Preface

We live in a complex world in which the competition between people and nations are increasing. Moreover is mankind as an "inhabitant" not always treating its "house" the Earth with due respect and care.

For instance the current enhanced greenhouse effect has the potential to drastically change living conditions. Alarmingly, the effect could be underestimated due to a reflecting mechanism of particle pollution. Moreover, around half of the "original" forests have been removed to give space for arable land, inducing a positive feedback for increased global heating. Another serious concern is that the numbers of animal species are decreasing partly due to Mankind's destructive ways of life. Many species provide "ecosystem services" which could be enormously valuable [1]. Bee-aided pollination is a striking example of such services.

Undisputed research has demonstrated that the Earth system is more than the sum of its parts so it is not recommendable to model the environmental impacts in a purely positivistic manner. Moreover, the ranking of different environmental problems is currently a task for legislators who drive the environmental initiatives of individual actors. Signs are showing that legislators are trying to introduce monetary fees on environmental loadings beyond e.g., sulphur dioxide, where the carbon dioxide taxes and trading systems are the most obvious examples. Recently the Swedish government suggested increasing the tax on ammunition which contains lead (Pb) in order to promote the development of alternatives.

More and more governments seem to understand that the current global economy is not sustainable from an environmental viewpoint. In order to grasp what kinds of environmental aspects could be involved in the electronics industry, a definition of an environmental problem is needed. An environmental problem can be regarded as such, if these three criteria are fulfilled: first, an objective change in the environment is to take place; second, this change shall have to be human induced; and third, this change shall be regarded as a problem by society. The vast and tremendously multifaceted electronics industry is characterized by its long supply chains and thereby many indirect environmental impacts associated with its products.

The microelectronic products used in everyday life seem small and harmless, but quite a lot of material and energy is needed to produce electronic components, especially the integrated circuit (IC).

The life cycle schematically consists of three phases which are manufacturing followed by the use phase, and last the end-of-life. One important network of manufacturing processes is the one associated with the production of ICs. However, the final assembly of electronics does not give rise to tremendous global environmental problems, compared to the processes further upstream.

The cradle-to-gate usage of primary energy (PEU) is around 2,300 MJ/kg and the CO_2 equivalent intensity 150 kg/kg for printed board assemblies[1] (PBA). However, the PBAs differ dependent on the electronic device in which they are used. *According to estimations* for an advanced telecom PBA, the silicon-based ICs are near 30% and printed wiring board is around 40% of the PEU. The so-called high-purity chemicals used in silicon wafer processing could at least make up 5% of the PEU for a PBA from "cradle-to-gate". The solder/adhesive part of the PBA is below 1% of the CO_2 and PEU scores. It seems that the solder/adhesive component is mostly interesting from an environmental risk management perspective in the waste treatment phase, and not due to energy usage concerns.

During the use phase the electronic products use electricity and the environmental load is dependent on how this electricity has been obtained from secondary energies. According to the International Energy Agency, combustion of the fossil fuel coal is the most common method worldwide and coal makes up around 40% of the primary energies used to obtain useful electricity. Global electricity conversion is also associated with metal emissions such as Hg and Pb. It is likely that the electricity usage worldwide will significantly increase, as a result of increased use of electronics. This development is part of the westernization of the world emphasized by the economic growth in, e.g., China, India, and Brazil.

In the developed world, at the end of the electronic product life only a small share is currently recycled, mostly to get hold of the valuable metals. (In the developing part of the world the electronics recycling situation is even worse.) The rest is first incinerated and then deposited in landfills, or directly deposited. The export of used products, e.g., obsolete computers, from the developed countries to developing is significant and increasing [2]. The microelectronics business is challenged by a number of recent environmental regulations. It is likely that an EU Directive addressing the recycling of waste from electronic and electrical equipment, WEEE, will improve the recycling rate in Europe [3]. Heavy-metal emissions (e.g., Pb in solders) occur as a result of improper recycling and therefore the global flows of electronics waste from the industrialized world to the developing one is currently leading to occupational health problems [4].

According to the European Community Directive 2000/0159 C5-0487/2002 (RoHS) regarding limitation of the use of certain environmentally harmful materials, the Member States were obliged as of July 1 2006 to ensure that, among other materials, Pb is not used in soldering materials employed in electrical and electronic equipment to be sold on the market [5]. Nevertheless, Pb can still be used for solder alloys containing 85wt% Pb.

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[1] Printed wiring board = printed circuit board = printed board = a board without components and interconnection materials

Actually, one of the most controversial issues that the electronics industry handles is the shift to Pb-free production. The Pb ban RoHS was proposed as Pb has been banned in other products, and also the legislators estimated the environmental risk, of Pb in electronics waste, as high for humans and biota. One reason for the legislators' worry was that in fact electronics recycling is not happening quickly enough. However, several actors have individually and together demanded exemptions due to cost and reliability concerns of Pb-free alternatives.

For the environmental scientist it should be rather straightforward to shed light on whether this ban of a specific Pb usage makes sense. It mainly depends on data available for the simulations and the uncertainty associated with those data. There exist a number of approaches to tackle the problem. One would be to test the following two hypotheses:

1. The phasing out of Pb from the electronics industry (mainly interconnection materials) is preferable seen from *different environmental cost perspectives*
2. Pb emissions will decrease (*in the same way as they did when Pb was phased out as additive to petrol*) if Pb is phased out from the electronics industry

In this book I present my own environmental life cycle assessment (LCA) based research containing data with which these specified hypotheses are tested. The book elaborates on the ability of LCAs to answer questions of global character. This covers certain conclusions which can be drawn from the perspective of LCA on the transitional Pb-free ban in the electronics industry. Special emphasis is given to consequential LCA, uncertainty analysis and the Japanese LIME impact assessment modeling system. The LCA approach has many well-known problems, but also many positive features, both of which I will account for in detail for the specific applications. Environmental impact predictions definitely belong to holistic science in contrast to analytic reductionism. This is because the environmental systems are complex and e.g., the LCA approach demands multidisciplinary thinking which in turn needs the knowledge and methodology from more than one discipline.

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