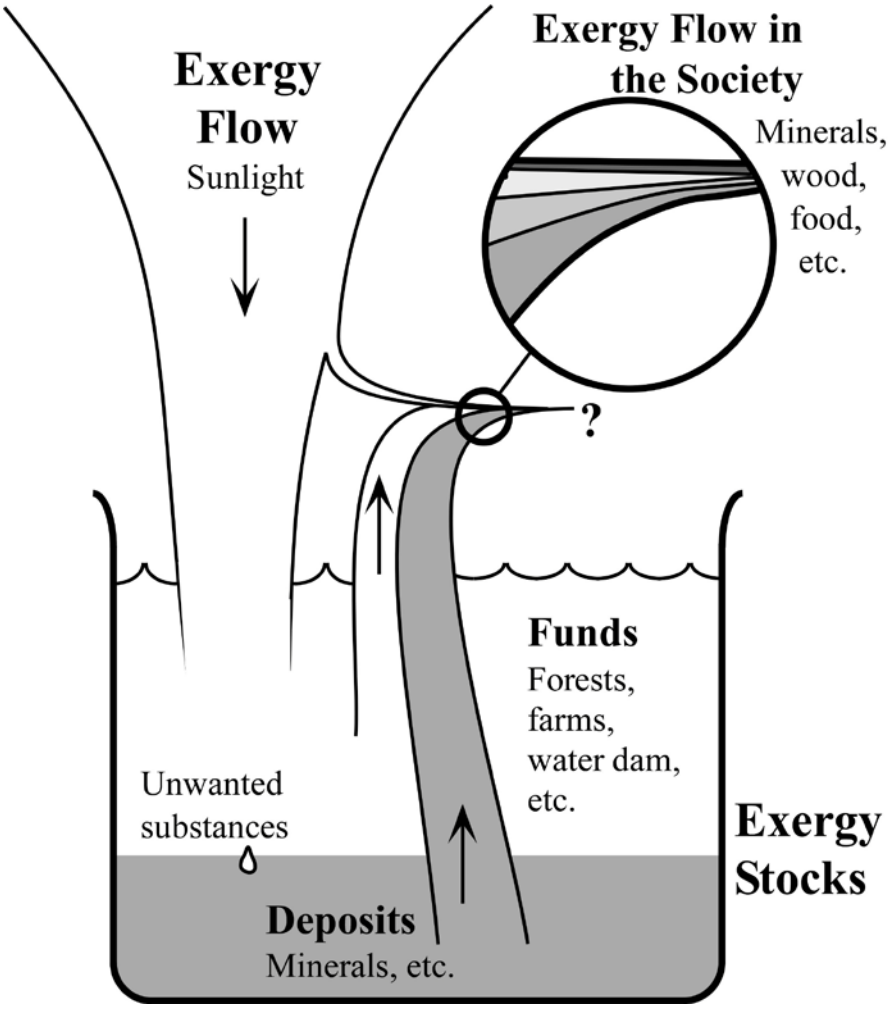

Fig. 5 Exergy flows to the society.

