Measurements and Sustainability

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Chapter 3 - Measurements and Sustainability

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1. Introduction

ICT engineers are developing and creating a virtual world for offering new services, new applications to help people both in their work and their daily life. Nevertheless, ICT engineers are practically always constrained in their project development by intrinsic hardware performances of calculators, storage systems and communication systems. The monitoring and measurement of physical ICT system performances are crucial to assess the CPU load, the available memory, the used bandwidth, etc. to guarantee the ICT-based services correctly work regarding their expected usage. The famous Mooreôs law whereby the number of transistors on a chip tends to double every eighteen months enabled a rapid growth of digital system performances. However, these technical performances do not provide a direct information about the level of quality of offered services. In ITU-T (International Telecommunication Union-Telecommunication standardisation sector) E.800 recommendation (ITU E800, 1994), quality of service is defined as ñthe collective effect of service performances, which determine the degree of satisfaction of a user of the serviceò.

The satisfaction of users is then the key of ICT business and has to be specified in a Service Level Agreement (SLA) signed between ICT experts and their customers. By definition, SLA is not a technical document and has to be understandable by all stakeholders of contract who are not necessary aware with ICT terminologies. Two major issues should be analysed during the SLA specification, one corresponds to the identification of relationships between the performance indicators defined by the userôs application and ICT technical performances, and one is related to the monitoring of these indicators to be sure that the contract is respected.

The purpose of translation between ICT and userôs application performances covers many types of difficulties. The translation can be direct such as the application response time corresponding for ICT experts to the time for processing and transporting the applicative request. In this case, the main problem is to clearly define the context of this requirement in terms of number of users, opening hours,é and to characterise the type of delay (worst case, average, confidence interval,é). However, the translation can be more complex when the userôs requirements are expressed by using specific professional terms. For example, the control of industrial process is assessed by analysing its stability behaviour around a set-point to be reached. In the research on Networked Control Systems (NCS), the identification of impact of ICT performances (and especially network) on industrial process stability requires complex preliminary studies and to develop new approaches (Vatanski et al, 2009). One another barrier in SLA definition is when the userôs requirements are specified with qualitative information and not quantitative information. The userôs perception on the quality of phone call, TV broadcast, Web browsing, etc. is subjective and then complicated to analyse and to associate with quantitative ICT parameters (delay, jitter,é). Usually, the userôs perception is transformed in a metric based on MOS (Mean Opinion Score) using a scale between 0 (no service) to 5 (perfect service) to guide the ICT expert in its technical configurations.

The monitoring of indicators specified in SLA is essential to identify the border between the ICT systems and the application itself. The goal is to be able to understand and to identify the cause of malfunctions and to determine the stakeholdersô responsibilities. ICT systems must be continually supervised to analyse its performances in order to detect, to anticipate and to recover faults. The assessment of ICT performances can be based on measures, on models or a combination of both.

Basically, the measurement requires probes, supervisors and standardised protocols to access the whole metrics. Usually, a MIB (Management Information Base) is implemented in each equipment (computer, printer, switch, router,é) and supports in a standardised hierarchical structure all the equipment properties (name, OS, version, storage capacities, bandwidth,é). The supervisors (such as Nagios, Centreon,é) can then collect or modify the information stored in MIB by using SNMP (Simple Network Management Protocol). This approach is apparently easy to implement, but in practice the selection of pertinent information (regarding SLA contract) inside a multitude of information defined in MIB is a complex process. Instead of measuring the parameters of equipment, one another solution is to directly analyse the performances of application or service defined in SLA. For that, robots are developed and simulates the userôs behaviour using the application. In all the cases, one inherent issue of measurement is its intrusiveness with two consequences: each request for monitoring ICT system consumes CPU, bandwidth and has then an impact of its performances and the response time of a monitoring request is dependent to the performance of ICT infrastructure.

Another approach to assess ICT performances is to use mathematical theories that can be split in two groups: the constructive methods and the black box methods. The constructive methods are based on the assembly of elementary components with specific properties and their combination enables to estimate average delays, average buffer occupation (queuing theory) or bounded delays, backlog bounds (network calculus theory) (Georges J.P et al 2005). In the second method, the ICT system or a part of the one is considered as a black box and its behaviour (output) is analysed regarding the changes of ICT parameters (input). From this analysis (ie. experiment design method), a model of ICT system can be defined. The black box method is less generic than the constructive method, but it is better correlated with the real ICT properties.

In supervision, it is very interesting to couple the measures and models. The models represent the expected behaviour of ICT system and the measures its real behaviour. A difference between models and measures enables to detect anomalies and to anticipate faults by a trend analysis. This combination of models and measures is one way to develop a smart supervision.

Since the birth of computer science and telecommunications, their performance evaluation mainly focused on technical and cost indicators. But, as explained in the beginning of this introduction, the final goal of ICT is to facilitate the life of people without adding undesirable edge effects on both their health and their quality of life. Therefore, these effects should be also assessed during the full lifecycle of ICT product or ICT-based solutions in considering its manufacturing step, its usage step and its next life. An overall assessment of pollution must be then achieved to determine the ICT carbon footprint, the toxic material rate used in ICT devices,é impacting on people health. Moreover, the earthôs resources used for ICT must be continually optimised to preserve the quality of life of current and future generations. The preservation of earthôs resources covers problematic such as the recycling and the intensive use of renewable energy. On another issue, the quality of life is also related to ethical questions for both employees in ICT companies and ICT users with general considerations such as the salary of employees, the gender balance,é or more specific to ICT area such as the protection of privacy and personnel data.

In summary, ICT must be assessed in including the three ñPò of pillars of sustainable development (figure 1) during the engineering process of the target system as a whole, by balancing People, Planet and Profit requirements with the final objective to design green ICT solutions.

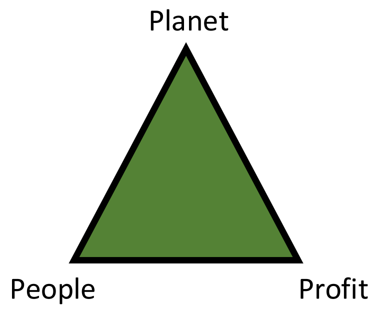


Figure 1. The three pillars of sustainable development

The ICT Engineering should be systemic in order to be able to analyse the contradiction, or positive effects between the three pillars. For example, the mitigation of datacentre energy consumption is interesting both in terms of Environment and Profit. But the increasing of datacentre capacity to growth business activities has as consequence to consume more energy generating a negative impact on the Planet. This kind of analysis well known under the name C2C fractal tile tool (W. McDonough and M. Braungart, 2002) is a new challenge and oblige ICT engineers to study the solution spaces not only on business and technical performances, but in associating new metrics coming from ecology and ethics. Thus, the SLA specifications are more complex in integrating additional requirements. This complexity can be managed in using systems engineering to guarantee that the development of ICT products, services and ICT-based solutions is sustainable and measurable for validating and verifying all technical solutions. The sustainability is not only expressed in term of longevity of solutions, but has to include properties of modularity, flexibility, scalability and recyclability.

The objective of the chapter ñMeasurement and Sustainabilityò is to show the different aspects of ICT metrics. The chapter is then organised as follow: The section 2 briefly explains the traditional metrics used to asses intrinsic ICT performances. The section 3 focuses on the performance indicators specific to environment and ethics. From a simple ICT architecture, the section 4 presents systems engineering approach to specify and to consider the measures in Green ICT-based solutions. The section 6 concludes the chapter.

2. **ICT technical measures**

2.1. Introduction

The measurement of ICT systems can be compared with measurement applied to any natural or artificial system of the world. However, the main difference with other systems is that ICT measures are related to data performances which is an abstract thing. In general way, ICT functional model can be described as in the figure 2.A in considering ICT system as a black box. The input and the output are data crossing ICT system. Controllers can be implemented over the system to manage the ICT Quality of Service (QoS) such as scheduler, smother, load balancer,é in order to meet the userôs requirement. Finally, energy is the resource required for supplying ICT system. ICT system offers three elementary types of services: data processing, data transport and data storage. Moreover, a set of ICT systems can provide a global service such multimedia service. Traditionally, the ICT system performances are assessed by observing the deviation between the requests of service sent by the user and containing the input data and its corresponding response of service supporting the output data. This deviation characterises the service offered by ICT system to the user. Finally, until very recently, energy is not analysed and is considered as an infinite resource without impact both on cost and environment.

