Can resource depletion be omitted from environmental impact assessments? [1]

Bo P. Weidema, *2.-0 LCA consultants, http://www.lca.dk*

INTRODUCTION: The nature of the resource problem

The main problem involved in valuing resource depletion is that the effect or damage occurs in the future and therefore our assessment depends on our assumptions on how this future looks like.

Resource depletion may not in itself be a problem if there is adequate time for humanity to develop technologies to deal with an imminent depletion, i.e.:

- technologies for harvesting adequate amounts of sustainable energy, and/or
- technologies (including societal arrangements) for a voluntary regulation of the size of the human population so that it becomes stable and adjusted to a size which can be sustained by the actual size of the resource basis.

The problem is that these technologies may not be developed in time to avoid damage during the transition period.

MATERIALS AND METHODS

Based on the above analysis of the nature of the resource problem, a distinction can be made between three types of future effects caused by present resource use:

1) Future increase in the energy requirement for extraction and preparation of those resources, which are presently available as stocks of high quality (e.g. high grade mineral ores),

2) Future decrease in human consumption opportunities, as a result of depletion of genetic resources (biodiversity),

3) Future decrease in human consumption opportunities, as a result of reaching an ultimate resource limit. Such a resource limit will affect the size and life quality of future human populations directly, and this may be aggravated by an increased pressure on ecosystems from the increased resource competition.

These three types of future effects are analysed separately in the sections below.

The relationship between inventory analysis and impact assessment

In principle, the life cycle inventory covers all human activities related to the production, consumption, and waste treatment of a product. This includes activities to avoid emissions, to alleviate the effects of emissions, and to maintain the capital equipment.

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[1] Text version of poster presented to the 3rd SETAC World Congress, Brighton 2000.05.21-25

If emissions are not routinely treated, they may call for later treatment or for later activities to alleviate their effects. If such future activities are planned or can be foreseen to be necessary, they are to be included in the inventory. If damage from the emission is avoided or alleviated, this damage is not to be included in the impact assessment. Only that part of the emission, which causes environmental effects, i.e. effects outside the studied system, is to be included in the impact assessment. Whether the damage is avoided or alleviated as part of a routine activity or as part of a later treatment or activity does not affect this division between inventory analysis and impact assessment.

If capital equipment is not routinely maintained, it will wear out and need replacement more quickly. Whenever maintenance and replacement of capital equipment is of significant size, it is usual to include both as part of the inventory analysis. However, if neither maintenance nor replacement of capital equipment were included in the inventory analysis, the wear on capital equipment *could* be recorded as an external effect of the studied product system, i.e. as a *depletion* of capital equipment.

In parallel to this, resource use may be viewed as a "wear" on a capital stock. This may be alleviated immediately and routinely, e.g. through recycling activities for metal resources or through activities aimed at maintaining the fertility of biological or soil resources. Such recycling and fertility maintenance activities are typically covered by the inventory analysis and would result in no resource depletion being recorded for the impact assessment. If the resources leave the studied system in a lower quality than when entering the system, this resource depletion may lead to a need for future processes to bring this lower grade resource back to its original quality, in order to use it as a basis for production. In parallel to the above reasoning for emissions, such future activities are to be included in the inventory, to the extent that they are planned or can be foreseen to be necessary. Also in this case, no resource depletion is recorded for the impact assessment. However, if such future activities are *not* planned or expected, the resource depletion should be recorded as such and its impacts on the system environment should be assessed, e.g. in the form of damage to human welfare or life as a result of future lack of resources.

If it is uncertain whether the above described future activities will actually happen, i.e. if they are not planned and cannot be foreseen to be necessary, but are only expected or just possible, this implies an uncertainty in the delimitation between inventory analysis and impact assessment. It may be necessary to treat this by applying different scenarios, ranging from full inclusion of the future processes in the inventory to no such inclusion and consequently assessment of the full impact on the system environment.

Future increase in energy requirement

The essential characteristic of mineral resources is the ore grade. For economic reasons, the high-grade ores are used first, resulting in a decrease in ore grade with time, slowly approximating the average concentration in the earth's crust. If the average concentration in waste is higher than the concentration in the earth's crust, waste will become an interesting source for resource extraction. With decreasing ore grade, more energy is needed for extraction. This means that a present day use of a mineral resource that results in a degrading of its quality, i.e. when it leaves the studied system in a lower quality than when entering the system, will lead to a future increase in energy requirement. Most available models suggest that ore grade decreases smoothly with time following a log-normal or log-binomial distribution (Blonk et al. 1997) and energy requirement is inversely proportional to the ore grade (Chapman and Roberts 1983). From these models, the increase in future energy requirement resulting from present day use can be calculated as a smoothly increasing value over time from the present and until the ore grade is equal to that of the waste from the studied product system. Combining this information with projections on future energy technologies, the expected effects of the present resource use can be modelled as part of the inventory.

A parallel reasoning can be made for present day use of wild biological resources (wild plants and wildlife), if this use results in lower accessibility. In most cases, adequate measures for maintaining the production potential are taken as part of the management of the resource (wildlife management, habitat management). If this is not the case, more efforts may be needed later to recreate the production potential. Such future activities should be included in the inventory. If lack of management is so extensive that it leads to permanent loss of biodiversity, this should be treated separately, see the section on biodiversity below.