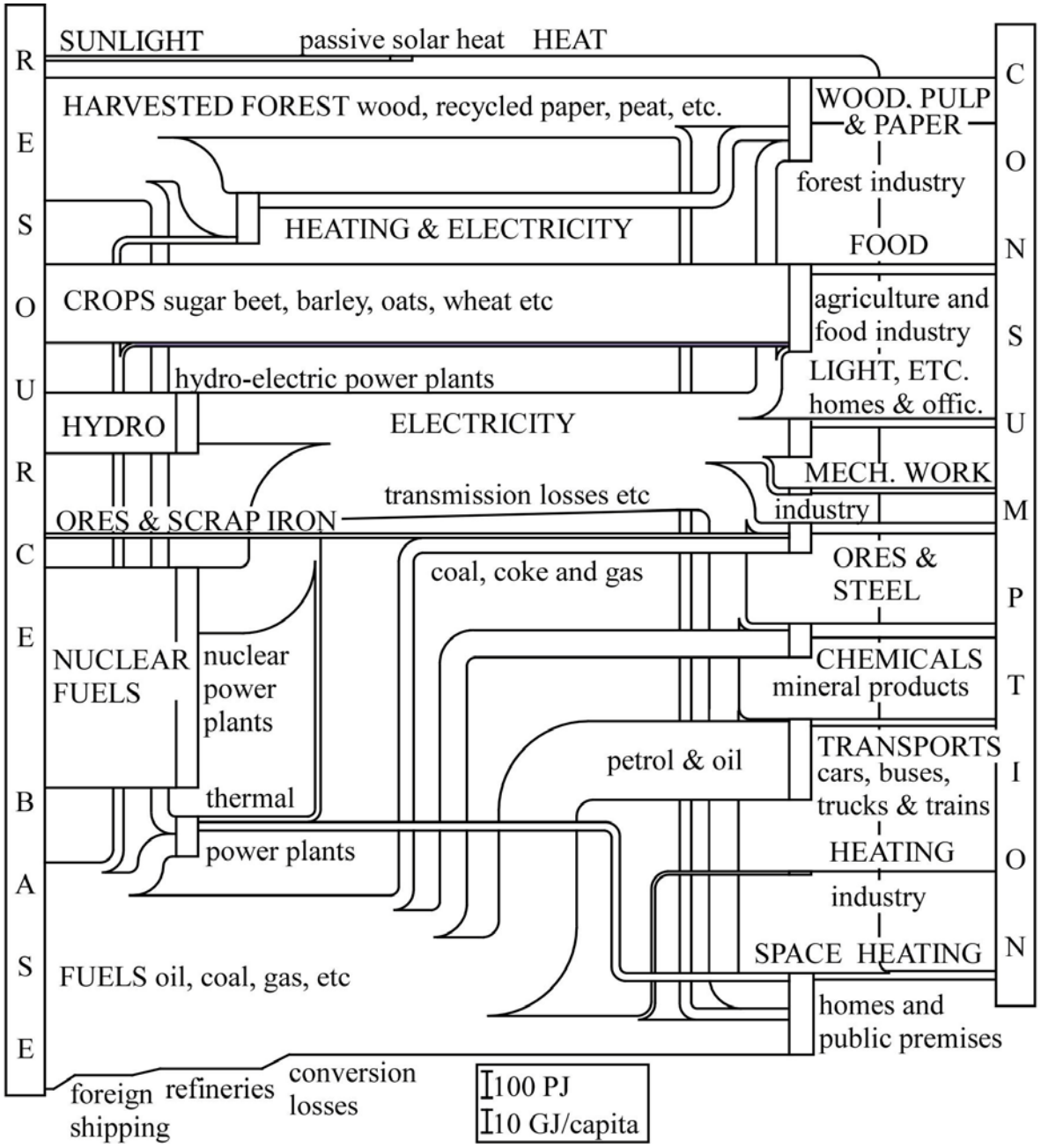

Fig. 6 Exergy use in the Swedish society in 1994.

Figure 6 shows the exergy flow in the society in more detail, in this case the main conversions of physical resources in Sweden in 1994 (Gong & Wall 2001). The flows go from the resource base to the consumption sector. Thus, the diagram basically represents the resource supply sector where resources such as crops and minerals are turned into consumer goods such as food, transport and thermal comfort. The inflows are ordered according to their origins. Sunlight is thus a renewable natural flow. Besides a minor use of wind power, far less than 5 PJ, this is the only direct use of a renewable natural flow. Harvested forests, agricultural crops, and hydropower are renewable exergy flows derived from funds. Iron ore, nuclear fuels, and fossil fuels are flows from deposits, which are exhaustible and also carry with them unwanted substances. The unfilled boxes represent exergy conversions, which in most cases represent a huge number of internal conversions and processes. The total inflow of resources during 1994 amounts to about 2720 PJ or 310 GJ per capita and the net output becomes 380 PJ or 40 GJ per capita. Thus, the overall efficiency of the supply sector can be

estimated to about 14%. As we can see, some sectors are extremely inefficient. Some resource conversion systems have a ridiculously poor efficiency. For exergy of nuclear fuel, of which only a fraction is plotted in this diagram, to space heating through short circuit heaters the utilization becomes less than 0.025% (Gong & Wall 2001).

The consequences of the present situation can be better understood from Fig. 7, where resource depletion and environmental destruction are two faces of the same problem, i.e. the use of deposits. Unwanted toxic substances are carried by the inflow of so called natural resources, e.g. fuels and metals, from the lithosphere to the sociosphere. The sociosphere is defined as the industrial society including humans, machines and infrastructure. As long as these substances are under control, i.e. within the sociosphere, this may not be a serious problem. Large amount of substances are accumulated in the sociosphere as constructions, e.g. buildings and machines and as long as these remain their substances may not affect the environment. However, when they are allowed to decompose they may pose a serious threat, e.g. old nuclear, chemical, and biological arms that are not properly stored or destroyed. This also relates to harmful substances that are accumulated by a purification system. However, human constructions and buildings will not last forever. Sooner or later they will deteriorate and their substances will end up in the environment. Thus, environmental pollution is an inevitable consequence of the use of deposits. In a closed system, nothing disappears and everything disperses, i.e. the first and second laws of thermodynamics, which state that all substances that are extracted from the lithosphere will unavoidably end up in the environment, i.e. the sociosphere, the biosphere, the atmosphere and the hydrosphere. This in turn will generate new unpredictable life forms to emerge. The situation will be further illustrated and explained below. Presently, only nature offers the machinery to put these substances back into the lithosphere, see Fig. 3.