The main attributes used in the data measurement are: quantity, throughput, quality, availability and security. However, in general case, the measure of these attributes is not directly useful in the performance assessment of ICT systems. The concept of metric defined as a measured attribute or a combination of measured attributes provides information more pertinent. One example of ICT metric is the available communication bandwidth. It is expressed in bits per second and its value is obtained by using models and several measurements.

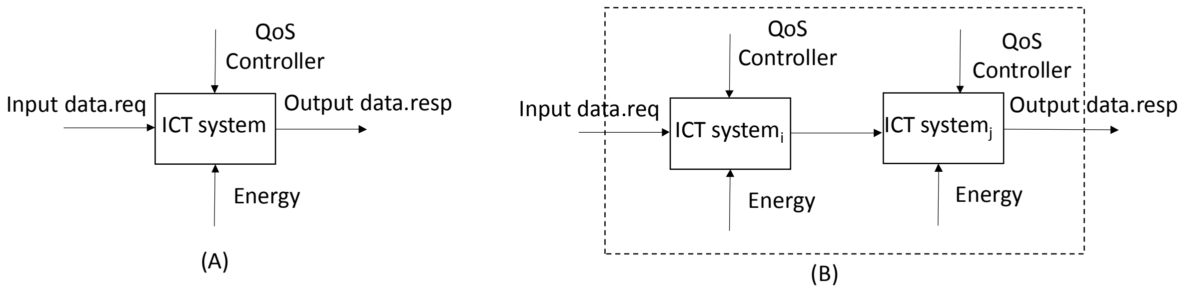


Figure 2. ICT system functional models

Moreover, the assessment of complex system composed of sub-systems (Figure 2.B) requires derived metrics. These complex metrics can be developed from combination of basic metrics relative to each subsystem. There are three classes of operation to get derived metrics which are additive metric, multiplicative metric and concave metric. The additive metric is calculated by adding basic metric of each part of the system. The one-way delay of a path calculated by summing the one-way delay on each link of the path illustrates the principle of additive metric. The multiplicative metric is calculated by multiplying metrics of each part of the system. The metric of packet loss ratio can use the multiplicative operation to assess a complex architecture. The concave metric is determined by selecting the minimum value of each part of the system. For example, the estimation of end to end bandwidth is constrained by the link with the lowest bandwidth.

A common metric applicable to all ICT systems is ***<u>Response Time</u>*** corresponding to the delay between service request arrival time in the system (input) and service response available on the output. It depends on both type of service and the data amount in the request. The response time is sometimes named delay or latency. The delay is calculated from two measures obtained from different devices and then requires that their clocks are synchronised or use the same clock. In the next sections, the different types of services are described.

2.2. Service of data processing

The data processing is characterised by two specific metrics: the processing capacity and the processing quality.

The *processing capacity* is the higher number of requests per time unit that could be sent (without loss of request) to ICT system input in order to be processed. Service tests (mathematical complex functions) are defined in order to compare the processing capacity of different services

The *processing quality* is given by the accuracy of the results. This metric is very important in scientific computation.

2.3. Service of data transport

The data transport service uses three specific metrics: the bandwidth, the jitter and the packet loss rate (Michaut F. and Lepage F., 2005). There are two types of bandwidth.

The first one is the *total path bandwidth* also called path capacity. It expresses the maximum total throughput accepted by the path.

The second one is the *available bandwidth* expressing the maximum throughput offered to the user. Thus, the available bandwidth is the path capacity minus the used traffic (concurrent traffic).

The bandwidth measure is based on interval packet times

The *jitter* is the delay variation between successive same requests. It is not a measured value but it is obtained by subtracting the delays of two successive requests.

The reliability of a communication network path is expressed by the *packet loss rate*. This metric is equal to the number of non-received packets divided by the total number of sent packets. It should be noted that erroneous packets are not generally considered outside the lost packets in computer networks because most applications require data integrity. Indeed, the frame reception driver discards each erroneous packet that becomes a lost packet. However, it is not a general rule, especially in audio or video networks because applications can accept a low rate of error. The measurement is achieved by using a sequence number in each packet and by counting the missing numbers.

2.4. Service of data storage

The data storage includes two metrics: the storage capacity and the data throughput.

The *storage capacity* is difficult to measure by service black-box approach. Fortunately, specific requests provide the total or remaining capacity of the storage system.

The *data throughput* is sometime different for read and write operations. For a write operation, the measure is achieved by counting the maximum amount of data that the service accepts per time unit. For a read operation, the measure is similar but applied to the service output. The time unit must be enough large to integrate gaps between storage units.

2.5. Multimedia service

A multimedia service has to allow the user to play multimedia data from voice or video acquisition crossing a chain of ICT systems. Two methods are used: the Full Reference method and the No Reference method.

The *Full Reference (FR) method* consists in comparing the quality of reference signal from the source (perfect signal) with the received signal (degraded signal). FR measures deliver the highest accuracy and repeatability. However, FR measures can only applied to dedicated tests in live networks.

The *No Reference (NR) method* uses the degraded signal without information about the reference signal. From the NR method, some characteristics of a conversion can be identified such the voice gender, the background noise,é

2.6. Conclusion

The fundamental activity of ICT engineer is to configure ICT systems for offering the best or optimised services to its customers regarding the main ICT metrics presented in this section. However, the recent strong increase of energy prices and the new environmental awareness by politics and people oblige the ICT engineer to consider energy in SLA. In this way, SLA is renamed Green SLA. For example, (Laszewski G. and Wang L., 2010) and (Makela T. and Luukkainen S., 2013) present new metrics on energy especially in the context of green SLA for datacentre. Moreover, the PoE (Power over Ethernet) technology is a new network service enabling to transport energy on data link, to remotely supply ICT products and finally to control the ICT devices status by using different sleeping modes. Thus, energy becomes an integral part of ICT metrics. However, limiting green SLA to only an energy metric is very restrictive and then the goal of the next section is to describe all the facets of Green ICT.

3. Ecological measures Ethical consideration

3.1. Introduction

The consideration of the three pillars of sustainable development in the design of ICT-based solutions is complex because many new parameters should be added during the design process and because the limit of study space is always difficult to determine. Indeed, the enterprise involved in sustainable development approach must analyse the environmental impact of its design process itself (project-system) and of the whole life cycle of designed systems (system-of-interest). The issue is to get a global result in integrating and in estimating not only the environmental footprint of the enterprise, but in including all stakeholders (subcontractors, suppliers, sellers, users, recycler,...) involved in the enterprise activity. The goal is to avoid that the enterprise elaborates a marketing communication on its green and ethical virtues in keeping its environmentally friendly activities and in outsourcing the others. In this context, the standardisation is a major aspect to successfully reach this objective in order to be able to ensure a seamless environmental monitoring between the different stakeholders. ISO 14001 standard provides a framework that an enterprise can follow to set up an effective environmental management system. However, the purpose of ISO 14001 is not to estimate environmental performances and cannot explicitly show if the enterprise pollutes.

The enterprise impact on environment should be based on a list of Key Performance Indicators (KPI). A KPI is a metric or measure used to quantify and evaluate organisational performance in relation to the meeting of targets and objectives. Many standardisation organisations or working groups proposed environmental KPI. The ITU report on ñGeneral specifications and key performance indicatorsò (ITU-T report, 2012) referenced an impressive list of initiatives specifying KPI. There are global initiatives such as Carbon Disclosure Project (CDP), Dow Jones Sustainability Index (DJSI), GHG Protocol corporate standard, Global Reporting Initiative (GRI), ISO 14031, ISO 14064-1 and initiatives from ICT sector such as European Telecommunications Network Operators Association (ETNO), European Telecommunication Standards Institute (ETSI), the Green Grid, GSM Association, International Electro technical Commission (IEC), International Telecommunication Union ï Study Group 5 (ITU-T SG5). In conclusion, ITU report (ITU-T report, 2012) does not propose a KPI harmonisation, but a general process to define environmental KPIs. This process is decomposed in three steps: defining the needs, listing relevant KPIs and Third-party verification of data collected for all environmental indicators. This method fully respects the basis of Systems Engineering developed in the section 4 of this chapter.

The standardisation requirement does not only concern the definition of environmental KPI, but also the specification of protocols enabling to collect KPI and to control ICT-based applications regarding the KPI status. The protocol IEEE P1888 on ñthe Ubiquitous Green Community Control Network Protocolò IEEE P1888 (2011) is an example illustrating the standardisation of remote control architecture for digital communities, intelligent building groups, and digital metropolitan networks in terms of the energy, environment, and security domains.

