Infrastructure of the information society and its energy demand

Laetitia Souchon
Ph.D Candidate INT/ETOS - France Telecom R&D
France
laetitia.souchon@orange-ftgroup.com

Bernard Aebischer
ETH Zurich, Centre for Energy Policy and Economics (CEPE)
Switzerland
baebischer@ethz.ch

Jacques Roturier
Professor Emeritus (retired from University of Bordeaux)
France
jacmon.roturier@laposte.net

Fabrice Flipo
INT/ETOS
France
fabrice.flipo@int-evry.fr

Keywords
ICTs, telecommunications, internet, energy demand, digital divide, sustainable development, use substitution, dematerialisation

Abstract
Energy demand of ICT end-use equipment, like personal computers, is considered a potentially important topic for almost 20 years. Policy measures, like the Energy Star Label and worldwide campaigns for low standby consumptions, are now successfully implemented in order that the energy demand of ICT end-use equipment is not growing uncontrolled.

But what about energy demand of the infrastructure needed to make use of the ICT end-use equipment? Some previous work will be reported in the field of voice centric telecommunication indicating that energy demand of the infrastructure is growing much faster than energy demand of the phone and reaches for mobile communication up to 90 % of total energy demand. Regarding the infrastructure for internet, a much more complex issue, the energy demand data, as found in the literature, are rather uncertain and partially contradictory. The fraction of energy demand for the infrastructure is probably today of the order of 30 % while mobile communication and other trends being expected to steadily increase then installing the infrastructure as the most important element of future energy demand of ICT.

In the present paper, a brief survey of several analyses of the energy demand of the infrastructure for ICT is given in section 1. In section 2, preliminary results of ongoing research presently performed by one of us (LS) in the framework of a France Telecom R&D Programme are presented. Finally, section 3 broadens the problematic to the interaction between ICT and contemporary societal and ecological contexts, as they are interlinked.

Introduction
The two major events recently organised by the United Nations entirely or in part on the African continent, namely the World Summit on Sustainable Development (SMDD/WSSD: Johannesburg 2002) and the World Summit on the Information Society[1] (SMSI/WSIS: Geneva 2003- Tunis 2005) have explicitly focussed on the challenges that the humanity is facing with during the third millennium. After Kofi A. Annan, the Secretary General of the United Nations[2], everybody recognizes that the "Digital Divide" is certainly ranking in the top five with energy conservation, water supply, climate change, food for all. However, in order to successfully win such "Digital Divide" challenge, there are some obstacles that are not commonly underlined and/or frequently ignored. In the present paper we propose a preliminary analysis of one of these: the electricity demand of the Telecoms sector (Internet, mobile phones...). We are not intending here to do it on a per equipment basis, this having been demonstrated in the last 20 years by several scientific teams including two of us (B.A., J.R.), which is the visible

1. More information published as part of conclusions of the WSIS may be found in the "Geneva Declaration" (http://www.itu.int/wsis/docs/geneva/official/dop-fr.html) and in the "Tunis Agenda for the Information Society" (http://www.itu.int/wsis/docs2/tunis/off/6rev1-fr.html)

2. Part of his message to World Telecommunications Day, 2004: "Today, numerous people could not conceive of their daily lives without ICT, ever more sophisticated, whether television, radio, mobile telephones or Internet. And yet, in the poorest countries of the world, millions of people experience the repercussions of a "digital divide" that deprives them of the advantages presented by ICT…."

part of the Iceberg[3]. Oppositely, we are concerned by its hidden part: the infrastructures and its electricity demand.

Then, our modest contribution to increased knowledge of this topic is a brief presentation of the stages in the emergence of the issues. The results and conclusions summarised in the present paper are based on a number of initiatives and analyses in the fields of energy and environment. A brief survey of several analyses of the energy demand of the infrastructure for ICT is given in section 1. In section 2, preliminary results of ongoing research presently performed by one of us (LS) in the framework of a France Telecom R&D Programme are presented. Finally, section 3 broadens the problematic to the interaction between ICT and contemporary societal and ecological contexts, as they are interlinked.

BRIEF SURVEY OF RECENT STUDIES POINTING OUT THE ENERGY DEMAND OF THE INFRASTRUCTURE ISSUES FOR ICT

A preliminary version[4] of the present work, facing a few technological, industrial, and social issues of the Information Society has been given by two of us (B.A., J.R.). Actually, the technologies supporting this Society are including both a visible face – machines such as PCs, televisions, mobile phones which are used on a daily basis – as well as a hidden side: the networks which enable the distribution of electricity and of telecommunications necessary to the interconnected functioning of "individual" technologies. It should be noted that other "infrastructures" as requested by the whole Internet economy, such as e-commerce, e-medicine, and telecommuting that are not ignored, remain out of the scope of the present work.

When only first-generation computers were considered, with local usage, the problem of infrastructure was less complex: by the 1960s, computers had become indispensable administrative tools, but the infrastructure upon which they relied was limited to the building in which they were placed, with a few additions: an electric cable guaranteeing an extra 100 to 1 000 kW, an emergency supply, an air-cooling system and an imposing array of capacitors to balance reactive energy. Such demand in infrastructure was not exceptional, whether at the individual building or at the industry level. Oppositely, when computers began to communicate with one another in the 1980s through the telephonic network, the limits to the speed of electronic transmission became evident. For example, telephone landlines constructed underground have already been made obsolete by fibre-optic cable, wireless, and satellite technologies. Nowadays, there is hardly an industrial or commercial or domestic equipment, which does not contain a microprocessor capable of using / providing resources to the Information Society. It is now time to regard with a more powerful attention, in order to optimize it, the triptych: computer' use, electricity grids, telecommunications networks. Of course, the transition between ICT utilization and the Information Society raises other questions than the ones put forth here where, for example, the use and maintenance of the triptych's elements should naturally play a central part. In this vein, if any user is able to note changes in his/her own environment (business or home), it is more difficult to have a more global vision of the infrastructures of information. Then, to clarify our own approach, these infrastructures are defined as "the set of technologies and the devices that encase them, systems supplying electricity and telecommunications grids which link two or more participants through the emission, the wired or wireless transmission, and the reception of digital signals, encrypted or not, which transform these signals into a format that is comprehensible to each system and/or user."

