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# Could energy hamper future developments in information and communication technologies (ICT) and knowledge engineering?

Ahmet Ziya Aktas

*Computer Engineering Department, Baskent University, Ankara, Turkey*

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ABSTRACT

Any electronic equipment contains silicon chips. Modern society, the Knowledge Society, has been possible through the development of low-cost silicon chips. Some researchers, however, have been claiming that "Moore's law" for silicon chip design and production of integrated circuits will remain valid only for the next 1 or 2 decades due to energy limitations. Thus, we cannot produce these chips as efficiently as before. The objective of this paper is to present and discuss this claim in terms of energy, information and communications technologies (ICT), computer engineering, knowledge and knowledge engineering, and electronics views. It also appears that the use of some advanced production techniques could extend the use of silicon chips. The author has been unable to find any study yet that has addressed the effect of this issue on the future of intelligence, knowledge and knowledge engineering and management. Hence, this may cited as an original feature of the present paper.

## 1. Introduction

ENERGY is a keyword that has become pertinent to the economic development and sustainability of all countries as well as the ecological future of the world. For a number of the last decades, energy and information and communications technologies (ICT) have developed in a synergistic fashion. However, in a relatively recent work, Borkar and Chien [1] sounded a warning about the relationship between energy and ICT such that: "Energy efficiency is the new fundamental limiter of processor performance, way beyond numbers of processors." The author believes that such a warning deserves a serious attention—not only for microprocessors but also for the future of ICT, which plays a key role in human development. The key objective of this article is the verification of this warning.

### 1.1. A brief review of a microprocessor

An integrated circuit is an electronic circuit, formed on a single silicon chip. Virtually all types of electronic equipment today use integrated circuits, and they have revolutionized the world of electronics. The low cost of integrated circuits has made possible the various types of computers, mobile phones, and other digital appliances that form part of our private and professional lives.

The world's first microprocessor, the 4004, was a joint development by Busicom, a Japanese firm, and Intel, a US semiconductor producer. That first successful microprocessor appeared in March 1971. Since then, microprocessors have undergone astonishing development. They have become the technology that opened up a new era of progress, which uses computer power to enhance human intelligence or knowledge. According to Shima [2], in the twentieth century, microprocessors increased the power of intelligence; next in the twenty-first century, they will evolve into a "tool to bring forth wisdom for all mankind."

### 1.2. Moore's law

In 1965 G.E. Moore had noted that "With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip". [3] Gordon E. Moore, Intel cofounder, observed in the mid-1960s that the number of transistors on silicon chips doubled roughly every 2 years as shown on Fig. 1. That observation has the name of "Moore's Law". Moore's Law has played a significant role in the silicon chip design and production of integrated circuits for almost 5 decades.

Initially, Moore was referring only to the number of transistors on the silicon chip. However, Moore's Law has also been consistent when applied to processing power. According to current thinking, Moore's Law was still valid in 2015. Some authorities, though, believe that the law no longer applies.

## 2. A debate on Moore's law

M. Kaku is an American futurist, theoretical physicist, popularizer of science, and author of a best-selling book, *The Future of the Mind*. In a

*E-mail address:* zaktas@baskent.edu.tr.

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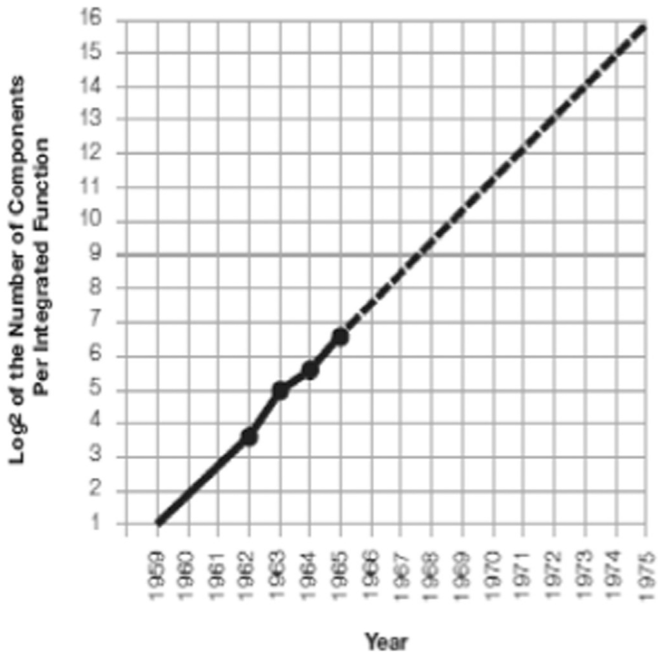