The approach used in this section is not to describe the list of environmental KPIs defined in the different working groups (mentioned previously), but to classify KPIs according to three categories: the pollution, the earthôs resources and ethic in order to cover all the facets of sustainable development.

3.2. ICT Impact on Pollution

By definition (Chapman P.M., 2007), the contamination is simply the presence of a substance where it should not be or concentrations above background. Whereas, the pollution is a contamination that results in or can result in adverse biological effects to resident communities. It means all pollutants are contaminants, but not all contaminants are pollutants. The pollution has different forms which are: air pollution, soil pollution, light pollution, noise pollution, thermal pollution, visual pollution and water pollution. All these forms of pollution can be generated by ICT sector. Therefore, it is essential to identify their causes in order to mitigate or to eliminate their impact on environment.

ICT products are composed of many chemical substances and toxic both for environment and people. For example, Beryllium used in relays, connections is dangerous for the workers manufacturing this electronic equipment, Bromated flame retardant used in mobile phone is neurotoxic, Cadmium used in the rechargeable computer batteries is toxic for kidneys and bones, Mercury in the flat screens affects the brain and central nervous system,é The management of these chemical substances during the life cycle of electronic products is one essential action in green context for informing the manufacturers, the users and the recyclers about the presence of toxic elements. Especially, in the end of product life cycle, the landfill of electronic wastes including hazardous products pollutes soil, atmosphere, water and also impacts on the beauty of landscape. The incineration releases heavy metals into the air and ashes. Obviously, there are two ways to limit this pollution. One consists in mitigating the usage of hazardous elements in the manufacturing of electronic equipment and one is relative to the well management of dismantling and recycling steps. The GS1 EPC global standard in the Consumer Electronics Supply Chain (GS1, 2010) is an interesting solution to ensure the traceability of electronic equipment by using RFID technologies. RFID enables to store on the electronic product a cartography of its components. A well knowledge of electronic product composition is essential to improve the efficiency of hazardous materials management and to prevent health issues of employers working on recycling process and who are in direct contact with electronic wastes. (Kubler et al, 2014) propose similar concept to embed RFID in material for improving the monitoring of material life cycle.

ñIf the cloud were a country, it would have the fifth largest electricity demand in the worldò (Green Peace international report, 2012). Quantitative information is provided in the Smart 2020 report (Smart 2020, 2008), on carbon emission induced by ICT in considering the whole electronic product life cycle including the ICT usage step and the manufacturing and dismantling steps (embodied carbon). The energy consumes by ICT sector significantly participates to carbon emission in atmosphere inducing air pollution and thermal pollution.

The energy consumes by ICT usage corresponds to the power supply to feed ICT equipment itself (computer, network,é), cooling systems, energy transport. The installation of BTS (Base Transceiver Station) in desert is a typical example well illustrating the logistic chain to be considered in the energy consumption estimation. It includes fuel to produce electricity from generators. This electricity is used both for BTS and cooling system. Finally, it is also necessary to manage a crew of tank trucks consuming themselves fuel to transport fuel to BTS generators. Another interesting example is the study of datacentre energy consumption. (Emerson Network Power, 2009) defines two categories of energy use: the demand size and the supply side. The demand size systems are the servers, storage, communications and other ICT systems that support the business. The supply-side systems include the UPS (Uninterruptible Power Supplies), power distribution, cooling, lighting and building switchgear. The Power Usage Effectiveness (PUE) proposed by (Green Grid, 2012) to assess datacentre efficiency is the ratio of facilities energy (supply side) to IT equipment energy (demand size) and is expressed as follow:

PUE= Total Facility Energy/IT equipment Energy

However, as mentioned by Ascierto, R. (2011), PUE is a simple metric which does not reflect the whole complexity of datacentres regarding its global efficiency. Especially, PUE does not provide performance on its usage (bandwidth, bytes,é).

Nevertheless, the interest of identifying all energy consumption sources is not only to control the global energy consumption of datacentre but to be able to develop a strategy to mitigate the energy consumption. Indeed (Emerson Network Power, 2009) shows the cascade of effects between component chain, in explaining the energy reduction of a server has an impact on the power supply, which has an impact on power distribution which has an impact on UPS and on cooling,é (Emerson Network Power, 2009) estimates 1 watt saved at the processor saves approximately 2.84 Watts of total consumption.

A good knowledge of these interactions is then crucial in the optimisation of energy consumption. In this optimisation, two criteria must be clearly identified which are energy and carbon emission. The mitigation of energy in ICT is mainly a business objective corresponding to the Profit pillar of sustainable development. As mentioned in (Emerson Network Power, 2009), the global electricity prices increased 56 percent between 2002 and 2006 and continue to growth. Thus, ICT sectors must optimise their energy consumption to limit the impact of energy costs on their business.

The carbon emission participates in the increasing of greenhouse gas (as methane,é) and is related to Planet pillar of sustainable development. Even if the carbon emission is correlated to the energy consumption, the optimisation of carbon emission regarding Planet criterion and the optimisation of energy consumption regarding Profit criterion can reach to two opposite strategies. Indeed, the selection of a clean energy to reduce pollution can increase the electricity prices. Moreover, the optimisation of carbon emission is more complex to handle and will be more and more complex with smart grid development, due to the variation of carbon rate in the energy production. The carbon emission optimisation algorithms should integrate these variations. The French company of Energy transport (RTE) provides in real time this kind of information and can be used to develop optimal strategies in the usage management of ICT equipment in Enterprise. For example, the observation of a peak on carbon to produce electricity could automatically configure the laptops in battery mode.

The smart 2020 report also analyses the embodied carbon collecting the carbon emission during both the manufacturing process of ICT components and their end of life treatment. In general way, (RICS QS & Construction Standards, 2012) explains embodied carbon has to consider the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or product.

The knowledge of embodied carbon and the carbon emitted during the usage phase enables to assess the sustainability of ICT-based solution or ICT product and then to estimate their optimum obsolescence. From this information, the global energy consumption of ICT product in activity can be compared with a new generation of ICT products using more energy efficient components in order to anticipate the ICT installation renewal. The approach consisting in extending the ICT product life at all costs may be in opposition with the objective of sustainability promoting environmental-friendly solutions. The concept of point or band of optimum obsolescence was explained by (Tuppen C., 2013) to define the right time to change a car, a notebook,é

The Electrosmog is the electromagnetic radiation emitted by electronic equipment (computers, mobile phones etc.) in the environment and is a hot topic in the scientific community to determine its real effect on health and then to determine if Electrosmog is a pollution form or rather a contamination. Radio waves health effects was intensively studied by national and international organisms like ICNIRP (International Commission on Non-Ionizing Radiation Protection), IEEE and WHO (World Health organization). The effects of electromagnetic fields on the human body depend not only on their field level but on their frequency and energy. All studies results claim that the unique non-controversial effect of non-ionising EMF is thermal effect (World Health Organization, 2006 and World Health Organization, 2011). To avoid it all organisms have determine the maximal acceptable values for EMF (IEEE, 2005), associated with the frequency range of the RF channel. Based on these recommendations, the government of each country or state has defined legal maximum level of EMF generated by wireless networks antennas and maximum Specific Absorption Rate (SAR) value. SAR is a measure of the maximum energy absorbed per unit of mass of the head of a person using a mobile phone. These values are sometime lower than the maximum. It is not disputed that electromagnetic fields above certain levels can trigger biological effects. For example, weak electromagnetic transmitters with a frequency spectrum between 0:1_10Mhz can affect animal behaviour, particularly the orientation of migrating birds (Ritz T. et al, 2004). But biological effect do not means health hazard. However researches are actively continuing to confirm that low level, long-term exposure to radiofrequency fields could not generate adverse health effects.

To limit Electrosmog, there are many proposals quickly now explained. One way is to use cognitive radio enabling to automatically detect the available channels in wire-less spectrum and to change accordingly its transmission and reception parameters (Stevenson C. et al, 2009) Another way is the smart antenna technique using spatial multiplexing and coding for removing interferences (Cui S. et al, 2005). Other solutions consist in implementing base stations and mobile phones using low power transmissions. However this approach tends to multiply (for an equivalent level of quality of service) the number of base stations and then tends to increase the energy consumption, the CO2 pollution and also worsens the aesthetic environment. Based on this idea, (Cerri G. et al, 2004) propose to reduce electromagnetic pollution of mobile communication systems in optimizing the radio base station location. Finally, a good improvement in wireless communication is to hide antennas into fake chimneys or fake trees. This is a good way to avoid electromagnetic hypersensitivity effect (Seitz H. et al, 2005) and to minimize the visual pollution.