Three facets of the infrastructure for ICT

Here we present three examples in order to illustrate different approaches to define the infrastructure for ICT and to provide a brief quantitative overview of some of the resulting consequences.

The supply of electricity

Each of the parts of the infrastructure of computing, in most instances, consumes electricity directly supplied by the electric grid, including the batteries of portable devices that are to be recharged from the grid as well. Schematically, the supply of electricity is transmitted from the medium voltage grid to the electronic circuits and to the storage medium inside the ICT-equipment[5] in several stages:

- A transformer lowers the voltage to 240 V (local electricity grid in Europe)
- An AC-DC converter switches the AC current to the DC one
- A DC-DC converter adapts the voltage requested by the appliance

Two additional mechanisms, used in larger office environments, should be cited:

- A UPS guaranteeing uninterrupted power
- A cooler to maintain a constant temperature

As well known, the relative contribution of truly "useful" electricity, the part consumed by the "final" electronic circuits (processors, memories, networks, and other modules contributing to the function of "computing") is significantly weaker, at most equal to a third of that which is distributed by the electricity grid. The subsidiary loss and/or consumption is not negligible (Aebischer et al. 2003):

- 50 % is lost in the transformation from 240 V AC to 1.5 V DC,
- 20 % is utilised for temperature control by internal ventilators,
- 50 % additional is used to cool the local air, and

3. See for example the booklet published by the IEA: Things That Go Blip in the Night (OECD-IEA Publications 2001)

4. A more complete version of the present introduction and section 1 has been published by two of us (BA and JR) in a paper as part of the volume « Infrastructures et Energie » edited by the CUEPE (University of Geneva) in their series «Energie, Environnement et Société»

5. We consider power supplies (AC-DC transformation) and DC-DC converters as well as fans and other devices to evacuate heat inside the ICT-equipment as part of the infrastructure needed to get the "useful" electricity to the "final" electronic circuits (processors, memories, networks, and other modules contributing to the function of "computing").

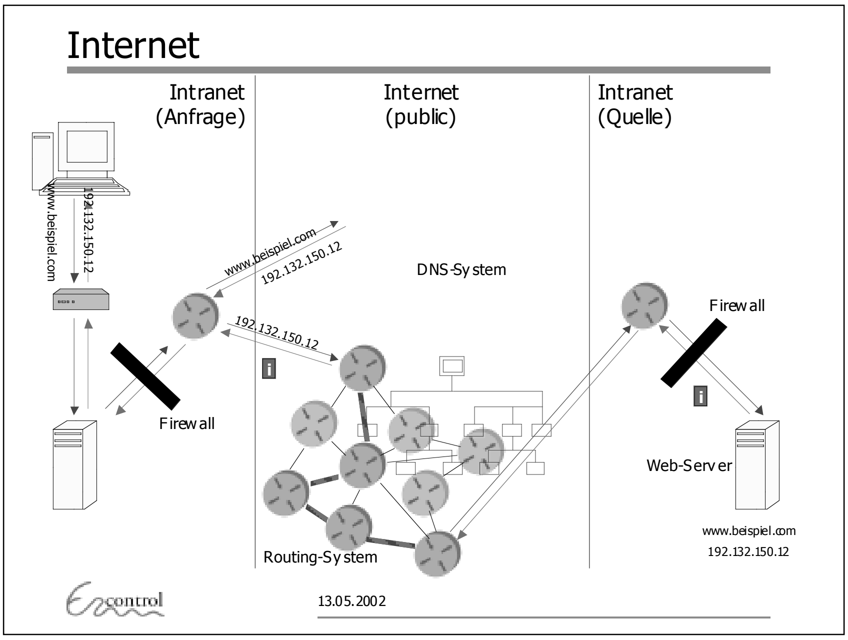

Figure 1. Infrastructures: Intranet and Internet (Aebischer et al., 2003).

- add another 30 to 40 % to account for imperfections in the output of UPS (Beyrand et al. 2004)

Inter- and Intra-Net grids

Today, using the Internet is child's play, but behind what the end user sees is a system of some complexity, as is indicated in figure 1. A professional end user is only rarely directly linked – by means of an Internet "provider" – to the web, but all information passes through a server or a suite of servers which assure the right of access. The transfer of information on the Internet takes place principally through wires and cables, but transmission through hertz waves is becoming more and more common. An analogous structure exists on the receiver side. The structure of the Internet is composed of the physical infrastructure necessary to transmit information between the two intranets, and of a coherent substructure ensuring optimal transport of information so that it arrives at its destination. In figure 1, the logical architecture is sketched schematically as the DNS (Domain Name System), a series of servers and software which translate a URL address to the corresponding IP address it must be reminded here that the control of the code and logical infrastructure of the Internet was a hotly contended point in the preparatory work for the WSIS. The physical infrastructure consists of the "routing" system (servers, hubs, capacitors, etc.) and of the transmissions network discussed in the next section. In general, information is not transported by the shortest possible route. Transmission at the speed of light, when set aside terrestrial distances, renders electronic distances practically negligible compared to the transmission capacity, which usually determines the total transmission time. It is not hard to believe, then, that a message from Zurich to Bordeaux passes through Geneva, Frankfurt or London and Paris (and why not the United States?). Along the way the information packets are processed by tens or hundreds of electronic devices (servers, routers, repeaters, switches). Each of these electronic components has a power on the order of 1 to 10 W. The time of transmission, on the other hand, is on the order of a thousandth or millionth of a second, and so the energy value is on the order of 10^{-5} to 10^{-8} Wh. This order of magnitude looks significantly smaller than the energy consumption of the end user. But in this estimation we have forgotten that all these tens or hundreds of servers, routers, repeaters, switches and others have to be ready all the time to process and transmit immediately any incoming information packet. During that standby-time the power drawn by the equipments is probably for most of them as high as during the actual processing time. And this standby time is certainly many orders of magnitude higher –especially during periods of low data flow. The simple calculation above is therefore not appropriate to evaluate energy demand of the infrastructure of the internet.

