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Sustainable electronics: On the trail of reconfigurable computing

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ABSTRACT

The electronics industry today is not yet *green* and/or *sustainable*. Indeed, the microelectronics industry is a consumer of primary materials, chemical products, water and energy. The manufacture of electronic products and their disposal at the end of their lives results in large quantities of waste products of varying degrees of toxicity that are difficult to deal with. Due to their high replacement rate, the lifespan of electronic products is spectacularly short. To reduce the environmental impact of electronic products the usual *reduce-reuse-recycle* (*3R*) trilogy appears to be insufficient. To achieve the objective of sustainable electronics, in this paper we suggest adding a fourth *R* for *reconfigure*. We recommend the use of the reconfiguration capacities of reconfigurable circuits such as FPGAs to reduce the functional obsolescence of electronic products by updating hardware. This paper is a survey of the sustainability of microelectronic. It presents some examples of pioneer works to illustrate the architecture of sustainable reconfigurable computing systems.

1. Introduction to sustainable electronics

The dark side of Moore's law is consumers' insatiable desire to own the very latest fashionable electronic device. Worldwide, users generally change their mobile phones every 18 months, because they are encouraged to do so by their service providers [1] and/or because they want to own the very latest technology [2,3]. Yet the real lifespan of a mobile phone is around 3.5 years [4]. This means that mobile phones and smartphones have the highest replacement rate in industrial history [4].

This trend is most apparent in the sales of a figurehead product, Apple's *iPhone*, which very rapidly cornered a 40% share of the smartphone market. On the day it was released, over 1.5 million *iPhone* 4G handsets were sold. At that point, it was the fourth version of the *iPhone* in the four years since its original launch. Apple's commercial strategy is to launch a new version of the product every year, which renders the old version unfashionable if not obsolete. The same strategy can be observed for the *iPad*, of which more than 300,000 were sold on the very first day of its release on the market. Apple and other smartphone companies follow the *planned obsolescence* marketing strategy. This strategy was popularized in 1960 by an American industrial designer, Brooks Stevens who gave the following definition "*Planned obsolescence results from the consumer's desire to own something a little newer, a little better, a little sooner than necessary*" [5]. The strategy has been the subject of quite a few studies for some years now, mainly its economic aspects [6]. But, recently some authors have criticized it and showed us new possible directions [7].

In 2009, 1.26 billion mobile phones were sold worldwide (which, for the first time, represented a 0.4% drop in sales compared to the previous year), and 174.2 million smartphones (which represented a 15% increase in sales compared to the previous year, and accounts for the decrease in sales of ordinary mobile phones, due to a shift in buyers' preferences toward the new products).

A similar phenomenon can be observed in the use of computers (portable or otherwise), which have a life expectancy of around 80,000 h, but whose actual lifespan (which corresponds to the length of actual use) is around 20,000 h [8] (a little more than two years [9]).

The high degree of usage of electronic products (computers, communication devices, embedded systems, etc.), combined with a high rate of replacement (or a reduced actual lifespan) has very serious environmental consequences when these are applied to the ensemble of these products. This environmental impact has many causes. To begin with, the manufacture of these complex products requires much energy and many materials, chemical products and large quantities of water. Second, energy consumption during the use of these products may be high if all the infrastructures (communication infrastructures, for instance) are taken into account. Finally, the manufacture of the products and their disposal at the end of their lives produces many waste products of varying degrees of toxicity and that are difficult to deal with. Consequently, to

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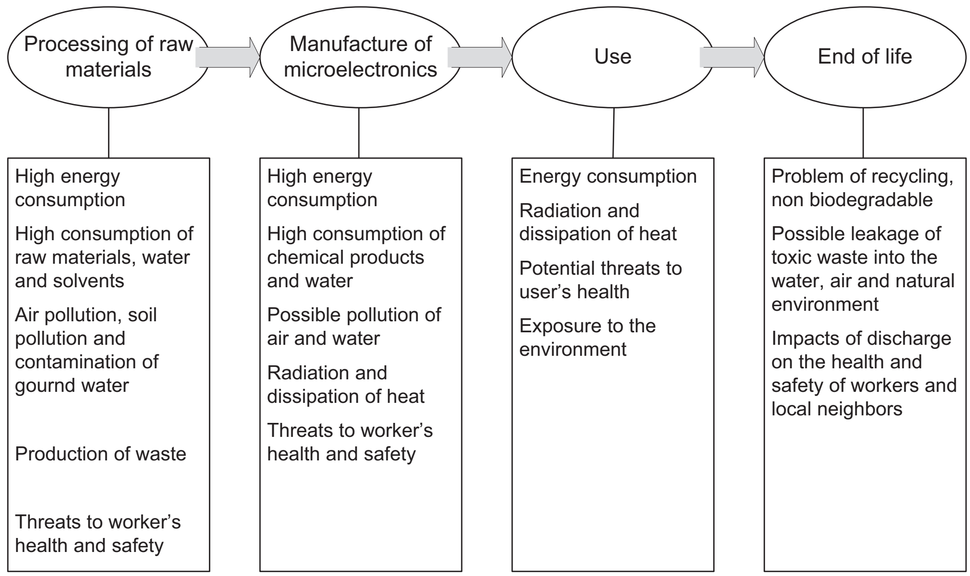