Two additional aspects related to pollution induced by ICT, but not really considered in Green ICT are the light and noise pollutions. The systematic usage of electronic documents is often recommended to limit paper documents in order to preserve the nature. However, computer screen generates a light pollution affecting the people health. The Computer Vision Syndrome defined by the American Optometric Association is the visual fatigue symptom (sore, dry, irritated or watery eyes, headaches, sleep disorder,é) of people using screen equipment. A specific information on that could be mentioned in each proposed ICT solution.

The noise pollution generated by cell phone ringtones and conversations in public area has also an impact on the quality of citizen life. This facet is related to ethical behaviour in the usage of ICT and is more complex to measure and assess.

3.3. Resource Efficiency

Janine Benyus in her book ñBiomimicryò (Benyus J.M., 2002) explains in the last chapter ñhow will we conduct businessò, that an ecosystem (Encyclopedia Britannica, 2012) is a complex of living organisms, their physical environment, and all their interrelationships within in a particular unit of space. The evolution of ecosystems generally occurs in two phases: the developing stage and the mature stage (Allenby B.R. and Cooper W.E., 1994). The developing stage involves few species and short food chains. This ecosystem is unstable but highly productive, in the sense that they build up organic matter faster than they break it down. The mature ecosystem is more complex, more diversified, and more stable. Currently, the business model used in our society and more especially in ICT sector is the developing stage, and the challenge is to move to the mature stage.

The business based on developing stage consider the natural resources are infinite. However, different studies estimates the earth reserves of a number of materials (Diederen A.M., 2009) (Cohen D., 2007) (Kesler S., 2007). For example the reserve for Indium is between 5 and 10 years, for copper 20 and 50 years and for Gallium 5 years. Indium, copper, Gallium are components used in Semi-conductors and there are two actions to be able to manufacture ICT products in long term. The first one consists in substituting these materials by another ones having the same properties, the second one is to generalise the recycling of ICT products. ñA tonne of gold ore yields 5 g of gold, compared to a staggering 400 g yielded from a tonne of used mobile phonesò (ITU-T report, 2012). In this context, the interest of recycling is then both ecological and economical. The report (EuPs, 2007), provides many interesting information about materials inside computers and screens.

The recycling in ICT sector is a big issue since the rapid obsolescence of the hardware and software, which continually offers new functionality with better performance, induces premature equipment renewal and produces electronic waste. The recycling has different aspects, including the reuse of old equipment in other applications and equipment dismantling. For example, reuse might involve replacing an old mobile phone with a new one and identifying a market for selling the old one to other customers with different needs. In the book óócradle to cradleôô (Donough W. and Braungart M. ,2002), the authors propose to design products with their raw materials separated into biological nutrients and technical nutrients. The interest is in avoiding the design of óómonstrous hybridsôô and in facilitating the recycling step by one part being dedicated to biological metabolisms and another part dedicated to technical metabolisms (enabling the recovery of rare materials, for example). This aspect is very important in the context of internet of things where electronic and battery are more and more mixed with the natural environment and should be carefully analysed during its implementation in thinking its dismantlement.

Standardisation and Legislation have a primordial role in the success of recycling step. For example, the Waste Electrical and Electronic Equipment Directive (WEEE, 2003) is the European Community Directive (2002/96/EC) which imposes responsibility for the disposal of waste electrical and electronic equipment on the ñmanufacturersò. Another example for limiting the e-waste is the recent ITU recommendations (ITU, 2011) (IUT-T L.1001, 2012), proposed to specify universal power adapter and charger solutions for both mobile and network devices enabling the consumers to reuse them when they buy new mobile phones, or other electronic equipment.

The limitation of natural reserves (Kesler S.E., 2007) concerns also energy (oil, gas,é) and implies to generalise the usage of renewal energies (solar, wind, water,é) in order to preserve the earthôs resources. Moreover, the recycling method can be also applied to energy and not only to material. Electronic equipment consumes energy and dissipates heat. This heat can be reused as a resource for other applications. For example, the heat emitted by a data centre can provide heat for buildings (Val-Europe, 2012).

ñWater is life, sustaining ecosystems and regulating our climate. But itôs a finite resource, and less than 1% of the worldôs fresh water is accessible for direct human useò (European Commission report, 2010). The water scarcity defined as the lack of sufficient available water resources to meet the demands of water usage within a region is another big challenge in the Green ICT. As explained by (Lewis A., 2013), ICT sector has a strong demand in energy especially in datacentre and energy sector is a large water consumer. Moreover, the air cooling in datacentre is recently replaced by water cooling system because water conducts heat than air and then warm water can be easier reused to heat building, swimming pools close to datacentre. For measuring the water consumption in datacentre, the Green Grid a metric named WUE (Water Usage Effectiveness) corresponding to the annual water usage divided by IT equipment energy, and is expressed in litres/kilowatt-hour. This metric is applied to the site consumption WUE_{site} and to the source consumption WUE_{source}. Nevertheless, the water consumption should be assessed during all the lifecycle of ICT products in considering their manufacturing, transport, recycling.

3.4. Main Green Measures of Performances

From the previous analysis, the objective is now to define three main metrics, named Measures of Performances (MoP) in the context of system engineering, enabling to consider in the development of Green ICT application the recyclability, the energy consumption and carbon emission Obviously, these MoP are first proposals (Drouant N. et al, 2014) and should be refined and completed by other ones in order to take into account all kinds of pollutions and resource scarcity issues. The table 1 provides all the notations used in the different equations.

Symbol	Description
X	Set of equipment for the architecture
$\|X\|$	Number of items of equipment in the architecture
X_s	Set of substitute equipment
X_r	Set of repackaged equipment: $X_r \in (X \bigcup X_s)$
$\overline{X_r}$	Set of used equipment never repackaged: $\overline{X_r} = (X \bigcup X_S) - X_r$
ρ_i	Recyclability rate for an item of equipment i
Γ	Recyclability rate of the whole architecture
E	Energy consumed by the whole architecture
E_m	Energy consumed by the equipment's manufacturing process
E_u	Energy consumed by the whole architecture during its use phase
P_u	Power consumption of the whole architecture during its use phase
E_d	Energy consumed during the dismantling phase of $\overline{X_r}$
f	Factor related to the environment (air, feed efficiency)
h	Number of operating hours per year
δ	Power consumption gain (relative to the traffic profile)
ω_i	Traffic load for a switch port i
ϵ_i	Power consumption of an item of equipment i
ø	Power consumption of a switch in the idle state (no traffic)
σ	Power consumption of a busy switch port (full load)
Φ	CO_2 emission for the whole architecture
α	Multiplicative gain between energy consumed and CO_2 emission by country
τ	Multiplicative gain caused by energy transportation losses

Table 1. Notations

3.4.1. MoP on recyclability

This metric (1) involves the set X_r of equipment that will never be repackaged or refurbished (for use in another architecture). In the worst case, it corresponds to |X| the total number of items of ICT equipment used in the ICT-based architecture plus X_s the equipment used to substitute for existing ICT equipment. Items of ICT equipment might be replaced because of failure, upgrades, or even extensions to the architecture. It is important to note here that this list of equipment has to be considered in terms of the whole architecture lifecycle.

The recyclability rate of an item of equipment (ɟ$_i$) ranges from 0 to 1, where 1 corresponds to 100% recyclability and means that the item is fully reusable as a resource in other applications. From (1), the management of metal can be taken into account in ɟ in using for example the recyclability rate of metals defined in (Graedel T.E., 2011) and named EOF-RR (End of Life Recycling Rate) including recycling as a pure metal (e.g. copper) and as an alloy (e.g. brass).

$$\Gamma = \frac{\sum_{i\in\overline{X_r}}\rho_i}{|\overline{X_r}|}, \quad \overline{X_r} = \left(X\bigcup X_S\right) - X_r \qquad (1)$$

To optimize this metric, it is necessary to select highly recyclable ICT equipment, to anticipate any repackaging, and to limit the number of items of ICT equipment to be implemented, except for those that are 100% recyclable (ũ=1). 100% recyclability is an ideal objective for a circular economy (Donough W. and Braungart M., 2002), even if it does not mean zero energy consumption corresponding to the MoP.

