

# Desperately seeking energy efficiency ... using Information and Communication Technologies?

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**Abstract**—This paper provides a reflection on the potential contribution of scientific computing with a view to improving energy system efficiency. First, we will consider energy efficiency globally in order to evaluate its potential. We will then focus on electricity, since electrical energy is interpreted as the universal vector of work. This will give us the understanding we need for envisaging a more efficient energy system. The use of ICTs (Information and Communication Technologies) as a final solution for improving system efficiency should be reconsidered. The drain on energy resources that they entail can, in fact, outweigh the expected gains. Better management of existing energy systems should therefore be privileged via scientific approaches designed to envisage the rational use of energy.

## I. INTRODUCTION

Energy has become an essential factor in a global context exacerbated by the contrast between our “capitalist project, insane and with unlimited expansion<sup>1</sup> and our tendency to forget the physical limits of this expansion. This expansion comes back to us in the form of “numerous testimonies ... as if to prove that our development can’t hold up: the build-up of greenhouse gases, the irreversible erosion of the diversity of species, the spread of the deserts and varied types of pollution, all the worrying symptoms of the breakdown inherited from our carefree past” [6]. Faced with these irreversible upheavals, energy efficiency - which can be defined simply as the eradication of superfluous consumption - is not just a way of responding to environment and climatic concerns, but also to the prospect of the depletion of fossil resources.

## II. WHERE ENERGY EFFICIENCY LIES

To quantify stocks of energy efficiency, we must localise losses in the energy chain. An analysis [10] of the chain, linking the producer to the consumer through the transformation stages of primary energy<sup>2</sup> to final energy and then to useful energy, led to the following values for the year 2002:

- global primary energy consumption of 10.4 Gtep [12] for useful energy of 3,857 Mtep, equal to a global energy chain yield of 37%;

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<sup>1</sup>In the words of philosopher Cornelius Castoriadis’s

<sup>2</sup>It should be stipulated that primary energy is defined as extracted, final energy as produced in a form fit for commerce, and useful energy as that which is truly necessary when taking into account the best available technology.

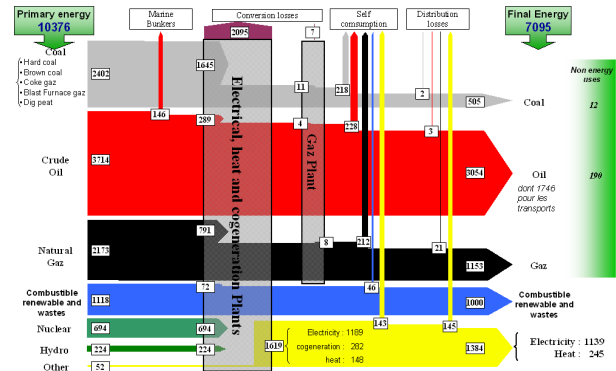


Fig. 1. Energy Supply Chain (World 2002): Electrical energy is severely disadvantaged by the efficiency of the Carnot cycle, transmission losses and applications’ lack of performance. As a result, the electrical vector’s efficiency is only 27%

- electricity’s share in the global assessment therefore accounts for 3,300 Mtep in terms of primary electricity and for 900 Mtep of useful electricity, equal to an electric yield of only 27%, making it inferior to the yield of the global chain.

The large amount of losses apparent throughout the energy chain can thus be taken as an indication of potential energy efficiency. For example, in France in the year 2000, the transformation yield from final energy to useful energy indicated that more than 45% of final energy could have been economized [19]. The main savings concern transportation, followed by residential and tertiary sectors, but it worth noting that over 30% of primary energy is never sold, since it is - lost before the meter -.

Moreover, to make an objective analysis of the economic, social and environmental indicators of sustainable development, the volume of accessible useful energy needs to be increased at the same time as minimizing the consumption of primary energy. It is particularly logical to exploit potential energy efficiency reserves, given the weak yields mentioned above.

