CHAPTER 3

Green IT current developments—A strategic view on ICT changing the global warming trend

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The rapid growth of carbon emissions is alarming and ICT is playing an important role in changing this trend. On the other hand, ICT usage is growing exponentially and the carbon footprint of the ICT sector itself has already surpassed in 2008 that of the aviation industry. This chapter, on current developments in Green IT, deals with greening the ICT sector itself, as with deployment of ICT to green other sectors. Greening IT requires greening the datacenter where most of the energy is being consumed. Virtualization and proliferation of cloud services will make computing and data access ubiquitous for the users and will help increase the utilization factor of ICT infrastructure, therefore increasing its energy efficiency. Green software and data life cycle management help decreasing the overall footprint of applications and avoiding over-sizing of hardware. ICT has been widely recognized as an enabler for a low-carbon future and greening by IT has become the motor of the rapidly growing green economy. Smart Grids is one of the most promising areas of greening by IT, as it enables optimization of electricity consumption, decentralization of energy production and deployment of renewable energy sources. ICT has also a major impact on decreasing the large carbon footprint of the transport sector by optimizing logistics, improving filling rates, reducing congestions and reducing the necessity of moving people and material. Smart buildings use ICT for improving insight in energy consumption and reduce its carbon footprint. ICT enables rethink building design and energy use and making buildings part of the energy solution instead of the problem. Greening the industry is a must as the world is since 1987 in overshoot in terms of raw material consumption. ICT can help in improving the efficiency of the industry, optimizing supply chains and raw material (re-)use and leading to customer participation as a prosumer of the industry. ICT is also widely deployed for dematerialization of content delivery and Big Data will help understanding customer behavior and assist in improving the adoption and deployment of sustainability measures. Finally, to avoid a rebound in energy consumption as a result of improving energy efficiency, a holistic approach in Green IT is highly recommended.

3.1 INTRODUCTION: GREEN IT AND SENSE OF URGENCY

Sustainability was defined by the WCED report "Our Common Future", published in 1987[1] as "to meet the needs of the present without compromising the ability of future generations to meet their own needs". The world's sustainable use of energy and raw material reached in 1987 the limit of planet capacity and since then it is in overshoot. Sustainable use calls for finding a balance between the three P's: People (social equity), Planet (environmental protection) and Profit (economic growth).

The growth of the ICT sector was largely related to the ability of ICT to support those three pillars of sustainability. ICT helped economic growth, improve efficiency of energy and raw material use and widen social access to wealth and prosperity. This growth has subsequently led to an exponential increase of energy use and carbon emission by the ICT sector itself. In

[1] http://www.un-documents.net/our-common-future.pdf

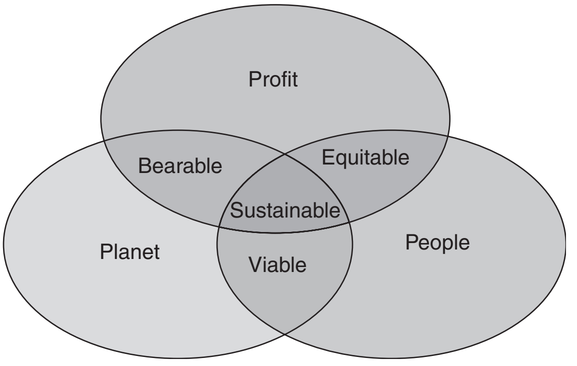

Figure 3.1. The Venn diagram of sustainable development[2].

2007, Gartner estimated that ICT industry accounts for 2% of global CO_2 emissions[2], a figure equivalent to the emission of the aviation industry and despite the overall environmental value of ICT, Gartner believed this is unsustainable.

Surveys of the evolution of ICT consumption produce an alarming conclusion: those emissions grew from 2% of global emissions in 2007 to 3% in 2009 and are projected to increase to a colossal 6% by 2020, while globally the overall Green IT maturity is still low[3]. The promise of ICT is nevertheless that it can more than compensate the growth of its own emissions by greening other industries. The World Wide Fund For Nature (WWF)[4] and the American Council for an Energy-Efficient Economy (ACEEE)[5] quoted that "For every extra kilowatt-hour of electricity that has been demanded by ICT, the U.S. economy increased its overall energy savings by a factor of about 10". The much-quoted 'SMART 2020' Report[6] sets this 'offset factor' at a multiple of five. We are all assuming that Green IT will play that projected role of greening enabler, but the recent surveys of ICT footprint tell us that those expectations at the moment are not only exaggerated but even potentially fatal if that gap between potential and reality is not rapidly overcome with an accelerated multidisciplinary research, development and implementation program for both greening IT and greening by IT.