Local and Distant Transmission Networks

This third example concerns the local and long-distance transmission grids. The grids can be differentiated in large strokes by the type of support (wires, fibre-optic, wireless) as well as by the distance of transmission. Information is transmitted over long distances through fibre-optic cables. The emergence of the Internet and the explosion of demand for the transmission of information sparked enormous investments to link together hubs in the United States, Europe and Asia and on other continents. Less-developed regions are connected by traditional telephone lines as well as by satellite, with transfer capacities markedly inferior to those of fibre-optic cables. The control of long-distance transmission networks, which falls into the hands of a small number of companies, is not discussed in the framework of WSIS. Local transmission, from larger enterprise to service provider, is still partially conducted across telephone lines, but more and more fibre-optic cables are being used. Recently, wireless transmission has gained a foothold in offices, homes, and public or semi-public spaces such as airports, train stations, hotels and restaurants and, in Switzerland e.g., more that 700 - Wi-Fi / WIMAX Points (hot spots) are already in

Table 1. Fraction of electricity demand of terminals and of infrastructure for different technologies (Faist et al., 2003)

	UMTS	GSM (with optimised charger)	GSM	stationary phone
2 phones	9%	25%	49%	39%
infrastructure	91%	75%	51%	61%

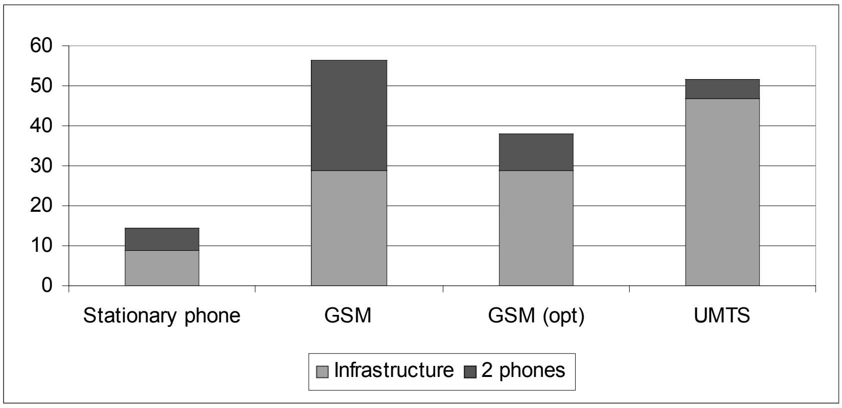

Figure 2: Specific electricity demand for information transmission of different technologies, in kWh/Gbit (Faist et al., 2003)

place. One wonders if this need to access the Internet at all times and in all places will now require infrastructure to widen the computer's omnipresence ("mobile computing"), similar to today's wireless telephone, or if a common infrastructure for the computer and the telephone will be possible. In this vein, to examine the environmental impact of the mobile telephone, Faist et al. (2003) studied in depth the infrastructure of the new UMTS system, considering in particular broadcasting stations: authors conclude that, requiring a portion on the order of 80 percent of the total, these stations dominate electricity demand, due essentially to the increased efficiency of mobile telephones and chargers.

What do we read about energy demand of the infrastructure

In the majority of studies of the energy demand of ICT products, the energy demand of infrastructure is not explicitly evaluated. In general, a part of this infrastructure is included, for example the servers used to access the Internet or that serve a programming platform; but the infrastructure that assures the distribution of electric current and the air conditioning coolers also constitutes the materials of the Internet and of the long-distance transmission network which are often "forgotten."

Mobile communication

Several studies analyse the life cycles of the entire system of "mobile communications," including the terminals, base stations, grids and administration. The results, however, are rarely presented in a manner that allows the analysis of each element's electricity consumption independently. Moreover, the definitions of these elements differ considerably across studies. Finally, rapid technological evolution makes a solid comparison between studies very difficult. For example, the consumption of a 1996 GSM unit was four to five times that of a system made in 2001. From 1996 to 2001 the electric power of the mobile unit was cut in half both in active and standby modes and, at the same time, the mean efficiency of the charger-battery combination increased roughly from 5 % to 11 % (Cremer et al. 2003, p 129 ff). The evolution of specific electric consumption by infrastructure, as Ericsson 2001/1 and 2001/2 notes, is much slower, and the correlation between demand for electricity by the terminal and infrastructure diminishes quickly for any given technology, for example the GSM (holding the number of machines and time of usage constant). With the emergence of a new technology (UMTS) this correlation, which depends on a multitude of factors (ratio of usage to the capacity of the system, energy efficiency of the units), can increase or decrease. Faist et al. (2003) show that the share of the end users diminishes from GSM- to UMTS-technology (see Table 1). New mobile technologies do not necessarily reduce the portion of electricity demand exerted by the terminals as observed in table 1 (for the UMTS and GSM systems it is assumed that the same quantity of information – 1 GB – is transmitted). The comparison of "GSM" to "GSM optimal charger" illustrates that the correlation between electricity for infrastructure and for terminals is very sensitive to the technical characteristics of the different machines. In sum, with regard to mobile telephones, the infrastructure-related portion of total electricity demand is, considering all of the above studies, at least half of the total demand for mobile communication.

The electricity demand per Gbit for new technologies continues to rise from stationary telephone to GSM and to UMTS, if we exclude the case of GSM with an inefficient charger (figure 2). Yet another, and surprising, result is seen in this figure: UMTS infrastructures consume more energy per Gbit than those of GSM, while UMTS terminals consume less.