Since the scenarios of increased demand on the 2050 horizon generally accept this growth hypothesis, they infer:

- the choice of an energy bouquet adapted to final needs;
- the needs to optimize the energy chain’s yield by at least optimizing network management, as we will discuss here.

It is therefore judicious to give the electric vector a preferential role. Among the reasons given by [10], the following three appear essential to us:

- electricity, which is unavoidable due to its specific uses

(and notably those linked to ICT), will have an increasing relative share in global demand as anticipated by prospective scenarios on the 2050 horizon;

- a recent interpretation [16] depicts electric energy as the privileged vector of energy domestication<sup>3</sup> ;
- an electric chain yield of 27% points to the largest potential economy.

For these reasons, the electric vector would appear to have the greatest potential for satisfying both demand and sustainability, as mentioned above. Although the “yield” of electric energy domestication appears to offer a valuable vector and usage of energy, it is a lot more vulnerable than other forms of energy, - i.e. more easily thermodynamically degradable -. Conversely, its optimization has superior leverage.

Among the optimization options explored, are:

- at usage level:
  - 1) the limitation of electricity usage and its specific uses;
  - 2) a reduction of the obsolescence of the end-use equipments, through DSM (Electricity Demand-side Management) and exemplary operations, which generates overconsumption estimated at 27% in France [19];
  - 3) the identification of optimizing final usages, by bringing them closer to the theoretical energy value of final services, and distinguishing those that benefit the most from a leverage effect, in order to privilege applied research initiatives.

The final point, when applied to ICTs, allows an estimation of their energetic impact (see section III).

- At production and transport level:
  - 1) a choice favoring renewable production in order to lower Carnot cycle weighting in the production of electricity;
  - 2) a choice favoring decentralized production to diminish transport losses;
  - 3) an optimization of the architectures and materials most likely to bring the electrical vector closer to an ideal performance.

All of these methods will nevertheless have to fit into a global optimization framework to avoid transferring pollution.

Since the main aim of network management is to balance supply and demand, it is imperative that it can satisfy calls on electrical power at any time in order to compensate for fluctuations in the electrical charge. There are two options:

<sup>3</sup>To stipulate what we understand by the interpretation of electric energy as the privileged vector of energy domestication: [16] shows that the best global transfer of mechanical power through the network is equivalent to the local laws of electromagnetism. This means that for a given architecture, the distribution of the currents and electrical charges evolves to:

- achieve optimum production in regard to consumption or, equally, minimum loss in value (heat);
- guarantee optimum reversibility between mechanical power consumed and produced throughout the network.

Electric energy thus displays the same “thermodynamic quality” as mechanical work. Its specific usages give it a universal value, in other words, the very highest added value.

- 1) investments in permanent production and supplementary transport capacities. These create an oversizing of the global system, and make it possible to respond to power demands. In fact, for a given geographical distribution of loads and generators, as the meshing of the grid increases, the Joule losses decrease, the voltage profile improves and the system becomes more stable. Moreover, if installed generation capacities increase, there are similar benefits for the power system, which shows that over-investment could lead to reduced losses;
- 2) a reduction in the level of reactive power and kinetic reserve (and associated over-consumption and over-investment). This can be achieved, by choosing a system for managing existing capacities that is dynamic, flexible and spatially precise. It should aim to satisfy active power needs by means of intelligent regulators and rush capacities set into the network without - compromising the quality of the electric energy supplied, namely its frequency and voltage. This is probably the most appropriate moment for evaluating the contribution of ICTs, and in particular their system checking/ordering/monitoring qualities (see e.g. [26]).

Which of these two options constitutes the best method of convergence towards energy efficiency?