This chapter outlines recent developments in greening the ICT sector (greening IT) and in deploying ICT for greening other sectors (greening by IT). Two frameworks for Green IT will be first presented. Greening IT research portfolio outlined here is focused on greening the datacenter, as the majority of carbon emissions of ICT are produced there, improving software and data use of infrastructure and deployment of virtualization and cloud services. Greening by IT is being positioned as essential to resolve the present conflict between growth and sustainability. ICT will be positioned in this chapter as an enabler of the new low-carbon sustainable economy. ICT is key to green major economic sectors such as energy, transport, buildings, industry and media. A holistic approach for deployment and use of ICT is though necessary in order to avoid the rebound effect of overutilization of world resources due to the improved efficiencies brought up by ICT.

[2]http://www.gartner.com/it/page.jsp?id=503867
[3]http://www.ictliteracy.info/rf.pdf/green_IT_global_benchmark.pdf
[4]http://assets.panda.org/downloads/identifying_the_1st_billion_tonnes_ict_academic_report_wwf_ecofys.pdf
[5]http://www.aceee.org/sites/default/files/publications/researchreports/E081.pdf
[6]http://www.smart2020.org/_assets/files/02_Smart2020Report.pdf

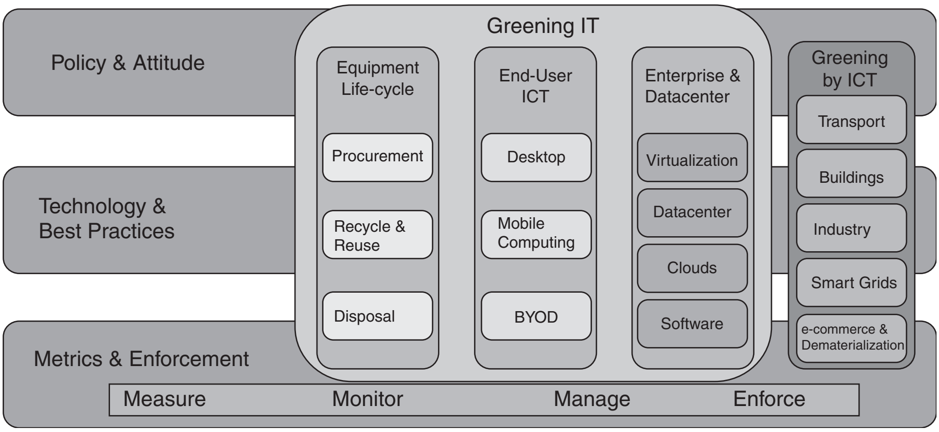

Figure 3.2. A variant framework of the one developed by Connection Research and RMIT University in 2010.

3.2 GREEN IT FRAMEWORK

One of the reasons for the mentioned gap between the high expectations and modest reality of Green IT impact on carbon emissions today is the lack of clarity in defining Green IT and understanding its many components. Green IT framework should cover both Greening IT and Greening by IT. The focus of Greening IT is on reducing the carbon footprint of the ICT sector itself. Greening IT requires collaboration between many parties including energy providers, installation equipment manufacturers, datacenter designers and service providers, IT equipment suppliers, software developers, universities & knowledge centers, designers and policy makers. Greening by IT is concerned with deployment of ICT for energy savings in other sectors. Greening by IT is per definition multidisciplinary and requires a close interaction between the ICT and the many application domains where ICT is a low-carbon enabler. All actions taken within a Green IT program should reflect policy, practice, attitude, technology, best practices, metrics and enforcement.

The framework presented above is a variant of that developed by Connection Research and RMIT University in 2010[7]. End user ICT is being fundamentally changed by the developments related to the present "bring-your-own-device"[8] (BYOD) possibilities in conjunction with public and private cloud offering. Many of the issues related to the use of ICT in offices will therefore shift towards the datacenters. As we will see later in this chapter, greening datacenters on the other hand, cannot be done in isolation without involvement of and collaboration with the energy provider. Datacenter energy label will depend on the ability to store hot and cold energy, and the possibility of becoming an intrinsic part of the smart energy grid. Greening by ICT must be conducted in close collaboration with and involvement of the ICT supplier as the success of the deployment of ICT will very much depend not only on the ICT applications developed but also on the willingness and ability of ICT vendors to conduct technological innovations in order to accommodate specific requirements in each area of industry. Community clouds and Big Data technologies will play an important role in maximizing the impact of ICT in greening other sectors.