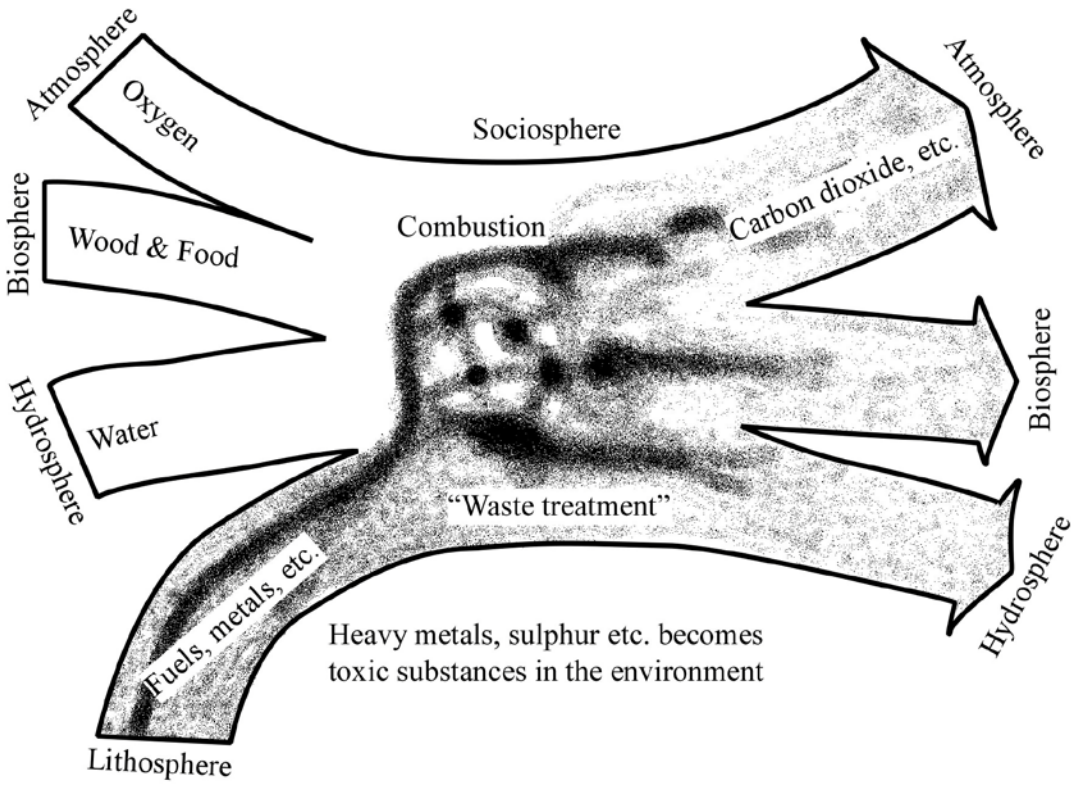

Figure 7. Resource depletion and environmental destruction are two sides of the same problem

The emission of waste substances from the industrial society, see Fig. 4, is likely to produce diverse and unpredictable consequences in the biosphere. New microorganisms adapted to new environments will appear see Fig. 8. Existing microorganisms, i.e. bacteria, fungi and viruses, provide the conditions on which present forms of life are founded. All forms of life are built on the existence of a specified mixture of certain microorganisms that in turn depend on a specific physical environment, see Fig. 8.

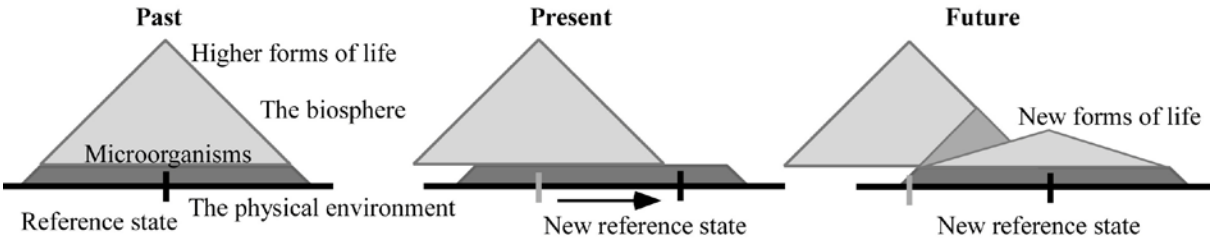

Figure 8 “Survival of the Fittest” is a driving force in the evolution.

