LCA Methodology

# Einstein's Lessons for Energy Accounting in LCA

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Abstract

The role and meaning of accounting for energy, including feedstock energy, is reviewed in connection to Einstein's special theory of relativity. It is argued that there is only one unambiguous interpretation of the term energy-content: The one that corresponds to $mc^2$. The implications for life cycle inventories is that all discussions concerning upper heating value, lower heating value, feedstock energy, etc. are pointless as long as the motivation for choosing one or the other is not specified in relation to the safeguard subjects defined for a particular analysis (LCA or energy analysis). The subjective aspects of energy accounting schemes, even though based on mere thermodynamics, are highlighted. In inventory analysis, it is recommended that energy carriers should be accounted separately and in mass terms.

For illustrative purposes, energy statistics and energy assessment are discussed in view of the safeguard subjects underlying the accounting procedures. Based on a set of theses, one possible energy accounting scheme as an indicator of the "consumption of non-renewable energy resources" within the impact assessment of LCA is sketched. It is emphasised that energy accounting schemes do not reflect environmental impacts caused by the energy sources, and the characteristics of the indicator "consumption of non-renewable energy resources" introduced here are highlighted.

Keywords: Conservation of mass/energy; energy; impact assessment; inherent energy; LCA; Life Cycle Assessment; life cycle inventory analysis; relativity theory; resources; safeguard subjects

## 1 Introduction

For a practitioner of life cycle assessment (LCA), the issue of energy accounting in life cycle inventory analysis (LCI) and life cycle impact assessment (LCIA) is at least confusing. Several books and papers that describe methodological issues with respect to LCI, or that present a case study, devote some space to considerations with respect to their way of accounting energy. Just two instances are Fava et al. (1991), who recommend that "fossil fuel raw materials inputs [...] are reported as an MJ value", and Hunt et al. (1992), who reported that "energy [has been] converted into Joules of energy". The discussion often involves considerations with respect to the lower heating value, the upper heating value, feedstock energy, etc.

It should be noted that the context of LCI is not unique in discussing these matters. In fact, many of the ideas that are presented or further developed evolve from the field of energy analysis (cf. Anonymous, 1974) and energy statistics (cf. Anonymous, 1976). On the other hand, however, not all literature on LCI deals with the issue of energy accounting. There are many books that propose to account for the mass of the energy carriers and other natural resources. For instance, Consoli et al. (1993) recommend that "the associated raw material consumption also may be accounted for in mass units". We thus see that the position of energy in LCA is far from settled.

This paper tries to define a consistent way of dealing with energy in LCA. It points out the consequences of the decision to account for energy carriers in energetic terms and of the choice how this accounting is performed. Amazingly, perhaps, these consequences will only be accessible considering Einstein's special theory of relativity. Although relativity theory is most often only of interest for particulate physics, it will be shown to have interesting implications for the accounting of energy in LCI and in LCIA.

## 2 Einstein's Equation and its Implications on Mass Balances of Energy Systems

Together with Pythagoras' theorem concerning triangles ($a^2 + b^2 = c^2$) and Newton's second law of dynamics ($F = ma$), Einstein's equation that unites the concepts of matter and energy ($E = mc^2$) is perhaps one of the most famous equations that have been published. It is often said that this



Int. J. LCA 3 (5) 266 – 272 (1998)

equation is the key to nuclear energy. Indeed, it is known that the mass of the inputs is higher than the mass of the outputs in a nuclear reaction. The energy released is given by

$$E_{released} = (m_{in}-m_{out})c^2 \quad (1)$$

LIVESEY (1966), for example, states that the fusion of two deuterium atoms ($H^2$) produces a helium atom ($He^3$) and a neutron (n) according to

$$H^2 + H^2 \rightarrow He^3 + n \quad (2)$$

The rest mass of the $H^2$-atoms is 2.014102 atomic mass units, that of the He-atom is 3.016030, and that of the neutron is 1.008665. This means that

$$m_{in}-m_{out} = 0.003509 \text{ atomic mass units} \quad (3)$$

Using the fact that one atomic mass unit corresponds to $1.66 \times 10^{-27}$ kg, this gives an energy release of

$$E_{released} = 5.24\times10^{-13}\text{ J} \quad (4)$$

Although the difference in mass is quite small, the fact that the velocity of light is very large, and that it enters the equation in a squared fashion, means that the energy that is released in such a nuclear fusion is tremendous when extrapolated to the macroscopic scale, where the number of particles (atoms, molecules) involved is on the order of $10^{23}$, and the energy released about $10^{10}$ J. Similar calculations can be held for nuclear fission. The mass "loss" of the two nuclear bombs that destroyed Hiroshima and Nagasaki, for instance, was about 1 gram each (March, 1996).