Internet (use of PCs online on the Internet)

Several studies have evaluated the electricity demand of the Internet and its corresponding infrastructures. Two methodological problems have arisen:

1. Determining the portion of total demand that can be attributed to PCs accessing the Internet

Table 2: Estimations of electricity demand for the Internet in Germany (Türk, 2001; Barthel, 2001)

	Fraction of total electricity	Electricity demand of Internet, in TWh/a	Fraction consumed by end-user (PC)	Fraction consumed by provider	Fraction consumed by network
Türk_max	1.7%	8.1%	5%	90%	5%
Türk _min	0.5%	2.3%	34%	56%	10%
Barthel_1	0.9%	4.2%	40%	26%	33%
Barthel_2	1.5%	7.3%	41%	26%	33%

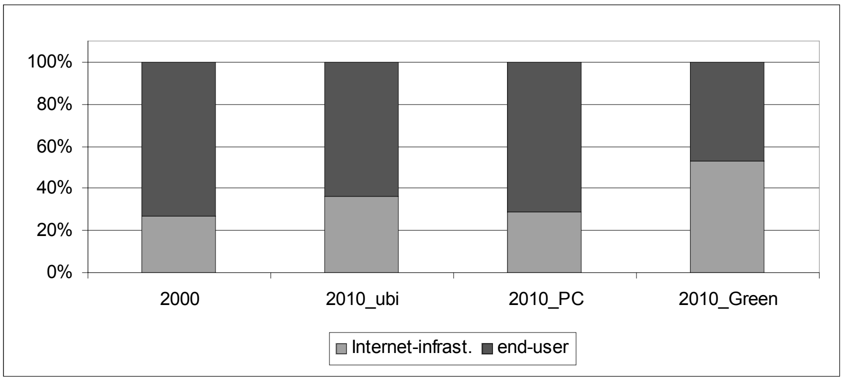

Figure 3: Fraction of electricity demand of terminals and of infrastructure in the year 2000 and in 2010 for different scenarios (Roth et al., 2002; Roth et al., 2005)

2. The quantification of the energy demand of the infrastructure.

With regard to the demand of PCs: Türk (2001, pages 54-55) uses 28 minutes per day for the average user, while Barthel (2001) and Mills use periods between 1 and 10 hours per day.

With regard to the demand of the infrastructure:

1. For the infrastructure (not including the grid): Türk uses the total demand of electricity of all servers in Germany (an estimated 2.8 million). Barthel puts this estimate at 1 million, as does Koomey who, however, departs from the hypothesis that a web server hosts an average of five websites.
2. In terms of grids: Türk attributes a third of electric consumption of Deutsche Telekom (fixnet) to Internet traffic. Based on estimations by Mills for United States routers and telephone centres, Barthel reduces these figures by a factor of 5.

Armed with these estimates, Türk and Barthel deem the portion of electricity devoted to the Internet (including end users) to be between 0.5 % and 1.7 % of total demand in Germany. The infrastructure component is, as for mobile telephones, on the order of 60 % to 95 % (table 2).

Infrastructure for ICT, including mobile telephones and the Internet

Roth et al (2002) as well as Cremer et al. (2003) compare the total energy demand of PCs with that of the infrastructure of the Internet. Because of the difficulty of quantifying the percentage of time spent online by individual computers and the trends towards constant Internet connection, the studies do not estimate the portion of energy required by PCs connected to the Internet.

- United States: Roth et al. 2002 and 2005

PCs and monitors, representing about 40 percent of total electricity demand of the ICT machinery in the non-residential sector, are the largest portion of this sector. Hardware used in the Internet infrastructure, for example in servers, computing and telecommunications networks, is the second largest, comprising for about 30 percent. In figure 3, the electricity demand of these infrastructures is compared to that of PCs and monitors in both the residential and non-residential sectors. Today, these infrastructures use 27 % of the electricity of PCs and screens. According to Roth et al (2002) the infrastructure demand will increase noticeably through 2010. The biggest increase is seen in the "Green" scenario, in which the consumption by computers declines the most. In the two other scenarios, the demand of electricity by terminals (PCs and monitors) remains greater than that of infrastructure. We note also that energy used for air-conditioning is not accounted for in these scenarios.

It seems clear that the growth of electricity demand of PCs and monitors in the residential sectors mirrors the one in the commercial sector. Servers remain the largest energy consumers in infrastructure in all scenarios except for 2010_PC, where UPS (uninterruptible power supplies) becomes dominant.

- Germany: Cremer et al., 2003

"In-house" and "Public" infrastructures

In order to evaluate the energy demand of ICT, Cremer, Aebischer et al (2003) divided the principle hardware equipment of ICT into four groups, as indicated in table 3. Two categories qualify as "infrastructure": "In-house" and "Public".

Cremer presents estimates of future electricity demand of each of the 2 categories of infrastructure. In figure 4, the share of total infrastructure (in-house and public taken together) relative to the total electricity demand of ICT rises to 29 % in 2001, an estimate very close to the one derived by Roth (restricted to PCs only) for the US. The share rises to 42 % in 2010

Table 3: Classification of ICT equipment (Cremer et al., 2003)

	End-use appliances		Infrastructure in-house		"Public" Infrastructure
	Household	Offices	Household	Offices	
Entertainment	Audio, video	Cameras, Telephony: fixed network and mobile PC and office equipment	**TV reception Internet-access; Telephone system**		
Communication	Telephony: fixed network and mobile			**Networking; Telephone system**	**Fixed network; mobile communication**
Data processing	PC and peripherals			**Servers, UPS**	**Data Centres**
Intelligent home	Many divers		**Networking**		

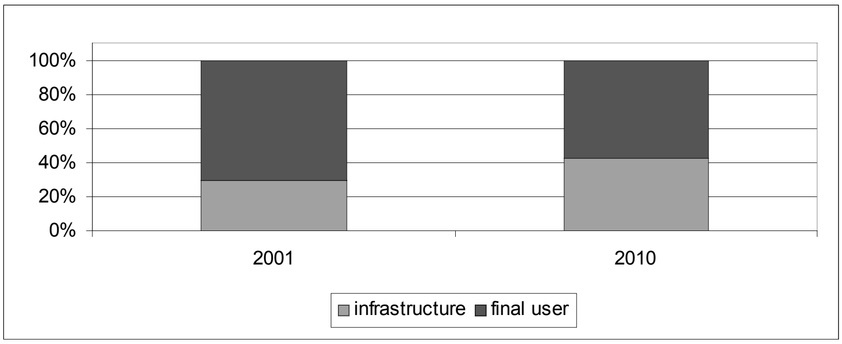

Figure 4: Fraction of electricity demand of final users and of infrastructure of total ICT in the residential and service/commercial sectors in 2000 and in 2010 (Cremer et al., 2003)

(in 9 years!). The rate of growth of electricity demand in various subgroups of infrastructure ranges from 7.3 % per year for home-use to 11 % for public elements of infrastructure. This rise is due in large part to digital television technology, which requires descramblers and adapters, as well as the diffusion of third-generation wireless telephones (UMTS) through public infrastructure. We also note that in the "service sector infrastructure" sub-group, servers represent the most significant part of the growth in demand, due to the double effect of the strong growth in number of servers and of their per unit consumption.

