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Drawing a chip environmental profile: environmental indicators for the semiconductor industry

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ABSTRACT

The semiconductor industry plays an ever-increasing role in society, providing microelectronic components called chips that are used in a wide variety of electronic applications. The rapid increase of the production of chips is responsible for considerable effects on the environment during the different phases of their life cycle. In spite of increasing pressure from stakeholders to control these effects, no international standard or agreement has yet been established. In this context, the paper proposes a set of environmental indicators that take into account the most serious damages induced by these products.

To establish an exhaustive list of indicators, the specificities of the semiconductor branch are first analysed in literature, identifying pressures on the sector coming from the downstream chain – chip buyers and users – and finally by analysing data from industrial case studies. In order to highlight the most significant direct and indirect impacts, each aspect of the chips' life cycle phases is studied independently. The indicators reflect the particularities of the industry and point out the major impact categories. They can be therefore be used for standardized environmental analysis of microelectronic products. The paper retains seven environmental indicators: resource depletion, eutrophication, water stress, toxicity, summer smog and local electrical consumption. The final set of indicators will help draw the environmental profile of the microelectronic chips over the full life cycle of the products. It is a step towards necessary standardization in the microelectronic industry. The indicators are consistent with current state of the art and can evolve as progress is made on the definition and calculation of new indicators.

1. Introduction

The relatively low cost of production of microelectronic components, also called chips or integrated circuits (ICs), has made computers, mobile phones and other electronic devices inextricable parts of the structure of modern societies. Their very fast expansion into all sectors of the economy contributes to worrying effects on the environment: pollution in manufacturing plants; depletion of raw materials; electricity consumption during use; and accumulation of electronic waste, amongst others.

This trend justifies current efforts to improve knowledge on the environmental risks and impacts of products in the microelectronic industry. This paper starts with the different potential impacts of the industry and determines the significant indicators that could be used to monitor the environmental consequences of the activity. Different indicators are currently available to characterize environmental impacts so the paper does not develop new ones but proceeds with state of the art indicators.

Life Cycle Assessment (LCA) is identified as a powerful technique to present a global vision of the impacts generated by products. Results are presented in the form of a profile, providing a baseline to control the environmental state of the product and suggest ways to improve it. In theory, the schema should account for all the aspects: climate change, eco-systems quality, biodiversity, etc., without minimizing or intensifying one effect rather than another. The reason for considering all the aspects is to avoid impact transfers: attempts to improve one type of impact can deteriorate another one, which had hitherto been neglected or not at all regarded as important for the industry. However, each industry has its own particular concerns and should act in priority to reduce the most significant impacts it produces and determine the adequate indicators to guide this.

The choice of indicators can be made by considering factors such as image, communication on previously achieved efforts and the ease of data collection (Olsthoorn et al., 2001), however, a scientific determination of indicators requires a deep analysis of every stage

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List of abbreviations and acronyms

CO	Carbon Monoxide
CML	Chain Management by Life Cycle Assessment
CVD	Chemical Vapour Deposition
DPSIR	Driving force, Pressure, State, Impact, Response
ESIA	European Semiconductor Industry Association
EuP	Eco-Design of Energy-using Products
GHG	Greenhouse Gas
IC	Integrated Circuit
ISO	International Organization for Standardization
ITRS	International Technology Roadmap for Semiconductors
ITU	International Telecommunication Union
KEPI	Key Environmental Priority Indicator
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
NGO	Non Government Organization
NOX	Nitrogen Oxides
OECD	Organization for Economic Co-operation and Development
PFC	Perfluorocarbon
RoHS	Restriction of the use of Hazardous Substances
SETAC	Society of Environmental Toxicology and Chemistry
TRACI	Tool for the Reduction and Assessment of Chemical and other Environmental Impacts
VOC	Volatile Organic Compound
WEEE	Waste Electrical and Electronic Equipment

of the life cycle. The effect on the environment of a product can be visualised through the approach developed by the OECD[1] called DPSIR: Driving force, Pressure, State, Impact, Response (Lütz and Felici, 2008). It was developed to clarify the causalities between the actions of society and the consequences on the environment and ecosystems, and also to identify the needs for action. Furthermore, according to ISO[2] 14031 (ISO, 1999), the selection and definition of environmental performance indicators has to take into account the significance of environmental aspects, the influence on the aspects and policy of the organization concerned and the views of other stakeholders. Indeed, the strategic positioning of a company is motivated essentially by external environmental, economic and social facets.