3.4.2. MoP on Energy Consumption

In the estimation of energy consumption (2), there are three stages, namely the manufacturing of the network equipment (E_m), the use of the ICT-based architecture (E_u), and the dismantling of ICT-based architecture (E_d). It is important to note that the objective of Green ICT is to reduce the energy consumption. With the expression (2), the dismantling step has a negative impact of this MoP leading to limit the effort of recycling. For this, (Williams E.D. and Sasaki Y., 2003), proposes a similar equation with a negative term for (E_d) to indicate the positive gain of recycling. However, the study of equation (2) should be globally analysed. A company developing an efficient management of its electronic waste will actually consume energy for the dismantling, but the company will mitigate the energy consumption for manufacturing its new ICT products in avoiding the extraction of new earth resources. Thus, the optimisation is not based on one product life cycle, but on the manufacturing of multiple products using always the same earth resources. Another interpretation of equation (2) is to recommend to reuse the obsolete products in other applications or for other users before recycling.

$$E = E_m + E_u + E_d = E_m + \int_{t=0}^{\text{end of lifecycle}} P_u(t)dt + E_d \qquad (2)$$

The energy induced by the transport of ICT products from the manufacturer to the customer is included in (E_m). In the same way, the energy consumed by ICT product transport for the recycling is associated with (E_d).

P_u represents the power consumption by the ICT-based architecture during its use phase. In the literature, many research works propose expressions for modelling the energy consumed by ICT equipment. There are two main classes of proposal. One involves high-level modelling, where the interest is in approximating the energy consumption of general network architectures. The other is specific to network technologies and provides precise outcomes.

Two examples in the network domain illustrate these two classes.

Firstly, (Foll L.S., 2008) considers a high-level model without specifying a networking technology. The objective is to develop a management tool for the France Telecom company that offers higher visibility for the current and future consumption of its network. In this context, the following macroscopic model is defined per year:

$$\int_{t}^{\text{one year}} P_u(t)dt = \sum_{i\in X}\epsilon_i \times f \times h \qquad (3)$$

Secondly, in (Reviriego P et al., 2012), the authors propose a more specific equation for estimating the energy consumption of a network architecture based on switched-Ethernet technology. The model for the Energy Efficient Ethernet switch is:

$$P_u = \o + \sigma \sum_{\text{port } i} \min(1, \delta\omega_i) \qquad (4)$$

Here, ů takes into account the difference between the power consumption at full load and the traffic-free power consumption divided by the number of ports in the Ethernet switch.

P_u can be also approximated by a simple measure of ICT product or by using information provided by the Energy Star label given the energy consumption of computers, displays and imaging equipment. However, the understanding of the relationship between both the network activities and configuration and its energy consumption is open and is very important regarding two issues. Firstly, a formal relationship will enable to then propose ICT optimised strategies to mitigate the energy consumption. Secondly, a formal relationship could be compared with the current monitoring of ICT infrastructure in order to develop smart sensors able to observe deviations with expected results and to automatically detect possible anomalies.

3.4.3. MoP on Carbon Emission

The Carbon Emission is estimated from Energy used during the whole Life cycle of the ICT product or ICT-based architecture and from the table 2 matching rate between energy consumption and CO2 emission in electricity production for some European countries.

Country	CO_2 factor
Sweden	0.04
France	0.09
Finland	0.24
Italy	0.59
Germany	0.6
Ireland	0.7
Luxembourg	1.08

Table 2. Factors for kg of CO_2 per kWh (Source IEA)

Since an equipment might be manufactured in one country, used in another one and dismantled in a different one, the gain Ŭ is related to the stage of the lifecyle (Ŭ$_m$ will hence correspond to the factor during the manufacturing stage). The estimate of CO_2 pollution is then obtained by:

$$\Phi = \Phi_m + \Phi_u + \Phi_d = \alpha_m E_m + \alpha_u E_u + \alpha_d E_d \qquad (5)$$

Moreover, (5) has to consider the location of energy production in order to privilege the use of energy produced near the network installation, thereby limiting energy-transport losses. To integrate this parameter, it is necessary to make visible that part of the CO_2 emission caused by energy transportation. Therefore, a factor ls is added to (5), giving:

$$\Phi = \sum_{s=m,u,d} \frac{\alpha_s}{\tau_s} \times E_s \qquad (6)$$

The factor ls represents the additional rate for transporting energy and for example, in France the energy lost during transport is 5% (i.e. ls=0.95).

Moreover (6) can be extended to include other local sources of energy, such as oil-burning power generators (to power GSM antennas in an emergency) and solar panels installed locally and dedicated to the network. The impact depends on the nature of the energy (electricity, oil), such that the general metric for CO_2 emission becomes:

$$\Phi = \sum_{s=m,u,d} \sum_{\text{energy source } i} \frac{\alpha_{s,i}}{\tau_{s,i}} \times E_{s,i} \qquad (7)$$

Where $E_{s,i}$ represents energy-source component i consumed during the stage s (manufacturing, use or dismantling). (7) is suitable in the context of smart microgrids (Perea E., 2008) whose the objective is to encourage the consumption of renewable energy produced locally.

3.5. Ethic in ICT

The design of Green ICT solutions should integrate all the pillars of sustainable development: Planet, Profit and People. Mainly, the papers on Green ICT focus on environment and neglects to consider human and ethic aspects. Nevertheless, the basis of ICT development is to help the citizens in their daily life and in their working activities. Moreover (Herold R., 2006) explains that ñthe consideration of computer ethics fundamentally emerged with the birth of computers.ò The issue of people pillar are that it covers many areas and it uses subjective metrics making difficult the assessment. In general way, ICT company should analyse its social responsibilities towards the customers, towards the employees and towards the community (Uddin M.B. 2008).

Social responsibilities towards the customers: The company has to develop (Uddin M.B. 2008) safe and durable ICT products and services, efficient after sales services, has to be prompt, reliable and courteous face to queries and complaints,é The company does not (Grupe F.H. et al 2002) exaggerate the performances of proposed solutions, proposes alternative solutions in well explaining their interest for offering multiple choices to customers,é . The privacy and anonymity rules should be clearly defined in avoiding the installation of cookies with the goal to sell customer (or personal) data to other companies (Herold R., 2006). The company has also to inform the customers about the content of applications and its restrictions in regard to the law (for example the parental control for videogame)

Social responsibilities towards employees: Ethic must be analysed during the design process of ICT project. The company has to define a general code of conduct for the management of employees (salary, gender, productivity,é) and for the selection of subcontractors in considering the working conditions of their employees (exploitation of children, no salary,é). Moreover, during the design process (Grupe F.H. et al 2002), the company has to respect simple and evident rules related to good practices in ICT such it does not used unlicensed software to develop new software, it must respect the privacy life of employees during conversations based on Email exchanges,é

Social responsibilities towards the community: Ethic must be also analysed before starting the ICT project. A preliminary study should analyse the impact of the new developed system on the society, on individual person and on the digital divide increasing or not the social divide. In (Herold R., 2006), the main questions identified are the computers in the workplace in assessing the impact of ICT on lost jobs, lost skills, health issues,é and the computer crime in installing spyware, in hacking servers,é Finally, social responsibilities towards the community includes education of ICT users. ICT users should better respect the environment in developing new good habits in turning off computers, printers when they are unused, in switching off mobile phones in a meeting, in recycling ink cartridges,é

For summarising, ICT companies should define Ethical guidelines in order to produce ICT-based solutions in compliance with people pillar requirements. Implicitly, an Ethic approach has a positive impact of the choices realised in the Planet pillar (Environmental Ethic) and in the Profit pillar in promoting the fair business.

3.6. Conclusion

The assessment of Green ICT solutions has to consider many performance indicators gathering both numerical and subjective information. There are many initiatives specifying metrics which are either general (outside ICT scope) or specific to one ICT domain such datacentre. In this section, three concrete Measures of Performances were described which necessitate to be refined and to be completed with new ones in order to cover all the aspects of sustainable development. In waiting for consensual and standardised metrics, the design of ICT-based solutions has to follow systemic approaches such as systems engineering. The interest of systems engineering is to handle complex systems, to specify measurable requirements in order to be translated then into Measures of Performances and to check that the performances are well satisfied during all the project life cycle.