An unknown portion of these servers is used in "Data Centres" [6], which raises a still-unresolved question: does this centralised infrastructure lead to greater efficiency in energy? The answer depends on the efficiency both of electricity supply, transformation and distribution on one side and of energy devoted to cooling. In Switzerland, this point is essential, as regulatory guidelines in the canton of Geneva mandate a stabilisation of consumption at 1990 levels. In order to bring about this goal, the Energy Department has defined a simple indicator, C1, to measure energy efficiency:

C1 = (electricity consumption by ICT hardware) / (total electricity consumption by the "Data Centre")

In a first stage, the minimum values of C1 required for construction permits as well as to assess consumption were obtained by modelling. The values suggested to the administration of the Canton of Geneva are a C1 above 0.65 for all future "Data Centres" and above 0.55 for existing data centres (Aebischer et al, 2003). More information about energy efficiency in data centres can be found in Aebischer, Eubank and Tschudi (2004).

6. See the recent study who estimates total power consumption by servers in the US and the world (Koomey, 2007)

PRELIMINARY RESULTS FROM FT R&D

Structure of ICT energy consumption: why are the results divergent?

Section 1 set out an overview of studies about ICT energy demand, and we are focusing in this section on a specific aspect: the question of the energy consumption structure of the ICT currently in use. This question raises various issues, and in particular the problem of allocating shares respectively to network infrastructures and terminals. If results differ from one study to another, it is for the reasons listed below.

1. The choice of perimeters selected by the authors.
Depending on the studies, the perimeters can be divided into:

- 3 types of sectors: Internet, mobile telephony, and more generally ICT
- 3 types of uses: professional, residential and industrial.

Example: While Roth focuses on ICT for professional use (Roth et al., 2002), Türk chooses the Internet infrastructure (Türk, 2001).

2. The equipment considered, particularly in the "network" part.
The list of equipment considered in the "network" part varies from one study to another. No convention or definition has been accepted by all the players to designate what this part represents, as shown in Table 4 which compares the items considered respectively by Roth et al. (2002), Cremer et al. (2003), and Kawamoto et al. (2001) for their "computer network" part.

3. Non-availability of data
The data required for carrying out this type of study, like the number of servers or routers for a country, are often not known (because the data is non-existent or confidential). This explains,

Table 4: Items included by various authors in their "computer network" part

Items included by Roth	Items included by Cremer	Items included by Kawamoto
Servers	Servers	Servers
LAN and WAN (Local and Wide Area Network) switches	Switches	LAN and WAN switches
Routers	Routers	LAN and WAN routers
Hubs	Hubs	LAN equipment: Access Device (Access concentrators and access servers) Hub (passive hubs and switching hubs)
UPS (Uninterruptible Power Supply)	UPS	
Modems/RAS Cable modem termination systems (CMTS).	DSL connection	
	Data Centres	

in the Türk study, the creation of two scenarios for the extreme cases (cf. section 1).

4. The absence of a link between the kWh observed and the uses which generate them.
A rapid review of uses clearly shows that the consumptions generated vary sharply, depending on geographical location (town, city), the user's age or the rate of equipment renewal. In general, existing studies use aggregations based on very general hypotheses about uses. Kawamoto for example defines an average use for each type of office equipment considered.

Other items which may be behind divergent results, such as the comparability of national networks which are not strictly identical, seem in our view *a priori* relatively insignificant.

The case of the Orange study

Objectives
Through our study at the operator Orange France, we are aiming to meet the following objectives:

- to provide information for the 3rd point relating to the lack of data
- to take finer data about uses into account
- to throw light on to the questions of perimeter and definition of network and terminals
- to quantify the impact of ICT at operator level, and then, by extrapolation and aggregation of auxiliary data, at national level (France).

The originality of our approach is to attempt to couple uses and consumptions, and thus provide information for point 4 presented above. We will base consumption measurements on existing sociological studies so as to start up a discussion, at a later stage, about use substitution and dematerialisation.

Methodology
In the current state of the study, we have, on the network side,

- established a cartography of equipment by delimiting 3 perimeters:
  – fixed telephone network equipment
  – mobile telephone network equipment
  – computer network equipment
- quantified the energy consumption of each group of equipment using internal measurements and reports.

On the terminals and users side, we will restrict the study initially to residential use, as reliable data is available. A study under way about the consumption of energy linked to communication practices in households will enable us to establish standard use scenarios. The consumptions generated by these various scenarios can thus be compared with the network consumption figures per user.

Initial results
The cartography of equipment, listing the items taken into account in our study, is presented in Table 5.

In the first stage, we carried out an energy balance in order to quantify the total consumption of the operator studied. In 2006, this electricity consumption amounted to about 1800 GWh; the breakdown between subsectors is given in Figure 5.

The second stage is under way, in particular the extrapolation of the consumption of Orange and the work on the uses presented above. The results will be set out at a later stage.

INTERACTION BETWEEN ICT AND CONTEMPORARY SOCIETAL AND ECOLOGICAL CONTEXTS

Due to heavy energy issues (climate change, oil depletion, nuclear risks and radionucleides dissemination etc.), the ways in which ICT make energy consumption change is an issue of considerable importance. The relationship between the deployment of ICT and the environment has been addressed in an OECD study (Berkhout & Hertin). This study distinguishes between several levels of expected impact, as shown in Table 6, and expresses hopes and fears rather than presenting quantified and identified effects.

After considering first-order effects in the energy field, we will now provide a brief overview of second and third order effects.