The relativistic expression for energy is relevant for energy produced by nuclear reactions. This is a well-known fact. In contrast, it is less widely acknowledged that the same equation is relevant for all other forms of energy.

If we carefully read Einstein's 1905 paper, we see that this idea is just there, "The mass of a body is a measure of its energy-content; if the energy changes by [$E$], the mass changes in the same sense by [$E/c^2$]" (EINSTEIN, 1905). The "loss" of mass in energy conversions other than those that involve nuclear reactions is much smaller than the 0.1% that typically holds for nuclear energy. For instance, the combustion of 1 kg of natural gas with a heating value of 36.4 MJ/m$^3$ and a density of 0.79 kg/m$^3$ amounts to an energy conversion of 46 MJ, which in turn corresponds to a mass of $5\times10^{-10}$ kg. If we extract the energy, the loss of mass in this process is on the order of one part in $10^9$. If we would "weigh" the energy, we would exactly measure this amount.

A few more examples (from March, 1996):

- A large electric power plant has an annual need of some $10^9$ kg coal. The typical amount of mass that is "lost" is about 1 kg per year.
- Heating 1 kg of water from 0 °C to 100 °C requires about $10^{-11}$ kg of energy (not fuel!). The mass of the heated water is consequently increased.

However, these systems may escape an experimental verification, because it will probably remain impossible to measure these extremely small differences in mass (cf. BOUSTEAD & HANCOCK, 1979, p. 40).

## 3 Consequences for Life Cycle Inventory Analysis

It is time to return to the topic of LCI, and to see what the special theory of relativity can contribute to our topic. In this section, the representation of unaggregated energy carriers, and the question of whether to report energy resource inputs in mass or energy terms are treated.

The practice that is advocated or followed in quite a few texts is to account the input of energy carriers in energetic terms. The authors of these texts implicitly aim at an aggregation of energy carriers (i.e. oil, natural gas, coal, uranium, etc.) on the basis of their heating values, the energy extractable with today's technologies. Due to the fact that energy consumption is defined on a mainly thermodynamic basis, it is often perceived as objective. However, as PATTERSON (1996, p. 383) writes, "it is false to assert that thermodynamic measures of energy efficiency are free of human values and perceptions." We agree with the statement of PATTERSON, and deduce that an aggregation, or valuation of energy-containing resources should only be performed during the impact assessment phase, taking the safeguard subject concept of the corresponding LCA into account. In the Inventory Analysis they should be kept separate.

But should they be reported in mass or energy units? Relativistic considerations show us that the energy-content of a "body" as Einstein put it, or of an "energy-carrier or material" as life cycle analysts usually put it, is strictly proportional to its mass, the proportionality constant being the square of the velocity of light. There is no fundamental reason why a lesser energy-content should be used.

So there are only two consistent options: resource inputs should be expressed in mass terms only, or the full, technology-independent, inherent energy (so, Einstein's full energy-content) should be used as an input figure. The exclusive "or" in the previous sentence is there to prevent double counting. It is not important which of the two options is chosen, because the equivalence of mass and energy means that the two are fully identical. Accounting resources and energy carriers in mass terms is then the most obvious choice, because emissions are mostly represented in mass terms as well (except for waste heat, noise, and radioactive releases). The equivalence between mass and energy, however, implies that it really doesn't matter. Indeed, in particulate physics we see that the mass of an electron is usually expressed as 0.5 MeV which is a unit of energy.

Hence, the Einstein's formula only describes a physical phenomenon and provides a kind of exchange rate instead of an undisputable weighting principle. However, it helps to better discuss existing energy accounting schemes to what we will turn in the next section.

## 4 $E = 2\ mc^2$, a Physically Unambiguous but Useless Characterisation Principle

The discussion so far has concentrated on the accounting of energy-containing flows in LCI. It is assumed that all flows, energy-containing or not, were kept separate during inventory analysis. The impact assessment could then deal with the problem of how to aggregate different energy-containing flows into a limited number of impact categories (characterisation) and how to weigh between those categories (valuation).