Biodiversity

Present rate of extinction of species is estimated upwards from 1000 species per year (out of an estimated total of $14*10^9$ species). It is generally agreed that the reduction in biodiversity is caused by over-exploitation of specific species (hunting and deliberate extermination), introduction of new species, and habitat destruction.

As a protection area, biodiversity is affected not only by direct or indirect use of biological resources (over-exploitation of specific species and physical habitat destruction) but also by many environmental mechanisms, both those typically included in environmental assessments (global warming, ozone depletion, acidification, eutrophication etc.) and such which are not so often included (e.g. introduction of new species). In this presentation, I deal only with those effects that are related to direct or indirect use of biological resources.

Over-exploitation of specific species, i.e. harvesting of species which are threatened with extinction, may be recorded as a resource use in the inventory (e.g. expressed in terms of numbers of individuals, weight or area exploited, allowing a later assessment of the size of the impact in relation to the size of the remaining and/or viable population and the value assigned to the species in question).

Physical habitat destruction may be recorded in the inventory in terms of both the area affected (when a change in habitat quality is implied) and area*time (to cover the effects of the mere occupation of an area). In the impact assessment, these inventory items may be weighted with coefficients expressing the specific characteristics of the affected area in relation to the species density relative to the average species density, the scarcity of areas where the specific ecosystem can exist, and the scarcity of areas where the specific ecosystem actually exists. This concept is further developed in Weidema & Lindeijer (2001).

The ultimate limiting resource - is not energy

Despite the increase in energy requirement for resource extraction, it is unlikely that energy will become a limiting resource. In 1992 the United Nations Population Division published some long-range population projections (UNPD 1992), which all show a rise in population to $8*10^9$ persons at some time between 2010 and 2030. Thereafter, the scenarios diverge more radically between a low fertility scenario (fertility rate 1.7) resulting in a population declining to $4.3 *10^9$ persons in 2150 and a high fertility scenario (fertility rate 2.5) where the population continues to grow to $28*10^9$ in the same period. At an energy consumption of 200GJ/person/year (the current OECD consumption), the presently estimated resource base of fossil fuels ($200*10^{12}$GJ according to WEC/IIASA 1995) will be able to sustain 10^{12} personyears. Combining this with the UNPD population projections, the time horizon for fossil fuel depletion can be calculated to occur between 150 and 100 years from now. In reality, fossil fuels can be expected to last much longer, since the current economic development will not allow the entire world population to enjoy an energy consumption of anything near 200GJ/person/year. Furthermore, the time when non-renewable fuels are required to cover the entire energy demand can be delayed at least another 100 years by the use of nuclear energy. Furthermore, energy efficiency has increased with approximately 1% annually, and this increase can be expected to continue, thus steadily lowering the ultimate requirement per person.

Since non-renewable energy covers only a very small part of today's energy consumption, it is nevertheless a vast transition of technology, which is necessary. There is presently little economic incentive for the development of non-renewable energy technologies. However, although the technologies are not yet fully developed and market ready, the basic knowledge of the potential technologies is available and the necessary steps for further development are known. Thus, given adequate economic or political pressure, 100 years should be fully adequate for the development and implementation of the necessary technology. This pressure is likely to come even sooner, because of the negative environmental effects of fossil fuel use.

Many estimates have been made of the ultimate production potential of renewable energy technologies, ranging from $0.6*10^{12}$GJ to $30*10^{12}$GJ annually, compared to the present annual global consumption of $0.4*10^{12}$GJ. As technologies develop, the estimates are likely to become more precise. Combined with more certain population projections, this will make it possible to take adequate policy measures (including more efficient population regulation) well in advance of any energy shortage. Whether such policy measures will actually be taken is, obviously, not possible to predict.

The ultimate limiting resource - is land

All human requirements may be met by provision of adequate energy and adequate land areas with production potential for agriculture and/or forestry. Since a sustainable energy supply must eventually be derived from use of land (for harvesting solar energy, either directly or indirectly in the form of bio-mass, wind power etc.), the question of the ultimately limiting resource can be reduced to one of availability of land. Thus, we may divide the available land resource into 3 categories according to the production potential for:

1) agricultural products,
2) forest products, and
3) non-biomass energy carriers and minerals.

In Figure 1, the available land areas are compared to the per capita requirements for these types of lands, assuming a living standard equal to that of industrialised countries. It can be seen that arable land has the highest requirement compared to availability. Thus, availability of arable land is the first limit to be reached for human consumption opportunities and population size.