Use substitution and dematerialisation

The goal of the European Sustainable Development Strategy is to break the link between growth and deterioration of the environment (p. 12), and this is one of the meanings of "dematerialisation". *"Dematerialisation is the reduction of the input of material flows in the operation of the economy, or the transformation of the functioning of the economy into a process which is less dependent on materials extracted from the natural environment"*

Table 5: Cartography of equipment of the operator Orange

	Fixed telephone network	Mobile telephone network	Computer network
Network "specific" equipment		Base station (BTS and NodeB)	DSLAM (Digital Subscriber Line Access Multiplexor)
		Base station controller (BSC and RNC)	ATM and IP networks: NAS and BAS (Network and Broadband Access Server), routers, switches, brewers
		Mini racks (repeaters and sites micro BTS / Node B)	High data access network for companies
		Network and Switching Sub-system (MSC, HLR, VLR…)	MDTN equipment (Multiservice Digital Telephonic Network)
Common equipment and infrastructure	Data centres	Data centres	Data centres
	Transmission Network	Transmission Network	Transmission Network
	Public telephone network switches	Public telephone network switches	Public telephone network switches
	Tertiary sector	Tertiary sector	Tertiary sector
		Switches and routers (Packet switching)	Switches and routers (Packet switching)

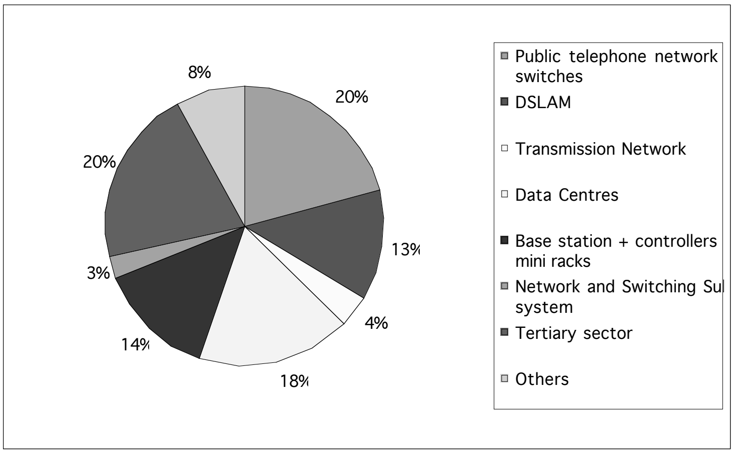

Figure 5: Energy breakdown of Orange consumption by subsector

Table 6: Impact of ICT on the environment. (Berkhout & Hertin, 2001).

	Positive impact	Negative impact
First-order effects	Environmental applications of ITC such as monitoring	Ecological impact of ICT production, such as WEEE
Second-order effects	Dematerialisation, structural change such as electronic administration	ICT products are added to existing products
Third-order effects	Change in lifestyles, such as "green" consumerism	"Rebound effect" such as growth in long-distance travel

(Haake p. 52). More empirically, studies on the link between growth and pressure on resources and on the environment have sought to show that beyond a certain level of wealth, economies experience a "point of inflection" beyond which pressure ceases to grow and on the contrary begins a salutary process of decline, with in the background the idea of reaching complete tertiarisation ("Kuznets curves" – Zuindeau, 1995). This view forms part of a continuous "developmentist" vein of thought: following the agricultural age and the industrial age, we are now in the information age, as is explicitly stated in the EU's strategy concerning ICT (i2010). The OECD made the following revealing statement, in its progress report on its three-year project for sustainable development (OECD, 1999, p. 20) "[...] *it could be that a minimum level of natural resources is essential for development*".

The digital economy, frequently described as "non-material", is often presented as an example to support this analysis. As reproduction and transport costs on the Internet are close to zero, this gives the illusion of an almost total uncoupling. The Lisbon Strategy explicitly refers to this link between the digital economy and the reduction of pressure on resources and on the environment (Alakeson & Wilsdon, 2003). It could be argued therefore that one only has to replace "material" techniques by "non-material" techniques for economic growth to continue, and for pressure on the environment and on resources to diminish. This led, with the arrival of ICT, during the decade 1985-1995, to the fantasy of the "paperless office" a dream which has however become a reality on a modest scale with the gradual build-up, particularly in the administrative field, of procedures resulting in the "dematerialisation" of various documents. Note however that consumption of paper increased by 24 % from 1988 to 1998 in the industrialised countries (Cohen 2001). Although it is difficult to say how much the use of paper contributed to this overall rise, as there are many factors involved, Mokhtarian (2003) claims that the effects of substitution in uses, such as the sending of documents by e-mail rather than by post, have been largely negligible compared with the use of the additional printing possibilities, such as access to a countless number of reports and documents on the Internet.

In the transport field, Mokhtarian also points out that from the first the emergence of communication technology has given rise to the idea of substitution. Travel, which was generally considered to be inconvenient, would be avoided, as was the case when the telephone was invented in 1876. Armand Mattelard also shows that transport and telecommunications are complementary: for example, without the telegraph it is impossible to synchronise train circulation (Mattelard, 2001). Grübler (The rise and fall of infrastructures, 1990) shows that the rise in information flows goes hand in hand with an equivalent increase in physical flows (and thus energy consumed) and does not make them decrease. Of course the curve varies depending on the country, but a rise in GDP inevitably leads to growth in pressure on resources and the environment.

A study on e-commerce (Matthews & al., 2001) shows that the reduction in energy consumption obtained by buying books on the Internet is largely offset by the increase in the kilometres travelled by the book, which now travels by air. F. Rodhain (2005) has pointed out that 10 years ago, Marvin (Marvin 1997) was already warning against an absolute belief in spontaneous substitution. To this must be added the "rebound effect", i.e. the resources saved on one product or service are used to consume another product, or more of the same product: while for example houses in France are now more economical in their energy consumption than in 1975, they are larger and more numerous, and as a result the consumption of the residential sector has continued to rise in absolute value.

The study by P. Radanne (Factor 4) also shows that the distribution solution *"19 tonnes – supermarket – home distribution of Internet order"* has 10 to 12 times less impact in energy consumption and greenhouse gas emission terms than the solution *"38 tonnes - hypermarket – customers who come by car"*, but its impact is still 4 times that of the solution *"19 tonnes – neighbourhood supermarket – customers who come on foot"*… which existed a few decades ago.