The incredible power of these tiny organisms must not be ignored. One single bacterium could in theory fill out the entire solar system within a few weeks if it were able to multiply without limitations. This describes the power of the living foundation of nature’s life support system and the danger of interfering with this system. By changing the physical environment it becomes unfavorable for existing microorganisms as well as for higher forms of life. Initially, this may be recorded as a reduction in the number of species. However, the new physical environment that is offered will also encourage new forms of life to appear, initially by new microorganisms that are better fitted to the new conditions, e.g. bacteria that develop immunity to antibiotics. Later new insects or insects with new characteristics will appear, such as the malaria mosquito resistant to DDT. This is what Darwin expresses as “the survival of the fittest.” Toxicity is a condition that can be reversed when transferred to different biological systems. A toxic substance is of course harmful for some organisms but at the same time it offers a new ecological niche that soon will be occupied by new organisms. This is a dangerous consequence of environmental pollution and an important perspective on the bird flu, H1N1 and new still unknown viruses. Thus, the industrial society may nourish its own extinction by degrading the biological foundations of human existence.

Sustainable Development

There are more than hundred definitions of sustainable development of which the most widely-used was coined in 1987 by the World Commission on Environment and Development in their report, *Our Common Future*: “to meet the needs of the present without compromising the ability of future generations to meet their own needs.” This may sound very attractive since everyone will get what they “need”, now and forever. However, this does not free the rich from dealing very concretely with the problems associated with redistribution of current wealth to those who are in greater need. Still, need must be treated with global justice to remain its meaning. United Nations Development Programme Human Development Report has stated that the annual income of the poorest 47 percent of the people of the world is less than the combined assets of the richest 225 people in the world. Given this obscenely unequal distribution of wealth and income, the top fifth of the world’s people consume 86 percent of all the goods and services while the bottom one-fifth must subsist on a mere 1.3 percent. Sustainable development must not become a mantra used as an excuse and justification to sustain economic growth at the expense of continued human suffering and environmental destruction. Thus, it must incorporate an explicit and well-founded notion of the globe’s carrying capacity and an awareness of the consequences of exceeding this. However, since the

Brundtland report was presented, resource depletion and environment destruction have only proceeded and worsen. The poor are still ignored and left out with a catastrophe. Thus, the time of lip service must be replaced with action and true change. This implies the fulfillment of moral obligations concealed for generations.

The World Commission on Environment and Development brought sustainable development to the world's attention. The Commission's report, *Our Common Future,* focused on three pillars of human well-being:

- economic conditions—such as wealth, employment, and technology;
- socio-political conditions—such as security and democracy; and
- environmental and resource conditions—such as the quality of our air and water and the availability of capital in the form of natural resources.

In addition to these pillars we also need to rely on certain physical conditions or a life support system for present forms of life. This could be depicted as a foundation for these pillars and for sustainable development to be reached, see Fig. 9. Without suitable physical conditions the idea of sustainable development will lack meaning no matter number or size of pillars.