[7] http://totalexec.posterous.com/latest-research-green-it-performance-internat
[8] http://www.gartner.com/resources/238100/238131/bring_your_own_device_new_op_238131.pdf

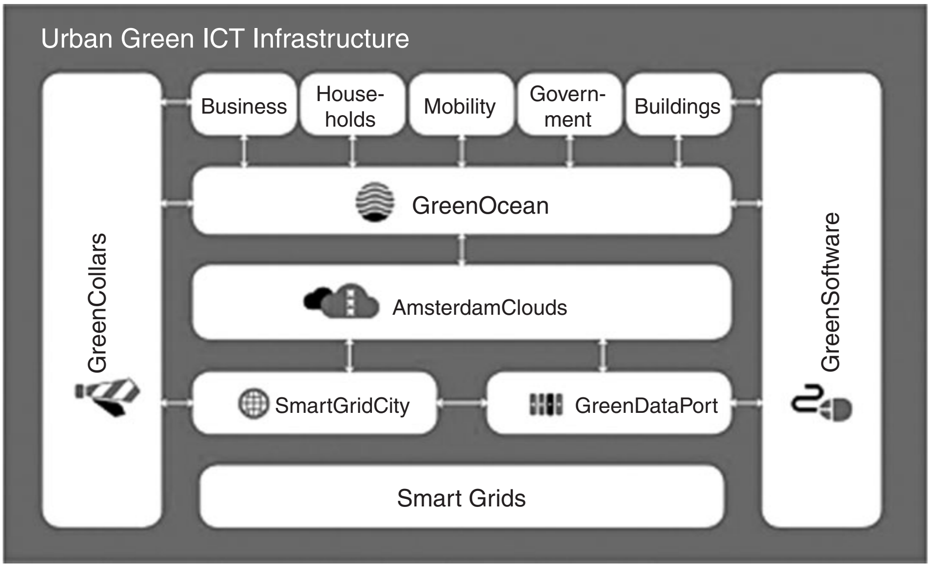

Figure 3.3. Another variant framework adopted by the consortium green IT Amsterdam Region.

Another framework was adopted by the consortium Green IT Amsterdam Region[9]. Founded in June 2010, the consortium was initiated by the City of Amsterdam to help achieve a reduction of carbon emissions of 40% in 2025 as compared to 1990. The consortium members are regional datacenters, ICT suppliers, energy companies, regional authorities, and knowledge institutes. The framework adopted by the consortium is oriented towards meeting carbon reduction goals through a mix of projects making datacenters greener, electricity grids smarter, software more energy efficient, developing and incorporating sustainability skills within education and business and contributing to the creation of an ocean of green IT applications. The projects initiated within the framework are a mix of activities with quick wins and long term developments and investment.

3.3 GREENING THE DATACENTER: THE POWER LOSS CHAIN

One of the most important areas of Greening IT is greening datacenters. The British Computer Society published in 2008 a chart[10] stating the percentage of energy delivered (blue part) at every stage of the Power Loss Chain ‘from fuel to CPU’. That chart gives a deep insight in the Green IT main issues that need to be tackled not only within the datacenter but also within the energy and ICT sectors as well.

The chart can be divided in three stages: The first stage, causing in absolute term the most significant losses, explains the importance of smart grids and power generation within the datacenter (as 65% of energy is lost at the power plant), the second stage in the middle of the power loss chain is concerned with greening the datacenter itself, and the third and last stage of the power loss chain, explains the high impact of virtualization and cloud technologies. Software and data life cycle management have an integral impact on the sizing of the equipment and total amount of energy needed. Finally, Big Data will provide better insight in user behavior, trends and correlations and will help improve energy efficiency of smart grids and ICT clouds.

[9]http://www.greenitamsterdam.nl/
[10]http://www.allhands.org.uk/2008/programme/download7004.html?id=1244&p=ppt

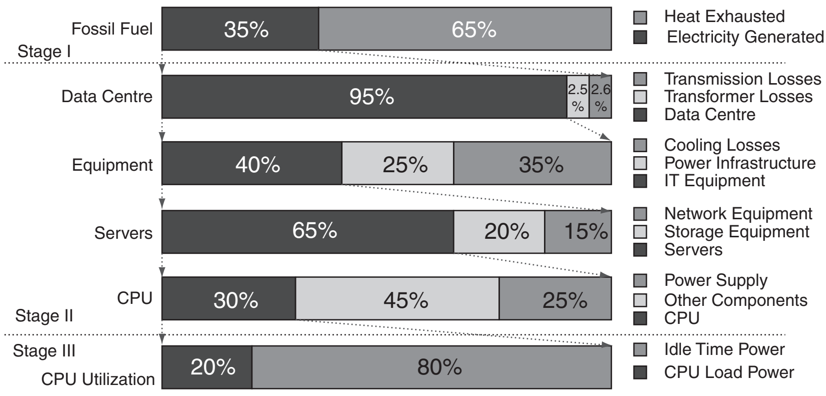

Figure 3.4. The percentage of energy delivered (blue part) at every stage of the power loss chain "from fuel to CPU" as defined by Liam Newcombe (BCS, 2008)