It is therefore no surprise that Bringezu & Schütz have shown that no dematerialisation can be observed in macroscopic terms (Bringezu & Schütz, 2001). Pressure on resources has clearly been reduced in the EU, but material imports and emissions have increased. Careful examination of the Kuznets curves shows that the decrease in pressure only applies to a few substances, and that tertiarisation is partly based on the relocation of activities which are resource-intensive and intensive in terms of waste production (Zuindeau 2005).

The question of the definition of the "functional unit"

When the Wuppertal Institut shows that downloading has "less impact" than buying a CD (Türk & al., 2003), is this a solution that needs only to be more widely applied? This is far from certain: the favourable ecological balance-sheet only applies if the user does not then use his disk drive to burn a CD. So the issue needs to be reformulated: it is not a matter of choosing between the "clean" and the "dirty" solution, as though the two were equivalent, but of choosing between unlimited downloading with a ban on burning CDs, or the rationed purchase of CDs from a shop. To talk about a "use substitution", one must be able to identify a social function which is maintained after the change in technical systems. L. Grisel & P. Osset have shown that the functional unit in LCA (life cycle analysis) is often defined - excluding both the social sciences and users - very approximately, which makes comparisons very difficult (Grisel & Osset, 2004). P. Breton & S. Proulx (2005) have also shown the difference there is between "information" and "communication" both in a technical sense, and in a social or societal sense. While communication is derived from the Latin "*communicare*" meaning *"to share"*, information which circulates on the Internet is not necessarily shared: secure networks and private networks are increasing in number, while global governance would suggest the need for more sharing. Information, derived from the Latin *"informatio"* (1274) meaning *"that which decides in law"*, thus refers to all the documents which tend to establish proof of an offense and its perpetrators (according to the etymological dictionary), a meaning which has of course evolved, but whose origin reflects the close link with justice, an aspect ignored by quantitative information theories. The quantity of kilobits transported does not give any indication about the value of the information for the community.

Quantitative debates about dematerialisation thus tend very largely to brush over qualitative debates about the social utility of the services rendered and their evolution. While GDP is continuing to grow, the social health indicator (SHI), the true indicator of progress, and many other indicators show that the situation is getting worse (Gadrey & Jany-Catrice, 2005).

The question of priorities

Azar & al. (Azar C., 2002, p. 9) have shown that complete uncoupling may not be the right goal; it is necessary to concentrate on decoupling impacts which give rise to concern, such as greenhouse gases and persistent organic pollutants. Pressure on the environment raises problems of absolute quantity (toxic waste, non-renewable resources) and relative quality (excess of greenhouse gases compared with recycling capacities).

LCA are not tools which enable genuine transparency in this field. Is it possible to compare greenhouse gases and nuclear waste merely on the basis of amounts produced, as material flow analysis tends to do? The weighting of all amounts with the same factor does not guarantee objectivity. The relative significance of impacts is a political question, codified in texts such as those mentioned earlier. But how can this be brought into the public debate? How can one arrive at objectivity through intersubjectivity? While it is often difficult for the energy debate to fully exist in societies, the Boissieu report reaffirms, like many other previous reports, that significant progress can only be made if all parts of society are fully involved (Boissieu, 2006). The example of the directive on WEEE (Waste from Electrical and Electronic Equipment) shows that the lack of debate about the definition of uses and their priorities puts a sharp brake on eco-design and waste reduction (Flipo & al. 2006). It is probable that the three orders of effects set out by the OECD above are not fully formulated at this stage: although they describe what is happening at ICT level, they do not consider the reasons which give rise to these trends.

Decision-making places

Many observers have pointed out the intersectorial nature of sustainable development. At international level, negotiations about the environment and development are still separate from each other. In the ICT field, the energy question arouses little interest. The recent CNUCED meeting in Geneva about ICT use (December 2006), did not raise any energy or waste questions. The 8th Conference of the Parties to the Basle Convention on toxic waste however raised the issue of electronic waste. The industrialists grouped together in the Global e-sustainability initiative (Gesi) since 2001 referred in their 2005 progress report to a certain increase in awareness, which has however had relatively little impact on decisions (Gesi, 2005). Meanwhile, sustainable development forums such as the Johannesburg Summit in 2002 continue to see ICT simply as a beneficial tool whose use should be made increasingly widespread.

Here as in many other fields, environment and development are having difficulty in achieving dialogue. Who defines needs? What are the fundamental needs? How can we divide up the various types of need? Who suffers from the adverse effects of a growth in consumption which it is hard to contain collectively? The solutions are not obvious, and the questions cannot be resolved using a technocratic approach. In this respect the TIC21 initiative (www.tic21.com) should be welcomed, as its aim is precisely to decompartmentalise approaches.

Conclusion

The extraordinary opportunities presented by the Internet economy (OECD, 2002[7]) make its numerous "hidden faces" (piracy, financial fraud) more bearable. Yet another hidden face is the colossal energy footprint, which is rarely the object of special attention. Although we have been contributing to this problem for nearly 20 years, it is only recently that an awareness of energy issues has penetrated the consciousness of users, and it is still not a priority among decision-makers. For users in industrialised countries, it is a matter, in effect, of paying a supplement on electric bills, which would be modest compared to the innumerable alternatives. We must recall that the energy demands of the Information Society can only be met with electricity. It is also important to highlight that as the production of electricity accounts for more than 30 percent of the CO_2 emissions of the energy sector, keeping this consumption in check could significantly reduce these emissions, as we have shown since the mid-90s (Roturier et al, 1994, Roturier et al., 1996). Those who participated in or closely watched the work of the SMSI in Geneva in 2003 and in its second phase in Tunis can attest to the scant interest that this theme generates.