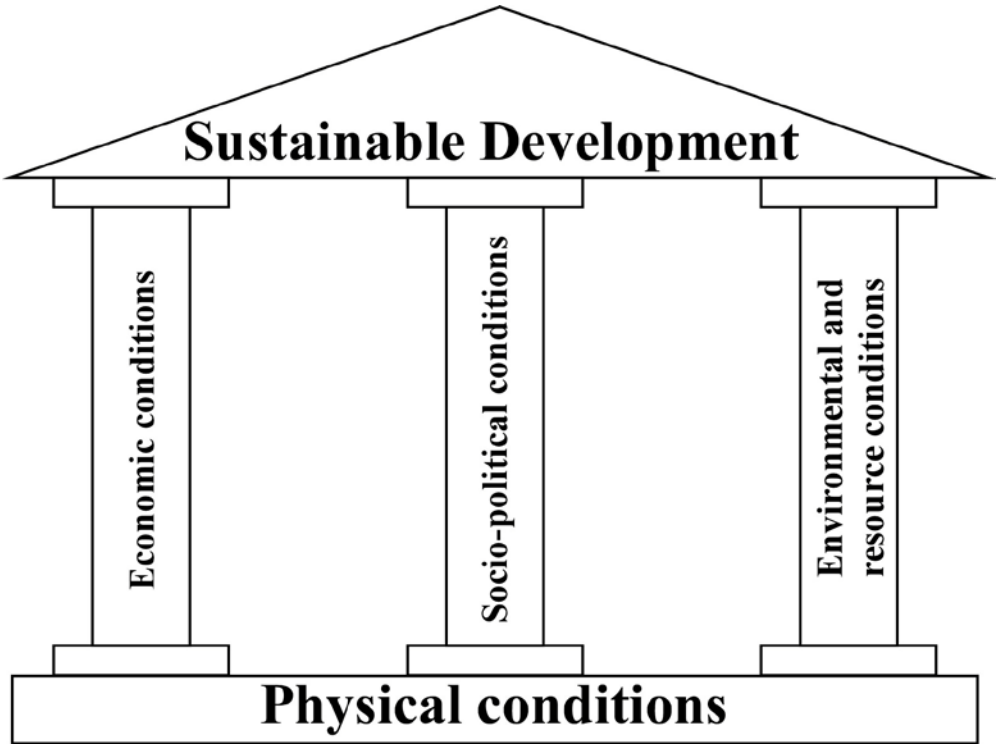

Fig. 9 Sustainable development based on suitable physical conditions.

The present unsustainable situation is due to altered physical conditions on Earth that is threatening the very existence of higher forms of life including human beings. Eventually, we must look beyond present religious, economical and political structures to find the conditions for a sustainable development. This implies a revision of the present cultural structures ruling the world. In addition, from a scientific point of view it is well known that we can't solve problems by using the same kind of thinking we used when we created them. A statement related to Einstein. To conclude we may say that the problem of sustainable development is not lack resources, the problem is that we use too much and the solution is to live with less.

Exergy is a suitable scientific concept in the work towards sustainable development. Exergy accounting of the use of energy and material resources provides important knowledge on how effective and balanced a society is in the matter of conserving nature's capital. This knowledge can identify areas in which technical and other improvements should be undertaken, and indicate the priorities, which should be assigned to conservation measures. Thus, exergy concept and tools are essential to the creation of a new engineering paradigm towards sustainable development.

Conclusions

From a sustainable development point of view, present industrial resource use is a dead-end technology, leading to nothing but resource depletion and environmental destruction in the long run. The exergy capital is used and become waste in a one-way flow (Fig. 4). Instead we need to develop a vital and sustainable society, similar to what is practiced by Nature.

Nature has so far generated life and awareness by means of natural evolution. Present social evolution is instead governed by increased wealth in terms of money, often indicated by Gross Domestic Production (GDP). This is when asphalt, smokestacks and color TVs replace rain forests, or when rice fields, cultivated for more than 5000 years, are converted to golf courses. This myth of progress must be questioned if we are serious in our efforts for sustainable development. At first we must find the roots to the problem. The reason for our failure is a consequence of our deep-rooted weakness for building empires. The so-called human civilizations appearing some 10,000 years ago may be characterized as the beginning of an empire builder era of humankind. This empire building era must come to an end in order to reestablish a sustainable development. Then, we must work for a change through education, true actions, practical exercises, and precaution. Finally we must secure a guidance based on morals and responsibility.

Exergy is an excellent concept to describe the use of energy and material resources in the society and in the environment. A society that consumes the exergy resources at a faster rate than they are renewed is not sustainable. From the description of the conditions of the present industrial society, we may conclude that this culture is not sustainable. One may argue about details, such as how or when, but not that a culture based on resource depletion and environmental destruction is doomed. The educational system has a crucial role to play to meet this change towards sustainable development. This must be based on a true understanding of our physical conditions. Exergy is a concept that offers a physical description of the life support systems as well as a better understanding of the use of energy and other resources in society. Thus, exergy and descriptions based on exergy are essential for our knowledge towards sustainable development.

Time to turn is here. Time to learn and time to unlearn has come. Education must practice true democracy and morals to enrich creativity and knowledge by means of joy in learning. Culture of peace must replace cultures of empire building, violence and fear. The torch of enlightenment and wisdom carried through the human history must be shared within a spirit of friendship and peace.

Acknowledgement

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Biography

Göran Wall was Ph.D. in 1986 and Associate Professor (Docent) 1995 in Physical Resource Theory at Chalmers University of Technology, Göteborg, Sweden. Since 1995 engaged in UNESCO's Encyclopedia of Life Support Systems and since 2008 with Gotland University in Sweden. More than fifty refereed papers; for further information see: exergy.se