In the semi-conductor sector it has mainly been external pressure that has, in the past, pushed the industry to learn more about the environmental impacts of its products. As a chip is only a small part of electronic applications, it is not intended for the general public but for industrial clients and has therefore not been a primary target of NGOs (Non Government Organizations) and consumers associations. Today, concerns are driven by generic stakeholder considerations, materialised by demands from extra-financial marking agencies. These agencies deliver ethical indexes like the Dow Jones Sustainability Index and usually call for reports on three major themes: climate strategy, water related risks and hazardous chemicals. In recent years, life cycle thinking has appeared in regulations across the world, most often initiated by the European Union (Szendiuch and Schischke 2006: RoHS (Restriction of the use of certain Hazardous Substances) (European Commission, 2002a), WEEE (Waste Electrical and Electronic Equipment) (European Commission, 2002b) and EuP (Eco-Design of Energy-using Products) (European Commission, 2005). These directives extend the responsibility of producers to the full product life cycle. Expectations from society can therefore be taken as the first motivation to study the environmental impacts of the microelectronic products.

The second motivation comes from industrial applications that need to evaluate the environmental potential of consumer products incorporating semi-conductors. The environmental performances of the applications are dependent on the chips embedded inside. The selection of significant aspects of a chip cannot therefore be detached from customer demands. However, indicators should cover the needs of the industrial customers without losing the original microelectronic specificities. Electronic and computer industries are the historical customers of the microelectronic industry but lately, many new applications with electric and electronic devices have appeared and common appliances, like coffee machines, cars, ink cartridges, light bulbs, medical applications, etc. integrate electronic functions. The diversity of customer markets tends to multiply environmental obligations. First of all, the electronic sector as a whole has been facing an increasing problem of electronic waste leading to the legislative frameworks mentioned above. In addition, the ITU[3] has been focussing on the greenhouse gas (GHG) emissions and energy consumption. Although the scope may seem restricted due to the international focus on GHGs, according to recent working groups (ITU, 2010), other environmental impacts like raw material depletion or water stress would be tackled later. Furthermore, the automotive sector insists on the use phase (limitation of air exhausts) and end-of-life (European Commission, 2002c). In this way each particular applicative sector introduces new requirements for the semiconductors.

Finally, the third motivation comes from microelectronic associations that have decided to take the lead on environmental concerns in their own industry. Chip manufacturers are regrouped in associations, such as ESIA,[4] that defend interests on a national, regional or global level. These associations reflect the trends within the sector in their reports. ITRS,[5] sponsored by the five leading chip manufacturing regions in the world: Europe, Japan, Korea, Taiwan, and the United States, includes an Environment Safety and Health Summary in their yearly roadmap (ITRS, 2013). However, ITRS is essentially a technology roadmap and the document insists on the needs for more robust and rapid assessment methodologies for chemicals, global warming, water and energy, along with some equipment life-cycle issues (ITRS, 2013). Another international consortium of leading semiconductor manufacturers, SEMATECH (2009),[6] has developed Key Environmental Priority Indicators (KEPIs) for the microelectronic sector as "specific expressions that provide information about an organization's environmental performances" (ISO, 1999). These KEPIs cover restricted concerns: global warming, water resource, chemical consumption and waste generation impacts. No knowledge management and classification of

[1] OECD: Organization for Economic Co-operation and Development – http://www.oecd.org.

[2] ISO: International Organization for Standardization – http://www.iso.org/iso/home.html.

[3] ITU: International Telecommunication Union – http://www.itu.int/en/Pages/default.aspx.

[4] ESIA: European Semiconductor Industry Association – http://www.eeca.be/esia/home.

[5] ITRS: International Technology Roadmap for Semiconductors – http://www.itrs.net/home.html.

[6] SEMATECH: http://sematech.org/index.htm.