Fig. 1. Lifecycle of electronic products and main risks associated with each stage

Adapted from [15].

identify the best way to reduce their environmental impact, the whole lifecycle of the electronic products has to be taken into account. Despite the massive diffusion of electronic products worldwide, their environmental impact is clearly not even remotely comparable to that of other sectors–particularly transport. For example, the environmental impact of a mobile telephone, from its design to recycling, is less than that of a family car driven for a mere 100 km! [10]. Another example: in 2004, Intel used 424 million liters of water per week in to manufacture its chips; whereas 757 million liters of water is needed just to print the Sunday edition of the *New York Times* each week [11].

These examples could lead us to think that we do not really need to reduce the environmental impact of electronic products. However, to ignore the issue would be overlook the impact all these products have on contemporary societies both today and in the years to come. Indeed, electronic products can – for instance – reduce the consumption of paper (electronic books and newspapers) and help reduce transport (audio and video conferences, electronic transfer of papers and forms, online administration procedures, etc.). It would not be viable for our digital societies not to use these products or to limit their future development and diffusion. On the contrary, we need to continue to develop our society with the help of these products, while simultaneously greatly reducing their environmental impact [12]. If certain products are replaced or certain uses improved, electronic products could, in the future, enable a massive reduction in the environmental impact of human activities. Indeed, the question of the beneficial effect of technological substitution on the environmental impact of human activities is not clear [13].

To reduce the environmental impact of electronic products (telecommunications terminals, computers, embedded systems, etc.) a detailed study their lifecycle is required from their development and manufacture until they wind up on the scrapheap. This can be achieved with a rapid simplified *life-cycle assessment* (LCA), such as that offered by the Interuniversity Research Center for the Life Cycle of Products, Processes and Services [14]. Such an assessment will clearly reveal which options need to be developed to reduce their environmental impact which, while insignificant compared to that of other industrial products used for human activities, needs reducing to lay the foundations for a digital society in which electronic products play an even more important role. This is what we attempt in the next section, before focusing on a new approach: the design of a reconfigurable hardware system to increase the lifespan of electronic products by reducing their functional obsolescence.

The paper is organized as follows: in Section 2, we analyze the environmental impact of electronic products. In Section 3, we provide an overview of the application of the reduce-reuse-recycle methodology to electronic products. In Section 4, we describe an alternative solution in the form of a reconfigurable hardware design for sustainability. Finally, in Section 5, we draw a number of conclusions.

2. Environmental impact of electronic products during their lifecycle

2.1. Lifecycle of electronic products

Electronic products have a classic lifecycle, as shown in the simplified diagram in Fig. 1 (this figure is inspired by one by Dhingra in a 2010 article [15], but is more complete in terms of the risks associated with each stage of the lifecycle). The four essential stages of the lifecycle of such products are the processing of raw materials, the manufacture of the products, their usage, and finally the end of their life (recycling and disposal). These different stages do not have the same environmental impact either in volume or in their consequences. The row of boxes in Fig. 1 lists some of the risks incurred at each stage plus the impacts on the health and safety of workers and of local residents upon disposal.

Fig. 2 uses the example of a Nokia mobile phone [10], and shows the proportional use of energy during each stage of the lifecycle (Fig. 2a and b). The percentages given are for an actual lifespan of 18 months in Fig. 2a. In this case, what is clear is that the stages of creation of the product, from the primary and secondary materials to the manufacture of the final product, have the greatest environmental impact. By contrast, the phase of actual use of the product (calculated for 36 months) represents slightly more than a quarter of total energy consumption. This proportion decreases greatly with a shorter lifespan – for instance, for a lifespan equal to the average life of mobile phones (18 months [1]), the proportion drops to 16.4% of total energy consumption. This can be explained simply by the fact that the other stages of the product's lifecycle use