The authors have taken on the task of raising awareness of the actors involved in building the Digital Society. To this end, we analysed several recent studies concerning what might be called the "energy iceberg" of ICT. Based on concrete examples, we have shown the depth of the invisible portion of electricity consumption by the Internet, highlighted that its footprint is greater than what the average user sees on his energy bill, and demonstrated that constant growth may well accompany a multiplication in electronic and digital hardware. We have shown that the electricity demand of infrastructure grows more quickly than that of PCs and other terminals and could easily grow to constitute 50 % of the total in a decade. We also note that most analyses leave out the footprints of air-conditioning and of various electric losses.

The evolution of energy consumption in the ICT sector closely depends on the decisions that will be taken to face present ecological and societal crisis. Both are interlinked. But the driving forces are unclear. The weight of information circulating on ICT infrastructure is highly variable, therefore the ICT consequences on energy consumption are deeply ambivalent. Decisions taken in the field of energy will impact information, which may be one of the major elements of societies' structuration.

7. OECD, 2002 OECD Information Technology Outlook : ICTs and the Information Technology (OECD Publications)

References

Aebischer B., Eubank H. and Tschudi W. (2004). Energy Efficiency Indicators for Data Centers, Proceedings of the International Conference on "Improving Energy Efficiency in Commercial Buildings, IEECB'04", Frankfurt, 21 – 22 April. http://www.cepe.ch/download/staff/bernard/Aebischer_IEECB04_final.pdf

Aebischer B., Frischknecht R., Genoud Ch., Huser A. und Varone F. (2003). Energy- and Eco-Efficiency of Data Centers. Study commissioned by DIAE/ScanE of the Canton of Geneva, Geneva, January http://www.cepe.ch/research/projects/datacentres/data_centres_final_report_05012003.pdf

Alakeson V. & Wilsdon J., Digital sustainability in Europe, Journal of Industrial Ecology, vol. 6, n°2, 2003, pp. 10-12

Azar C., Holmberg J. & Karlsson S., Decoupling – past trends and prospects for the future, Environmental Advisory Council, Ministry of the Environment, Sweden, 2002

Barthel C. et al., 2001: GHG Emission Trends of the Internet in Germany, in: Langrock, Thomas/Ott, Hermann E./Takeuchi, Tsuneo (Eds.): Japan & Germany: International Climate Policy & the ICT Sector, Wuppertal Spezial 19, Wuppertal

Beyrand et al., 2004 (private communication) - see also Patricia Vallejo: "Caractéristiques Des Alimentations Sans Interruption" MD3E Unpublished Report

Breton P. & Proulx S., L'explosion de la communication, Paris, La Découverte, 2005

Cremer C., Aebischer B. et al., Energy Consumption of Information and Communication Technology (ICT) in Germany up to 2010, 2003. http://www.cepe.ch/download/projects/INFO-KOM/ISI%2BCEPE-ICT-english.pdf

Ericsson, 2001/1. Die Infrastruktur von Mobilfunknetzen. Funktion und Elemente http://www.ericsson.com/de/broschueren/infrastruktur_mobilfunknetze.pdf

Ericsson, 2001/2. Von GSM zu UMTS. Informationen über neue Mobilfunktechniken http://www.ericsson.com/de/broschueren/von_gsm_zu_umts.pdf

Etude Institut Chronopost - Ipsos, L'impact des TIC sur la porosité des temps professionnels et personnels, 2004

Faist Emmenegger M. et al., 2003: LCA des Mobilfunksystems UMTS. Finanziert durch Forschungsstiftung Mobilkommunikation, ETHZ, Uster http://www.mobile-research.ethz.ch/var/sb_frischknecht_pref7.pdf

Gesi, Contribution to a more sustainable knowledge economy, 2005

Grisel L. & Osset P., L'Analyse du Cycle de Vie d'un produit ou d'un service - applications et mise en pratique, AFNOR Editions, 2004

Grübler A.., The rise and fall of infrastructures, 1990

IBM ECP-News, Vol. 5, Nr. 2, May 2001

Kawamoto K. et al, Electricity Used by Office Equipment and Network Equipment in the U.S., Energy Analysis Department, University of California Berkeley, 2001

Koomey (2007): Estimating total power consumption by servers in the U.S. and the world, Staff Scientist, Lawrence Berkeley National Laboratory and Consulting Professor, Stanford University.

Kruse J., 2002: Ein gemeinsames Funknetz für UMTS in der Schweiz. Ökonomische Aspekte. „Avenir Suisse", März

Mattelard A., Histoire de la société de l'information, Paris, La Découverte, 2001

Mitchell-Jackson, J.D., 2001. Energy Needs in an Internet Economy. A Closer Look at Data Centers. University of California, Berkeley

Morosoli, B.P., Die Full-Service-Provider kommen. Vom einfachen Internetzugang zur komplexen Dienstleistung. NZZ, 06.02.2001

OCDE, Le projet triennal de l'OCDE pour le développement durable - Rapport d'étape, PAC/AFF(99)1, 1999.

Pittrof, Ch., 2001. Web Hosting allein hat keine Zukunft. Nachfrage nach Gesamtlösungen zwingt zur Differenzierung. NZZ, 06.02.2001

Roth K. et al., Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings - Volume I: Energy Consumption Baseline, ADL, Cambridge, MA, USA, 2002 http://www.tiaxllc.com/aboutus/pdfs/officeequipvol1.pdf

Roth K. et al., 2005. The Potential to Reduce Information and Communication Technology (ICT) Energy Consumption. Conférence Special CEPE-Colloquium, ETHZ, Zürich, 13 octobre http://www.cepe.ch/download/news-events/ICT_Savings_CEPE2005.pdf

Schallaböck K.O., Utzmann I., Alakeson V. & Jorgensen B., Telework and sustainable development – Final report, 2003

Türk V., 2001: Assessing the Resource Intensity of the Internet Infrastructure. Data Analysis for a Material-Flow Oriented Approach & First Results on Electricity Consumption. Thesis for the fulfillment of the Master of Science in Environmental Management and Policy, Lund, Sweden, September

Türk V. et al., The environmental and social impacts of digital music – a case study with EMI – Final report, July 2003, Deliverable 12, Digital Europe project

Acknowledgementss

One of the authors (BA) acknowledges financial support by the research programme "Electricity" of the Swiss Federal Office of Energy.