Let us start with Einstein's full energy content. If the total energy input is to be regarded as one of the impact categories to be considered, the only unambiguous and technology-independent measure of the energy-content of a material is $c^2$ times its mass. A similar observation has been reported by FRISCHKNECHT & HOFSTETTER (1995) and FRISCHKNECHT et al. (1996, Part III, p. 18). Therefore, Einstein's full energy content and consequently the total mass of the inputs could provide an alternative though an identical yardstick. Thus, the MIPS-concept (SCHMIDT-BLEEK, 1993a; 1993b), that has been proposed as a proxy measure under the ideological assumption of de-materialisation, can after all be interpreted as an exact measure for the total material/energy input.

We may go one step further and take into account that every life cycle not only consumes but also produces mass in the form of emissions, and that the mass of these outputs has an energy-content which in principle may be used to convert energy. It seems fair to correct for this output and only consider the net material/energy input. The problem is now that the full equivalence of mass and energy in combination with the first law of thermodynamics makes a perfect material/energy balance for every life cycle (neglecting coproduct allocation, of course), even though the balance may be closed only after millennia in a really extensive LCI, where capital goods needed to produce capital goods are included, and the cradle of every product may be found in Eden and the grave in the apocalypse. For instance, the energy that is released in the form of friction heat along a life cycle represents a certain mass that must be accounted for as an output. Thus, the exact measure that could be constructed would always (apart from disturbing coproduct allocation details) yield a zero result. Mass throughput and energy throughput are therefore too trivial to consider in a characterisation procedure.

From the above considerations it becomes obvious that we need to specify which part of the mass/energy throughput is relevant, what is considered to be a useful energy flow for a valuation of any kind of product system. Or, in the words of BOULDING (1981) (quoted in PATTERSON, 1996, p. 383), "In applying physical concepts like energy to social and economic systems, certain pitfalls have to be avoided, some of which are very easy to fall into. In the first place, it is very important to recognise that all significant efficiency concepts which are based on purely physical inputs and outputs may not be significant in human terms, or at least the significance has to be evaluated. The more output per unit of input, the more efficient we expect it to be. The significance of the efficiency concept, however, depends on the significance of the outputs and inputs in terms of human valuation." In the next section, some considerations are made about a human valuation on the basis of a concept of usefulness (how shall the usefulness of outputs and inputs be measured?).

## 5 Consequences for Life Cycle Impact Assessment

One way of introducing such a human valuation would be to only consider the amount of energy extractable by today's technologies. In this case, the characterisation factors of total energy input become time-dependent. For instance, the present "combustion" technology is not able to extract more energy from 1 kg natural gas than a certain limit. That is the reason for using upper heating values or variants thereof. Future technologies, However, may be able to extract more energy from that same 1 kg. For instance, a technique might be developed to extract more energy from natural gas by shooting "hot neutrons" to the atoms. We might even extract the total amount of energy of the gas by letting it react with anti-gas that consists of atoms that are made up of anti-protons, anti-neutrons, and positrons.

A same reasoning may be held for the inherent energy. Suppose that uranium was already in use as a construction material in the pre-nuclear era, like it is now being used to stabilise vessels and aircraft. LCAs of these antique products would then have to take the energy-content of uranium into account. Clearly, the practitioners of those days would say that the inherent energy of uranium is zero (or perhaps close to zero if the possibility of oxidation is taken into account). Now, after the discovery of nuclear fission, we would say that the LCAs of those days are wrong. We can argue that they were wrong because they didn't know our current technology. But similarly, our grandchildren may argue that all present-day LCAs are wrong, because we do not know their technology. The implication is that LCAs are always wrong because not every technological development can be foreseen. LCA analysts will have to live with this shortcoming due to an ever developing technological and scientific knowledge. The effects anticipated in such an energy accounting scheme are supposed to be in congruence with the ones observed in the development of energy technologies. LCAs and their conclusions have therefore to be seen in their temporal context.

There are several other ways to create a non-trivial (that is, non-zero) result, some of which are used in official statistics. Due to their normative character, they should be situated in the impact assessment phase, which is biased towards the choice of safeguard subjects and the underlying argumentation. In other words, the characterisation principle has to be consistent with the choice of safeguard subjects.

Sometimes "resource use" is seen as a safeguard subject in itself (CONSOLI et al., 1993; ANONYMOUS, 1996) and sometimes as an impact category leading to an indirect damage to human and ecological health (see for this discussion, e.g. MÜLLER-WENK, 1997, p. 41 ff.; HOFSTETTER et al., 1997, p. 7 ff.). In consequence, scarcity aspects (e.g. GUINÉE & HEIJUNGS, 1995) or exergy losses (e.g. FINNVEDEN, 1994) may be applied as well as the consequences of a decreasing resource concentration in the earth's crust (BLONK et al., 1997).