4. Systems Engineering for designing sustainable ICT-based architectures

4.1. Introduction

The development of Green ICT solutions is highly complex because they have to consider the business, the environment and the people in the design loop requiring to analyse the system as a whole during its whole life cycle. Therefore, the design of Green ICT systems requires formal or semi-formal methodologies and tools enabling to specify, verify and validate measures of performances expressed both by the userôs requirements and by the context of sustainable development. Moreover, to reach the global Green ICT objectives, the assessment should not only focus on ICT performances of system-of-interest, but also study environmental performances of the project-system itself. In this section, the goal is to present an example for studying ICT systems in using Systems Engineering (Pyster A. et al 2011) (INCOSE, 2010). This example of a student project in the Erasmus Mundus Master in PERCCOM (Pervasive Computing and COMmunications for sustainable development) (www.perccom.eu) highlights some major issues of the requirements specification process (Jin, 2006).

4.2. Stakeholder requirements definition.

The will-to-be operational domain in this study is an ICT architecture composed of ten computers and to three Cisco 3560 PoE-24 ports switches. Two alternative solutions more reliable are also analysed (figure 3). The first one implements four switches and the second one five switches. The ICT architecture is planned for 5 years (usage step). The architecture is installed in France and the ICT products are manufactured in China.

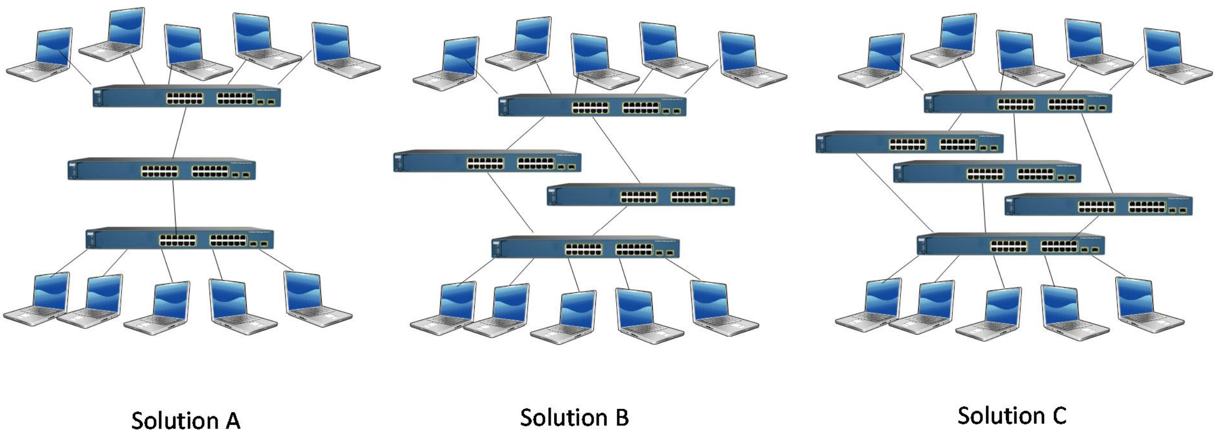


Figure 3. ICT-based architectures

The objective of the system engineering process (figure 4) is to analyse the performances of these ICT architectures (GICT0) regarding the ecology pillar (GICT0.1), the ethic pillar (GICT0) and the economic pillar (GICT0.3) from the three ICT architecture solutions. In ecology pillar, the intermediate requirements are to estimate the recyclability of ICT devices (GICT0.1.0), the radio wave emission (GICT0.1.1) and the ICT carbon emission (GICT0.1.2). In the ethic pillar, the requirement is to control anonymity and privacy of ICT users (GICT0.2) with appropriate data access policy. In the economy Pillar, the requirement is to calculate the energy cost of ICT architecture.

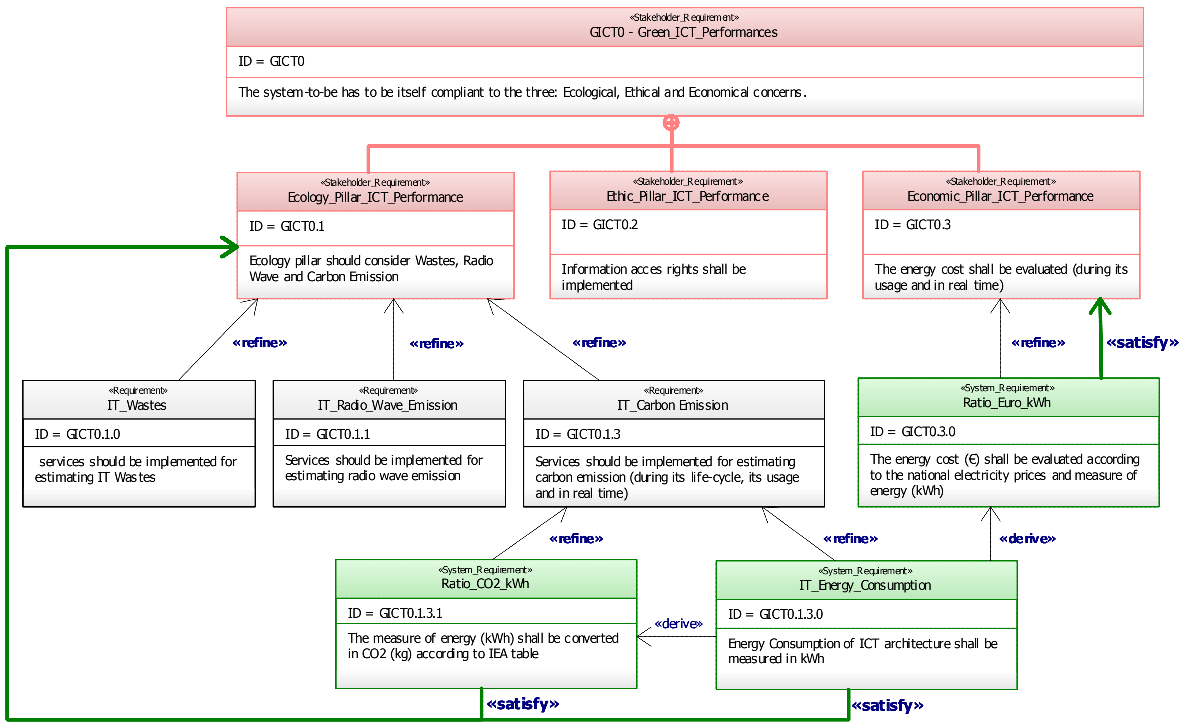


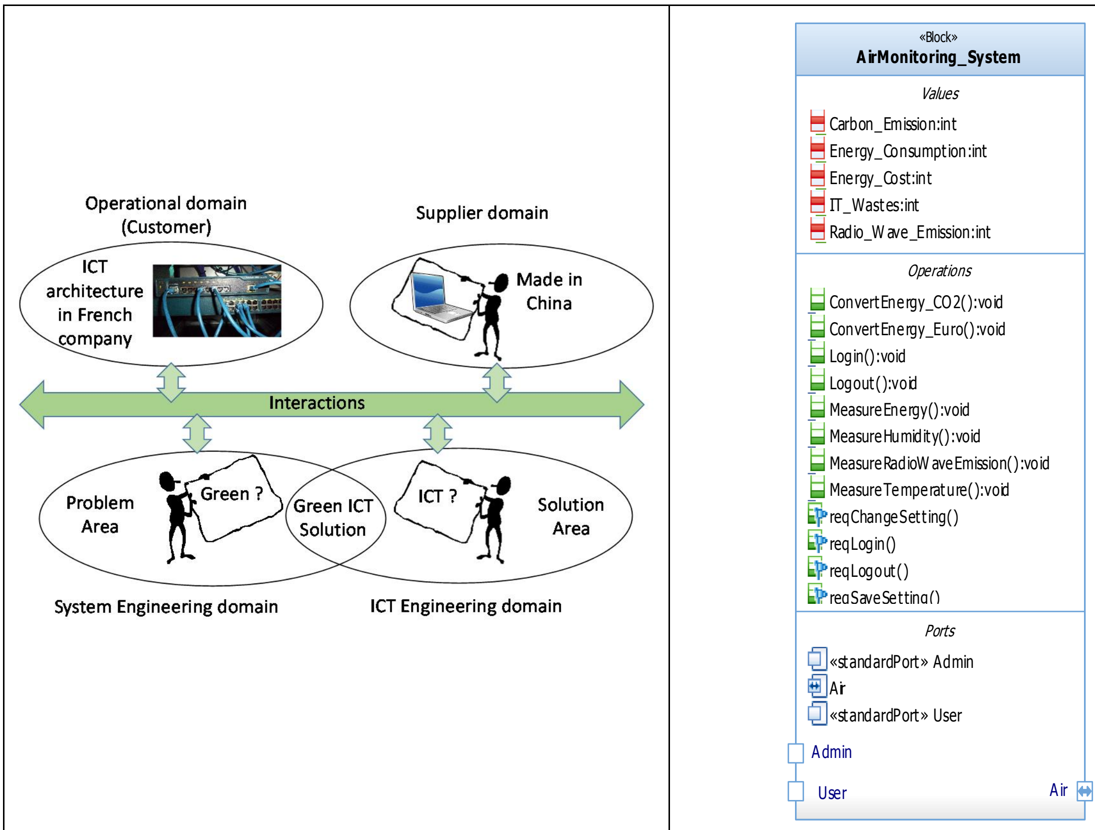
Figure 4. System requirements SysML Diagram