Current network architectures tend to correspond to the first option, with performances and reliability/quality as mentioned above. However, as a first step towards finding a solution, it is worth considering the necessary scientific and technical developments for making the second option a strong and efficient one. Among the numerous approaches that come under scientific computing and that we propose putting into use, the following are worth mentioning :

- modelling and optimization<sup>4</sup> are necessary steps in the development of these procedures. In allowing a better physical understanding of these machines, they contribute to technological improvement and innovation [13];
- the particular methods for creating reliable regulators for modelling, validating and optimizing a multi-energy system [22], [20];
- monitoring, using a platform for the management and dynamic adaptation of components<sup>5</sup> [3].

The prerequisite of these various approaches is that they should take into account the energy efficiency stakes that we have described, and that they should do so in a global way that

<sup>4</sup>Mathematical tools such as sensitivity analyses mean that dynamic function templates can be created by establishing the influence of physical or conception parameters on the machine’s energy results.

<sup>5</sup>Despite the evolution of software programs designed to simplify the development of embedded systems, they have proved inadequate in situations where equipment might spontaneously appear or disappear, such as in domotics and BHTs (high-technology buildings) -(study in collaboration with the CSTB (Scientific Centre for Building and Civil Engineering) in Sophia Antipolis, France) -. Since the programs are designed as a combination of components, their adaptation involves a dynamic modification of these combinations, according to pre-defined set-ups linked to the spontaneous appearance or disappearance of certain components and according to user needs and context of use (BHT example: energy management strategies in domestic usage). Our method facilitates the expression of the adaptation of these programs at a declaratory level in the dynamic management platform of the Womp components.

allows for the development of standard tools for optimizing all of the systems.

A second step towards a solution is to take into account the Life Cycle Analysis. This is because it is a vital factor in the mediation between the demand made on reactive power production and kinetic reserve means and the capacities of rush-production and monitoring for a given level of reliability and availability. In fact, both the over-sizing of installations and Joules losses must be taken into account through monitoring and watching over rush-production capacities, as well as their (initial) energy content. The energetic materiality of ICTs must also therefore be envisaged.

Hereunder, we provide some keys to finding a solution.

### III. THE ENERGY MATERIALITY OF ICTS

It cannot be denied that the use of ICTs, either for network management as previously envisaged, or for the management of any other type of system, can bring solutions that aim at making more rational use of energy. However, it is important to mention once more that the impact of ICTs, particularly in terms of energy consumption, must be evaluated globally, i.e. with a Life Cycle Analysis approach.

Numerous studies have looked at the role of ICTs in improving traditional energy efficiency, notably in the United States, and have argued for structural dematerialization<sup>6</sup> [21]. However, authors frequently warn against the over-optimistic in the use of ICTs, whose energetic materiality is proven [7]. They point out for example, that the impacts of ICTs are widely controversial, particularly in the US, and state:

“Analysis of the American economy’s “dematerialization” is misleading. Unlike Europe and Japan, the United States did not undertake any large-scale energy saving programmes in the 1970s. Given this, the country now enjoys considerable potential energy savings, which it has begun to explore since the Kyoto agreement on climate change. The improved energy intensity indicator, often the subject of American studies, does not necessarily imply the transition towards a new economy based on ICTs, which use less energy and matter. It is rather a reflection of the setting up of traditional energy saving programmes. We should therefore be wary and not come to hasty conclusions.”

Today, energetic materiality linked to ICTs is apparent in the rise in electricity consumption specifically linked to their usage. All agree that the use of Internet and increased levels of equipment linked to information and communication lead to considerable consumption surpluses. In order to better anticipate this energetic impact, we will break down ICTs into components (DRAM, microprocessor, etc.), devices (PC, console, etc.) and usages (on-site measurements (Data-Center) and Internet).

The energy value of the components can thus be evaluated via:

<sup>6</sup>This is the definition as used in [7]. Most environmental problems stem from a material and/or energy flow that comes from a natural resource. As an illustration, the production and consumption of fossil energy are responsible for the greatest proportion of emissions, which are themselves responsible for urban atmospheric pollution and the bulk of greenhouse gases. Dematerialization aims to reduce these flows in order to limit the negative impact on the environment, while limiting the usage of natural resources [11].