Depending on the reasoning chosen, economy- and/or technology-dependent parameters are introduced into the characterisation. We already discussed the technology dependency of heating values, which might be applied in a separate category of "energy resource depletion". The same applies for methods which allow for an aggregation of resources independent of their applications such as present use rates, extractable stocks or future additional environmental interventions due to reduced ore qualities (e.g. reduced ore concentrations).

Instead of aiming at a technology-independent indicator for resource depletion (which probably does not exist) we plea to make a choice that is as explicit as possible concerning its motivation on the one hand, and the indicator chosen (e.g. cumulative energy demand, CED) as well as the technology assumed on the other. In the next section, the link between safeguard subjects and an operationalisation of energy accounting will be shown on the basis of the examples of international energy statistics and energy assessment as defined by ANONYMOUS (1997).

## 6 The Link Between Safeguard Subjects and the Purpose of Energy Accounting (two examples)

In the case of energetic resources or energy carriers and their aggregation, the link between safeguard subjects and the purpose(s) of accounting procedures applied in energy statistics, cumulative energy demand, or some LCA case studies is not straightforward.

The discussions about energy accounting in energy statistics, energy analysis and LCA mainly focus on heating values, nuclear energy, renewable energy, combined heat and power plants, and feedstock energy.

The problems related to heating values has been discussed in section 5 and will not be evaluated further. Feedstock energy and combined heat and power plants are topics related to allocation problems in multi-function systems (i.e. joint production, cascade systems, recycling and waste treatment options). They are independent of the parameters analysed (i.e. money, energy or environmental impacts), and are discussed extensively in other papers (see, e.g. KLÖPFFER, 1996; HEIJUNGS et al., 1997; FRISCHKNECHT, 1998). We will therefore not go into details here. The remaining items will be discussed in relation to their application in energy statistics and energy assessment.

International energy statistics (ANONYMOUS 1976, 1995) serve multiple purposes. In principle, they have the characteristic of energy-economic decision support and energy planning. For these purposes, it is necessary to aggregate different kinds of energetic resources used for the production of heat and electricity. There, the concept of primary energy has the meaning of a common denominator where substitution between electricity, power and heat is possible. ANONYMOUS (1976) states that a common unit is useful to estimate total energy requirements, forecasting and the study of substitution and conservation. They use the enthalpy, i.e. the binding energy between atoms of the fuel for coal, gas and oil power plants. Hence these kinds of fuels and its lower or upper heating values[1] are the reference supply sources. The problem to account for hydro, geothermal and later for nuclear power is solved by applying the partial substitution principle, i.e. it is assumed that if the electricity were not produced by hydro or nuclear power it would have to be produced by a fossil power station. Therefore the average fuel use in the conventional thermal power plants of a country was used. Due to the high share of hydro power during the 60ies in some countries, the European average fuel use was sometimes chosen. To support this view of substitution, an exception was made for Norway.

The electricity supply system in Norway shows a very high share of hydro power and to a large extent the substitute of electricity would be fuels burned at the point of final consumption. As a consequence, ANONYMOUS (1976) uses a primary energy demand for Norwegian hydro power which lies between the one for a thermal power station and a standard fossil heating system (57%). However, while this substitution principle may deliver useful information about the amount of fossil fuels displaced, it fails to adequately show transformation losses (GÖRGEN, 1996, p. 35).

In 1989, international organisations have abandoned the substitution method in favour of the efficiency method, where representative physical efficiencies are applied for the assessment of energy carriers. In ANONYMOUS (1995), nuclear power is now converted to primary energy using an average efficiency of 33%. Hydro-electricity and electricity produced by other non-thermal means (wind, tide, photovoltaic, etc.) are converted assuming 100% efficiency. For electricity produced from geothermal heat, an efficiency of 10% is applied[2]. No more country specific exceptions are made.

We learn from this example that the guiding principle of making energies commensurable was the replacement of fossil energy referring to the technology standard of the period when the statistics were started. The recent developments show that the resource aspect of fossil fuels are receded into the background. However, a clear motivation and reasoning for the efficiency figures applied is missing for the time being.