4.3. System requirements analysis

In this paper, only the estimations of carbon emission and energy cost are analysed. Thus, system requirements (figure 4) defined by the expert in systems engineering are specified in order to satisfy the stakeholder requirements. In both cases, the ICT energy consumption should be measured (GICT0.1.3.0). The carbon emission is calculated from the ICT energy consumption and the conversion tables between CO_2 and Energy (GICT0.1.3.1). The energy costs are calculated from ICT energy consumption and the electricity price (GICT03.0).

The carbon emission shall be a priori calculated during the usage step of ICT architecture and also during its whole life-cycle. Moreover, the carbon emission shall be measured in real-time during its usage step. Finally, the energy costs shall be a priori calculated during only its usage step. From these system requirements different functions were developed.

The expert in System Engineering has no competence in ICT domain to propose ICT solutions regarding the system requirements. As stated by (Bouffaron et al, 2014), the driver of any specification process (as requirement analysis process) is a quest for knowledge as design property from any specialist engineers to the system engineer. The aim of this knowledge is to bring the gap between stakeholder requirements, system requirements and ICT architectural constraints. Thus, ICT Experts are involved in the design process to provide their knowledge in applying the green ICT measure of performances defined in the section 3.4. The figure 5 shows the interactions of all the knowledge domains of the study.



(a) multi-domains collaborative process | (b) executable system block

Figure 5. Systems Specification Process

4.4. System requirements Validation and Verification

The systems engineering project framework is based on systems thinking (Lawson *et al*. 2014) and on a model-based integrative approach aiming to check the ñright-system requirements-rightò from the early stages of a project. The goal is to deeply explore the problem to design first the overall required system in a concurrent, recursive and iterative process, in contradistinction to traditional sequential engineering approaches focusing first on solution issues. The use of models for verification and validation of measurable requirements to component solution integration is compliant with the last recommended best practices in industry (Fanmuy *et al*., 2012). The objective is to check the compliance of system requirements to stakeholderôs requirements by execution of models in order to functionally design the required system as a whole before to architect it by allocating COTS or specific components. PERCCOM students execute their system specification by models transformation with a SysML-based tool (Sysml - Harmony) and are trained to ongoing developments related to *Tool independent Exchange of Simulation Models* (Blochwitz *et al*., 2012).

4. 5. ICT Expertise and results

The ICT expert proposes methods and results for providing the required information on the three ICT architecture solutions.

Function: Energy consumption estimation of ICT architecture

The Energy consumption of all devices implemented in the ICT architecture has been measured by ICT experts and the values obtained are 35 Wh for the switch, and 100Wh for the computer. The network works 24/7 and the ten computers 10h per day. By using the equation 2 (E_u), the total Energy consumptions of ICT architectures during 5 years are:

ĭ Solution A: 22849 kWh ĭ Solution B: 24382 kWh ĭ Solution C: 25915kWh

Function: Energy cost estimation of ICT architecture

With an average price of French Kwh (0.12úKWh), the total ICT cost Energy Consumptions are:

ĭ Solution A: 2741ú ĭ Solution B: 2925ú ĭ Solution C: 3109ú

Function: Carbon Emission estimation of ICT architecture

By using the CO2 factor per Kwh in France (0.09), the ICT carbon emissions are (Ŭ$_u E_u$ in the equation 5)

ĭ Solution A: 2056 kg $C0_2$ ĭ Solution B: 2194 kg CO_2 ĭ Solution C: 2332kg CO_2

Function: Energy consumption of ICT architecture life cycle

The analysis of energy consumption during the whole life cycle requires to know the energy used for the manufacturing and the dismantling. In (EuPs, 2007), the energy consumes to manufacture a computer is 900kWh and as approximation this value is used for computers and switches of architectures. For the dismantling, the literature does not currently provide information about that. Thus, 200 kWh is the empirical value selected.

By using the formula: $E_m + E_u + E_d$ (Equation 2), the energy consumptions of ICT architectures are then:

- Solution A: 11700 + 22849 + 2600 = 37149 kWh
- Solution B: 12600 + 24382 + 2800 = 39782 kWh
- Solution C: 13500 + 25915 + 3000 = 42415 kWh

Function: Carbon Emission of ICT architecture life cycle

As the product is manufactured in China with a CO2 factor per Kwh at 0.97, and recycled in France, the carbon emissions are from the expression Ŭ$_m E_m$ + Ŭ$_u E_u$ + Ŭ$_d E_d$ (equation 5):

- Solution A: (11700 * 0.97) + (22849 * 0.09) + (2600 *0.09) = 11349 + 2056 + 234 = 13639 kg CO_2
- Solution B: (12600 * 0.97) + (24382 * 0.09) + (2800 *0.09) = 12222 + 2194 + 252 = 14668 kg CO_2
- Solution C: (13500 * 0.97) + (25915 * 0.09) + (3000 *0.09) = 13095 + 2332 + 270 = 15697 kg CO_2

The interest of this result is not on the global quantity of CO_2 emission but in the ratio between the manufacturing and usage steps. The carbon emitted during the manufacturing corresponds around to 3 years of carbon emission for its usage. In the context of planet pillar, it appears the engineering effort should be mainly achieved at manufacturing level and not at usage level. Nevertheless, the strong increase of energy prices is a good motivation to develop sophisticated engineering in order to mitigate the energy costs (profit pillar).

Function: Real-time measure of ICT energy consumption

The network architecture is based on Cisco products enabling to monitor energy consumption of devices implementing EnergyWise MIB. A monitoring software was developed for collecting by using SNMP all energy consumptions of devices compatible with EnergyWise. The interest of using SNMP is to gather other ICT information such the bandwidth usage, the temperature of equipment, etcé and to easily propose indicators of efficiency such the ratio between energy consumption of ICT architecture and its usage, to create smart monitoring in analysing the variation of energy consumption regarding the temperature, the traffic, the network configuration (number of connected ports, port speed,é).

For the other ICT devices which do not implement EnergyWise, Raritan intelligent PDUs are used. The Raritan PDU enables to especially collect the energy consumption of computers in the platform.

Function: Real-time measure of ICT Carbon Emission

The carbon emission is estimated from the measurement of energy consumed by ICT architecture and from the CO_2 factor per Kwh produced in France provided in real-time by French Company of Energy Transport (RTE) and accessible from Internet. The figure 6 shows the interface developed in this project by PERCCOM students.

Figure 6. Monitoring ICT Energy consumption and Carbon emission

4.6. Traceability matrix

The design process of green ICT architectures has to guarantee the sustainability of proposed solutions. The verification step is then crucial to check the process design. The table 3 shows that all the functions were tested confirming the system requirements satisfy the stakeholder requirements. The study of traceability matrix avoids to deliver ill-conceived projects requiring to reconsider the project. A re-design step leads to change the initial choices in selecting new ICT products to substitute un-adapted products, to develop software patches, to dismantle certain solutions,é All these modifications generates premature and useless wastes, consumes additional energy and generates wobbly solutions less sustainable.

In conclusion, Systems Engineering provides good practices to eco-design complex systems and especially to green the design of green ICT project.