- the electricity consumed by computer microprocessors in the United States ten years ago, adding up to 13% of global electricity consumption [17];
- the fact that the American semiconductor industry, one of the highest electricity-consuming industries in the world, has become the biggest manufacturing sector in the United States since the start of the century, with an annual turnover of US\$ 50Billion [17];
- the electricity consumption of microprocessors - is increasing in power according to Moore’s law - and is rising sharply in relation to their physical volume [24][14].

Several studies allow a breakdown of consumption levels linked to the use of an average computer and its peripheral:

- losses linked to electrical consumer goods left on standby mode in the home (of which personal computers account for an increasingly large share) represent between 5 to 15% of residential energy consumption [2];
- for the ADEME (rench Agency for Environment and Energy Management), the consumption linked to use of a PC is estimated at 0.9MWh/year [1]. This figure is probably under-estimated for homes, where PCs are older and broadband connections are on the rise;
- [7] indicates typical consumption of around 150W for a personal computer of average power;
- electricity intensity in France is growing with the use of computers [4].

Using these values, we can quantify the implications of ICT-linked usage in terms of electricity consumption. We can attempt to evaluate the consumption of equipment linked to the Internet: by considering  $10^9$  households (residential in the developed world and possibly in the emerging, even tertiary, world), we can introduce over-consumption of around 1000TWh/year. To this must be added the energy necessary to produce the PCs, which is approximately 10% of current electricity production.

This empirical calculation comes close to the analysis of [17], taken up in [7], which indicates that (in 1999) the level of electricity consumption linked to Internet use was equivalent to 8% of the total electricity consumption of the United States.

Lastly, it is worth remembering the Californian electricity crisis, which was the result not only of market manipulation following deregulation, but also of an increase in electricity consumption, corresponding to the height of the Internet bubble in Silicon Valley [6].

At his point, let us consider the architecture of the Internet network, for which computers [17] require a range of electrical devices to push, amplify, transmit, receive, drive and control bits, thus creating an “echo effect” never before seen in the evolution of electricity usage. It is, in fact, pertinent to point out the architectural similarity between this network and an energy surveillance monitoring network, with all that this implies in terms of electricity consumption.

In this case, the use of electricity, not for service ends, but for the monitoring of its own distribution network, would be at the same levels as current auto consumption (10%), taking into account the performance levels of current technologies. And this makes it indispensable to include it in the architecture of

the Life Cycle Analysis, with an emphasis on ICT monitoring qualities.

#### IV. CONCLUSION

The materiality of ICTs, is proven, but now how can they be used to lead to greater energy efficiency?

It should be recognized that without ICTs, it is probably not possible to optimize, either products, or energy flows.

However, there is a risk that their irrational use might lead to a counter-productive energy equation.

ICT energy efficiency must therefore be improved (there are lines of research being developed, for example, on memory performance [5][8]), as must energy domestication techniques. It is, however, probably appropriate, to target coherent initiatives of which the primary goal is to quantify energy stakes.

- Here we come back to questions about the theoretical energetic value of the manipulation of one bit of information, which is at the basis of ICT functioning. In theory, its value cannot be nil, since the bit-flip corresponds to a reduction of the missing information, and, in respecting the second principle of thermodynamics, the entropy cannot be reduced without spending energy [9]. The necessary reflection on this subject, which is of a fundamental, - even philosophical -, nature, should be compared with the current consolidated consumption of a Gflop [18]
- ICT energy efficiency, by acting both on a usage which is at the base of economic growth, and on a technology that is set to become an integral part of a "universal" energy network, would have a considerable leverage effect and optimization, resulting in perhaps the most efficient reserve of sustainable growth;
- This problem is not a new one, since it prevailed in the development of micro-electronics in the 1960s, along with other requirements such as reliability, cost, compactness and rapidity, [23]: at the time 15MW (final) were needed to undertake  $10^9$  binary operations.

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