According to the developers of the cumulative energy demand (defined in ANONYMOUS, 1997), the purpose of an energy assessment[3] lies in the assessment of the overall energy consumption, and the evaluation of energetically relevant activities within the life cycle of a product or service. Furthermore, it should provide information about the emissions related to energy supply systems. Nothing is said about aspects of resource protection. Due to the totally different emission behaviour of energy systems (e.g. fissile versus fossil fuels, application of flue gas treatment), we prefer to concentrate in energy assessment on resource protection aspects of energy consumption.

The definition of the impact category that is supposed to reflect the depletion of resources should clearly be inspired by conceptual ideas on what exactly the problem is (HEIJUNGS et al., 1997). According to HOFSTETTER et al. (1997, p. 7), we may distinguish at least four aspects of resource protection, namely

- intrinsic value,
- depletion aspect,
- depreciation aspect, and
- replacement aspect.

All of them ask for a specific and distinct aggregation approach. Furthermore, if resource protection has to do with maintaining use options for future generations (depletion aspect), energetic considerations are only one aspect.

One possible indicator, "consumption of non-renewable energetic resources", will be sketched based on the following three theses:

1. Deposits[4] and unsustainably used stocks of funds do have an intrinsic value.

2. The available amount of energy contained in energetic resources determines their intrinsic value.

3. All other aspects like abundance, societal demand, possibilities for substitution etc. add nothing to the value of energetic resources.

From the theses, we may derive that the energy extractable from energy resources underlying a certain technology standard (i.e. best-available technology today, or foreseeable in the future) seems to be a sensible parameter. Sustainably used renewable resources[5] would not be included based on the three theses because their stock of funds remains constant.

The indicator outlined above gives a certain penalty to energy systems which use energy sources where a high technical energy potential is assumed such as uranium 235, where only about half of the amount extracted is converted to heat in the power station. This efficiency loss due to conversion losses within the upstream activities (enrichment) and in the power plant itself therefore has to be attributed to the nuclear energy system. One might discuss whether the part of the resource that has not yet been converted to waste heat along the process chain (e.g. deriched uranium 235 from enrichment plants, coal (low concentration) in mining wastes) should be accounted for the present energy system or not.

An indicator "consumption of non-renewable energetic resources" used in LCA would therefore comprise:

- fossil energy, aggregated based on the amount of fossil resources extracted, and weighted with the upper heating value;

- nuclear energy, aggregated based on the amount of fissile resources extracted, and weighted with the fission energy extractable using today's best available technology (i.e. light water reactors);

- unsustainably used renewable resources (e.g. energy wood from clearcutting primary forests), aggregated based on the amount of unsustainably used renewable resources extracted, and weighted with the upper heating value.

We emphasise that this proposal is just one possible way to aggregate energy sources to a distinct, resource oriented indicator in impact assessment. Let us summarise the main characteristics of the indicator introduced above:

- Energy resources have an intrinsic value.

- The value of energetic resources is expressed by the amount of energy extractable using today's technology, thus neglecting scientific and technological progress as well as non-energetic aspects like abundance of the resource, societal demand, etc.

- From an energy safeguard point of view, the use of sustainably used renewable energy resources is assumed to be unproblematic and therefore a zero value is attributed to them.

- Environmental impacts due to emissions in air and water released by processes related to the energy sources considered are completely neglected in this accounting procedure that explicitly concentrates on deposit aspects.

- The consumption of other, non-energetically used resources is not included in this indicator. Additional efforts are needed to make these different kinds of resource consumptions commensurable.

## 7 Conclusions

A review of the principles of special theory of relativity and of energy accounting schemes like energy statistics and energy assessment yields recommendations that are of interest for the methodology of LCI and LCIA:

- Any energy accounting scheme, though relying on thermodynamic principles inevitably depends on human values and perceptions. Life cycle inventory analysis should therefore be kept free from any energy accounting scheme which aggregates different energy sources.
- In life cycle inventory analysis, inputs of energy carriers, like hard coal, natural gas, crude oil, and uranium shall separately be accounted for in mass terms.
- Lower heating values, upper heating values and feedstock energy of fuels and materials shall not be accounted for in the life cycle inventory analysis. These properties may be of interest, just like the fibre length of paper products, the tensile strength of materials, or the heavy metal content of fossil fuels, but they shall not find a place in the inventory table.
- Any energy accounting scheme fails to adequately represent environmental impacts caused by the different energy sources. Energy accounting schemes have to be applied with great care if they should serve as a streamlining indicator for environmental impacts. Any coincidence with the outcome of a complete LCA would be accidental.
- The use of an energy accounting scheme as a streamlining indicator for environmental impacts in the way described in section 6 would imply that the effects on human and ecological health of 1 kWh electricity from nuclear power roughly equal the effects due to 1 kWh of electricity produced in a fossil-fired power plant, or the effects due to about 3 kWh heat from a fossil fuelled boiler.
- We advocate to restrict the purpose of energy accounting schemes to aspects of resource depletion. They shall be based on the reasoning given in the goal and scope definition of a particular LCA or energy analysis, why and how resources are defined as a safeguard subject. In existing energy accounting schemes, this relation between the accounting procedure and its purposes is seldom made explicitly.
- Energy accounting schemes are highly dependent on the aspect(s) considered as relevant in relation to resource consumption (i.e. intrinsic value, resource depletion, resource depreciation, resource substitution).
- Guidelines for the calculation of cumulative energy demands shall comprise a set of possible, different but widespread reasonings about the safeguard subjects for energy sources and a set of corresponding accounting procedures related to these reasonings.

**Acknowledgements**

We wish to thank Prof. Peter SUTER, Niels JUNGBLUTH (ETHZ) and unknown reviewers for their valuable comments on earlier drafts of this paper.

**Footnotes**

[1] In the 60ies and 70ies the vapour in the exhaust gas was never condensated to prevent corrosion problems. Therefore, the technology when the statistics were made is the basis for the accounting principle, i.e. the lower heating value (net energy content) is normally used. ANONYMOUS (1975) mentions explicitly that they are aware that the upper heating value is used in statistics in Japan and North America. Nowadays, the best of today's technology would probably be used, i.e. the upper heating value would be applied.

[2] We did not find the reasoning for applying such a very low efficiency on geothermal electricity.

[3] As mentioned above, such an assessment has to be motivated by the chosen safeguard subjects. Only if it can be concluded that the use of energy is damaging one of the safeguard subjects do the following thoughts become relevant.

[4] FINNVEDEN (1996, p. 40) defines deposits as "[...] resources that have no, or only very limited regrowth possibility within a relevant time horizon (human lifetime(s)), and are therefore depleted when extracted."

[5] Changes in resource quality (i.e. water quality) as well as competition aspects (rivers may also be used for fishery or sports, recreation, etc.) due to the use of water for electricity generation are neglected here.

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## LCA Strategies

# Hellenic Life Cycle Assessment Network (HELCANET)

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The Hellenic Life Cycle Assessment Network (HELCANET) was created in February 1998 by the Laboratory of Heat Transfer and Environmental Engineering (LHTEE) of the Aristotle University of Thessaloniki (AUT) to facilitate the development of LCA in Greece. HELCANET is the first and only network established in Greece for the promotion of LCA development.

### Mission

To make the tool of LCA available to the Greek public and to demonstrate its importance for a sustainable future.

### Objectives of HELCANET

The main objectives of HELCANET are:

- To promote and support scientific research, education, training, dissemination of information and development in the area of life cycle issues.
- To catalyze the development and application of life cycle assessment by pooling the talent and resources of industry and other organizations interested in LCA.
- To be a platform for discussion on LCA research and development via the regular and rapid exchange of information between Greek universities, research institutes, companies, authorities and governmental organizations.

### Areas of Focus

Social dialogue and methodology development in Greece, piloting the product and process Life Cycle Assessment in:

- public policy
- waste management
- energy systems
- building materials
- ecolabeling criteria, ISO 14040, inventory, data bases, data quality, impact assessment, recycling, policy, design for environment.

### Organizational Structure

The overall coordination of HELCANET's activities is performed by LHTEE, Aristotle University of Thessaloniki. Prof. Nicolas MOUSSIOPOULOS is the chairman of the board and Angeliki BOURA is the coordinator of the HELCANET.

HELCANET has a Board with members from different organizations: LHTEE (Laboratory of Heat Transfer and Environmental Engineering), JRC (Joint Research Center), Columbia University of New York, the Greek Ministry of Environment, Physical Planning and Public Works, Siemens S.A., General Foods S.A.

HELCANET members are mainly Greeks active in or interested in LCA methodology development and people interested in LCA applications, from academic institutions, industry, authorities and governmental organizations. The network is open to everyone.

**For further information** about HELCANET and a registration procedure in order to become a member of the network, please refer to the following web page:

http://aix.meng.auth.gr/lhtee/helcanet

or contact:

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