Stakeholder Requirements	System Requirements	Functions	Verification method	Test Case	Test Result
GICT0.1 Ecology_Pilar_ICT Performance	GICT0.1.3.0 IT_Energy_Consumption	Energy consumption estimation of ICT architecture	Documentation	TC1	OK
		Energy consumption of ICT architecture life cycle	Documentation	TC2	OK
		Real-time measure of ICT energy consumption	Demonstration	TC3	OK
	GICT0.1.3.1 Ratio_CO2_Kwh	Carbon Emission estimation of ICT architecture	Documentation	TC1	OK
		Carbon Emission of ICT architecture life cycle	Documentation	TC2	OK
		Real-time measure of ICT Carbon Emission	Demonstration	TC3	OK
GICT0.3 Economic_Pillar_ICT_Performance	GICT03.0 Ratio_Euro_Kwh	Energy cost estimation of ICT architecture	Documentation	TC1	OK

Table 3. Traceability matrix

4.7. Eco-efficiency metrics

The results of previous study shows obvious conclusions: The carbon emission and cost energy increase with the number of ICT products in the architecture. However as explained by Ascierto, R. (2011) on PUE metric about Datacenters, the ICT system should be assessed in global way in considering the intrinsic performances of ICT including the metrics presented in the section 2. For illustrating this comment, three stakeholder requirements are added in the study:

During the usage of ICT architecture the carbon emission shall be less than 3000 kgCO_2, the energy cost shall be less than 3000ú and the reliability shall be SIL2 (10^{-7} <failures per hour <10^{-6}, in (IEC Standard 61508, 2005)).

Thus, eco-efficiency metrics coupling the green performances with other intrinsic ICT performances should be developed. These eco-efficiency metrics bring together various kinds of information, making it difficult to define a global equation that includes all requirements. A radar diagram is an interesting representation to show both the network performance and the requirements. Each Measure of Performances then corresponds to one axis of the radar. To improve the radar readability, all axes are normalized and zoomed into the interest points. The global view offered by the radar diagram should make the analysis of network solutions easier, both for the designer and the customer. The best solution is the one where all the MoP results are in the centre of the radar, but the best one relative to the requirement (optimised solution) is the one where the MoP results are close and beneath the specification line.

For estimating reliability MoP, it is necessary to define n_i as being the number of items of equipment forming a path i. Item is either a link or a switch. Let ə be the failure probability per hour for any item and ε =1- ə as the non-failure probability. It is considered that all switches and links have failures per hour equal to ə=10^{-5}. The failure probability of a network (P) composed of p independent paths depends on the failure probability of each path i (Pi) such that:

$$P = \prod_{i=1}^{p} P_i = \prod_{i=1}^{p} (1 - \mu^{n_i})$$

For example, considering the solution C, there are three paths formed by three items (one switch plus two links). This gives:

$$P = \left(1 - \left(1 - 10^{-5}\right)^3\right)^3 = 2.7 \times 10^{-14}$$

The results are for solution A: 3.10^{-5} and for solution B: 9.10^{-10}

All the Measures of Performances and the requirements are collected in a single radar (figure 7). The System Engineer can then select the most appropriate solution. The radar diagram shows is that only the solution B satisfies all the stakeholder requirements (green line) since the reliability of solution A is not acceptable and the energy cost of solution C is too high. If all solutions are not satisfactory, the stakeholder requirements should be redefined, refined in iterative way with the system and ICT engineers in order to converge to consensual and acceptable solutions.

Regarding ethic consideration, this iterative process in the systems engineering approach provides professionalism and respects the ethical bases for IT decision making defined by (Grupe F.H. et al 2002).

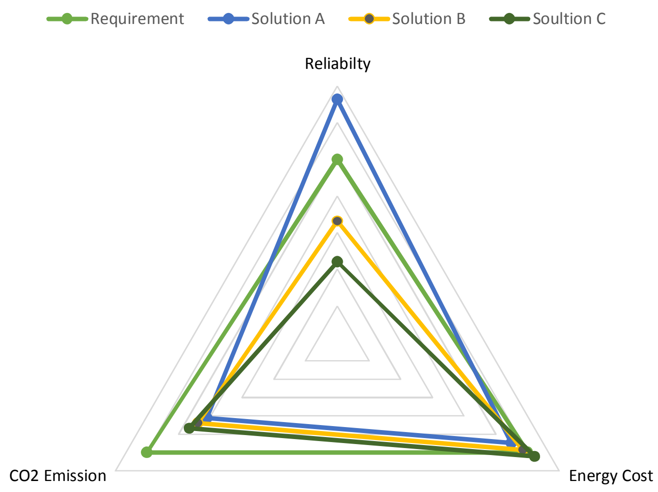


Figure 7. Radar diagram

5. Conclusion

The design of green ICT-based solutions should be studied in considering the three pillars of sustainable development (figure 1). The analysis is complex because it conducts to develop an ICT solutions with three objectives having sometimes opposite criteria. Moreover, the analysis of ICT impact on planet covers an unlimited scope which should include all the pollution forms and the earthǿs resource management making difficult its global assessment during the whole ICT product life cycle. Pragmatically, Green ICT mainly focuses on energy optimisation. The major explanation is that it is a win-win activity due to its double benefits on planet and on profit pillars. The recycling has also a positive incidence on these both pillars since it enables to indefinitely reuse the rare materials more and more expensive. However, its implementation is very complex and the return of investment is less immediate than energy. Regarding the people pillar, there are many contributions in the literature on Computer Ethic. However, from our best of knowledge, there are not significant contributions coupling Computer Ethic with Green ICT in a global sustainable development approach. People pillar should be analysed at two levels: (1) on how is designed the ICT solution and (2) on how is used the developed ICT solution.

Nevertheless, the representation of sustainable development from a triangle is restrictive and especially hides the ICT performances corresponding to the fundamental activities of ICT engineers. Perhaps, it is one reason explaining the first green metrics in datacentres do not include itself datacentre activities. The goal of the sustainable development triangle is to force the ICT engineer to analyse the interactions between the three pillars in order to converge to balanced solutions satisfying all the stakeholders. However, the base requirements for an ICT professional when creating new ICT solutions is to specify SLA with economy and ICT metrics. In the figure 8, a new axis is then added to the triangle of sustainable development enabling to integrate ICT metrics in the Green ICT systems engineering. From this Green ICT metric pyramid, the ICT engineer is now able to study the relationships between ICT metrics and the ones of sustainable development triangle in order to propose eco-efficiency green ICT metrics and to specify Green SLA.

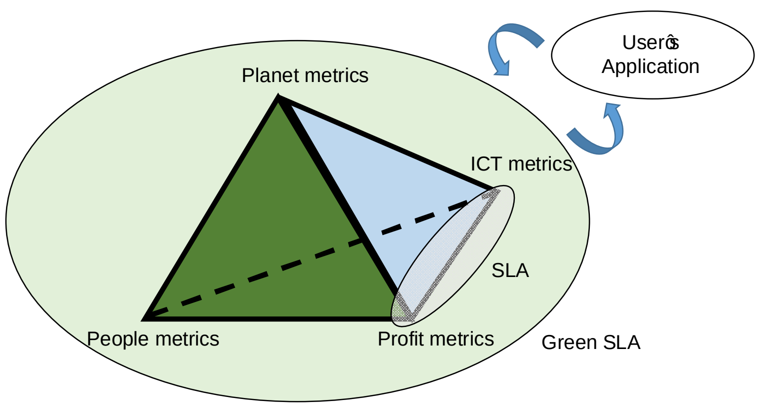


Figure 8. Green ICT Metric pyramid.

A systems engineering approach is recommended in green ICT projects in order to develop more sustainable ICT-based solutions gathering in the same study all the stakeholder requirements and enabling to check the conformity of solutions. Moreover, new constraints directly related to the climate change make more complex ICT engineering. Indeed, ICT sector contributes to climate change and the consequence is ICT sector has to propose resilient ICT solutions face to the climate changes. (ITU, 2014) explains the risks posed by both acute weather events (e.g. short-term extreme events such as cyclones and intense rainfall and flooding) and chronic trends (e.g. long-term changes in temperature, seasonality and sea level rise) to guarantee reliable telecommunication infrastructures. For example the installation of antenna should be more robust face to extreme wind, lightning, heavy snow fall. In (ITU, 2014), a checklist of new constraints is proposed to be sure that all these new extreme conditions were envisaged in ICT engineering step.

Finally, the SMART 2020 (Smart 2020, 2008) report shows the ambivalence of ICT sector since it was responsible in 2007 for 2% of global carbon emissions and then participates to the climate change, but ICT sector could contribute to mitigate the carbon footprint of other human activity sectors such as transport, buildings, power and industry by improving their energy efficiency. In this context the role of ICT Engineers is to design and to create new smart metering in order to analyse and control in real time the energy consumption of applications. These metrics defined by applications (transport, building,é) are additional metrics not include in Green ICT metrics presented in this chapter.

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