**Fig. 1.** No. of components on a chip in 15 years.

conversation recorded on YouTube on May 13, 2012, he predicted that, “In about 10 years or so, we will see the collapse of Moore's Law. In fact, already, we see a slowing down of Moore's Law. Computer power simply cannot maintain its rapid exponential rise using standard silicon technology.”[4] Even Intel Corporation has admitted that. At the International Supercomputing Conference (ISC) of the Association for Computing Machinery (ACM) in June 2011, the head of the Intel architecture group and vice president, K. Skaugen, stated, “Moore's Law was not in itself sufficient for the company to achieve exascale performance by 2018.” The Intel officer went on to present Intel's tri-gate technology (so-called 3D processors) as the solution since they would mean “No more end of life for Moore's Law.” [5] However, it is doubtful whether they could prevent the breakdown of Moore's Law owing to heat and leakage problems with integrated circuits. Kaku had stated, “So there is an ultimate limit set by the laws of thermal dynamics and set by the laws of quantum mechanics as to how much computing power you can do with silicon.” He named several other options, such as protein, DNA, optical, quantum, and molecular computers, instead of using silicon chips [4].

A study by Purdue University [6] claimed “Single-atom transistor is end of Moore's Law; may be beginning of quantum computing.” As part of that research project, the researchers built the smallest-ever transistor using a single phosphorus atom. The atomic-sized transistor and wires could allow researchers to control gated qubits of information in future quantum computers. That single-atom transistor has one serious limitation: it must have very cold temperatures—at least as cold as liquid nitrogen.

Borkar and Chien [1] had observed that in the 20 years following their invention, microprocessors (also called single-chip computers) have achieved rapid growth in performance. That was due to three key technology drivers: transistor-speed scaling; core microarchitecture techniques; and cache memories.

The predictions of Borkar and Chien [1] for the next 20 years were as follows:

• Energy will be the key in limiting performance;

• Thus, the objective is ultimately the purest form of energy-proportional computing at the lowest-possible levels of energy.

## 3. Energy issue in microprocessors

As noted by Gammaitoni [7], basic ICT devices dissipate power as heat. Energy dissipation takes two forms: power dissipation in the integrated circuits; and noise-limiting computation performance.

An ICT device inputs information and energy (in the form of work), processes information, and outputs information and energy (mostly in the form of heat). It may be appropriate here to make a note about the term “information. Information is used as a generic term to denote data /information/knowledge triple.

However, Nano-scale devices of the future will closely affect ICT while processing information in transforming work into heat and heat into work. Thus, information processing and energy management are intimately interrelated [7].

## 4. ICT carbon footprint

### 4.1. ICT carbon footprint

A carbon footprint is the total amount of greenhouse gases produced either directly or indirectly to support human activities. It is measured in equivalent tons of carbon dioxide. ICT accounts for 2% of global carbon emissions. It is, therefore, obvious that using more energy-efficient ICT devices (such as computers, communications systems, and data centers) will have a direct effect on the carbon footprint of ICT. It is, however, necessary to take into consideration the role of ICT in the remaining 98% of global carbon emissions—with respect to smart cities, smart cars, smart buildings, smart infrastructure, smart grids, and smart logistics—shortly, the smart world [8].

The SMART 2020 Report [9] was published by an independent non-profit organization, Climate Group and the Global e-Sustainability Initiative (GeSI), toward achieving a low-carbon economy in the Information, or rather Knowledge, Age. That report predicts that smarter technology use could reduce global emissions by 15%. On top of other gains, the report notes that replacing physical products and services with virtual equivalents could result in a 6% reduction in the estimated low carbon footprint of the ICT sector.

### 4.2. Smart cities

In 2010, IBM started an initiative called “Let's Build a Smarter Planet,” and announced “the decade for a smarter planet” [10]. Energy and water were named together as one of the seven core components of a smart city; the others are city strategy & administration, health care, education, social services, public safety, and transportation. IBM has produced a motto for energy: “Smarter power for a smarter planet.” The planet is becoming *smarter*: one way or another, almost everything makes use of intelligence. In other words, ICT is everywhere [11]. The manufacturing and use of ICT equipment have an associated energy footprint and $CO_2$ emission footprint [11]. The European Commission has started the ICT footprint initiative, which aims to find a global consensus in the ICT industry for a common definition and measurement framework.

Van Heddegem et al. [11] have classified ICT tools and services as follows:

a) Communication network
  - Access equipment on customer premises
  - Telecom operator networks

b) Personal computers
  - LCD (liquid crystal display) monitors
  - CRT (cathode ray tube) monitors
  - Laptops
  - Desktops

c) Data Centers
  - Servers