***Figure 1**. Available land areas compared to per capita requirements, assuming a living standard equal to that of industrialised countries.*

	Available		Required	
	Total ha	Relative	ha per Capita	Relative
Arable land[a]	$1.7*10^9$	13%	0.24	29%
Forest land[b]	$4.4*10^9$	33%	0.25	30%
Other land[c]	$7.3*10^9$	54%	0.35	42%
Total	$13.4*10^9$	100%	0.84	100%

a) Available arable land is the present $1.4*10^9$ ha (FAO 1992) plus 22% potentially arable (Buring & Dudal 1987). The present arable land use is 0.24 ha per person, which yields a nutritional value of 11 MJ/person/day, which is well above the dietary requirement. Future per capita requirement may be kept at this level, since a 50% increase in yield (global average) can be expected from general application of presently available agricultural technology, allowing an additional 0.09 ha per person to be reserved for an increase in the animal part of the diet from 15% to 30%, which is the ratio in industrialised countries. Further possibilities for increasing biological primary production (e.g. artificial lighting) and entirely new ways of producing food (e. g. by microbial conversion of biomass) have not been taken into account.

b) Available forest land is the $3.4*10^9$ ha existing forests according to FAO plus $1*10^9$ ha available for afforestation according to Winjum et al. (1992). Global timber production (excluding fuel) is $1.6*10^9$ m^3 or 0.25 m^3 per person, which equals the net annual stemwood growth from 0.1 ha. In industrialised countries, the consumption is 4-6 times higher than the world average, requiring a forest area of approx. 0.5 ha. A conservative estimate, based on presently obtained growth data, suggests that this area requirement can be halved by increasing productivity by selective logging followed by natural regrowth and by reserving 10% of the forest area in the tropics for plantations, which may yield 30 m^3/ha or more.

c) Using solar power, the area required for an energy consumption of 200GJ/person/year (the current OECD consumption) is only 0.15 ha, using the estimate by Pimentel et al. (1994) of $0.75*10^{-3}$ ha/GJ electricity produced. Other estimates range to both sides of this estimate. The mai difference in the area estimates stem from differences in the predicted efficiency of the mature photovoltaic technology as well as differences in assumed losses in storage and/or transmission. Hille (1995) points out that the ultimate limiting factor for solar energy capture may not be the are requirement, but the availability of the materials necessary to be "stored" in the energy conversion technology, especially the conductive material copper. Land area for mining of minerals has not been included since mining does not pre-empt use for energy harvesting, once the minerals have been extracted.

This conclusion is stable, even to large modifications in the underlying assumptions (given in the notes to Figure 1). Productivity increases in forestry are so much easier to obtain than similar increases in the productivity of arable land, and even if land area for forests were assumed to stay at present levels, arable land would still be relatively much more scarce compared to the requirement. The same is true if using more conservative estimates for the area requirements for solar power. Also, the area requirement for housing and infrastructure has not been included in figure 1. Using the level of industrialised countries an additional 0.2 ha*year/person should be reserved for this. Housing and infrastructure is typically placed on land suitable for agriculture, thus emphasising the conclusion that arable land will be the first resource to become limiting. Furthermore, it may be argued that a certain percentage of agricultural lands should be reserved for conservation of the natural ecosystem types native to potentially arable lands. This would further increase the pressure on this resource.

With a per capita requirement for arable land of 0.24 ha, the available land for this purpose ($1.7*10^9$ ha) will only sustain $7*10^9$ persons. The UNPD projections mentioned above predicts already $8*10^9$ persons at some time between 2010 and 2030. The efficiency increase in agricultural production may take place more quickly than the change to an industrialised lifestyle, so that the per capita requirement for arable land may be kept below 0.24 ha for a period. Combined with the low fertility scenario, where the $8*10^9$ is the maximum reached, this could support the opinion that resource effects on human consumption opportunities can be altogether avoided. However, this must be characterised as a very optimistic scenario, especially since the 0.24 ha does not include areas for housing, infrastructure, and ecosystem conservation.

A more realistic scenario is that availability of arable land will become a problem either temporarily or permanently. This may first increase pressure on ecosystems leading to loss of biodiversity and secondly it may lead to food shortage involving direct human suffering and death.

However, present uses of arable lands have little influence on this future problem. We must distinguish between resource use (where the present use does not limit the extent of future use) and resource depletion (where present use renders agricultural lands less fit for future use). Only the latter should be accounted for in environmental assessments.

Many of the present man-made changes to arable lands may at first glance seem to limit future agricultural use (e.g. erosion or even desertification, use for housing and infrastructure). However, the production potential can in most cases be regained by adequate measures, involving e.g. external supply of water and nutrients and improving the soil structure. These measures all require energy and may therefore be treated as described under depletion of stock resources (see the uppermost of the three boxes), i.e. the future processes necessary for reclamation of the production potential of arable land can be included in the inventory.

However, it may be questioned to what extent the appropriate measures (to reclaim the production potential of arable lands) will actually be taken, since adequate finance for this purpose may be limited even when arable lands become scarce. This is especially true if the depleted areas are placed in poor countries. In such instances, present depletion may lead to direct, future effects to human life, human health, and ecosystem functions. Such effects should be included in the impact assessment.

RESULTS AND DISCUSSION

Based on an analysis of the relationship between inventory analysis and impact assessment, it is suggested that the future increase in energy requirement should be dealt with as part of the inventory analysis. The ultimate resource is identified as arable land, which allows the impact assessment to be limited to two key resources: genetic resources (biodiversity) and arable land.

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