3.4 GREEN IT AND SMART GRIDS (STAGE I)

Electrical smart grids enable optimization of electricity production and usage by producing, analyzing and using a wide range of information about the grid and its users. Smart grids are also essential in greening the power generation itself by offering citizens the possibility to generate sustainable energy like solar or wind energy empowering consumers to become a "prosumer" in energy[11]. Smart software is key in linking power usage data, analyzing patterns and trends, and enabling real-time balancing of energy production and distribution. Smart grids are therefore essential in the conversion of the power industry to become customer-centric and improve, however paradoxical this may sound, the efficiency of the power generation process by enabling decentralization of energy production. This will lead to the optimization of the power station size, minimizing its footprint and maximizing its utilization factor. Network and Big Data technologies will also play an important role in the transformation of electrical grid operations exploiting data sources in order to improve the production, power distribution and usage efficiency.

Smart grid technology is a rapidly evolving area of innovation and development[12]. Sensors and Smart meters are making significant changes in the utility industry offering the possibility of new applications and helping develop smarter buildings and smarter communities. Some of the biggest challenges in smart grids are currently the decentralization of energy production and the incorporation of new power storage possibilities like soil heat storage and electric vehicles as part of the smart grid. This requires new ICT technologies like demand-side management applications, and distributed generation management, including virtual power plants and local smart grids. The Science Park Amsterdam has already developed an R&D plan for experimenting in intelligent networks for smart grids with focus on applications and effects of the deployment of smart meters, decentral sustainable energy production and incorporation of the data center in the power grid[13]. Datacenters do have a large capability of conventional electricity generators that are rarely used and only deployed in the case of power interruptions. Those large capital investments with substantial CO_2 footprints could be better exploited if they form part of the smart grid itself and can be deployed for a better balancing of the power production at peek consumption periods.

[11] http://www.efficiencyconnectionsnw.com/uploads/01_Williams_1Dec2010_Macrowikinomics.pdf
[12] http://www.globalsmartgridfederation.org/documents/GSGFreport_stateofworldsmartgrid_4_26_12_000.pdf
[13] https://dl.dropbox.com/u/4042336/PowerMatcher%40Science%20Park%20Amsterdam.pdf

Research activities should provide a model for understanding how smart grids are evolving and analyze the impact of smart meters, regional power generation at homes or at the datacenter on electricity distribution, and customer behavior. Incorporation of energy production within the datacenter is a hot research domain and many innovative datacenter concepts are worth investigating[14,15,16]. Interesting new applications are virtual power plants, outage management and asset management. Interesting growth areas are smart grid software, data analytics and related applications and services.

3.5 GREENING DATACENTERS (STAGE II)

The global economic slowdown is forcing governments and organizations to reduce costs and avoid capital investment through consolidation of their ICT infrastructures[17]. The uncertainty about the future energy supply and rising costs of electricity are also putting the datacenter energy consumption in the spotlight. Enterprises are becoming more cautious about building new local datacenters, adding to the attraction of alternative models in the form of outsourcing, hosting and ultimately cloud computing services. Government rules and regulations to which datacenters must adhere do vary between countries and regions[18,19,20], however, datacenters are increasingly under the purview of regulatory and voluntary agreements on energy efficiency, green house gas (GHG) emissions, water consumption, and other environmental issues. Such moves increase the commercial benefits of green datacenter design and provide further momentum for research topics in, and for the market of, energy-efficient technologies.

Complexity of datacenters makes it impossible to have one single technology or design model to make a data center green. Greening an existing datacenter means a continuous program of improvement based on best practices and green technology guidelines. New datacenters must be green by design, built to meet the specific business requirements and use new technological possibilities. Higher computing power densities, frequently due to virtualization and higher dependency of businesses on ICT are putting additional strains on datacenter power and cooling requirements. Virtualization is however recognized as the innovation with the greatest impact on the shape of modern datacenters. It is also recognized as one of the most effective steps toward improving power efficiency of existing datacenters. In order to gain the maximum benefits from virtualization, the various components of the datacenter infrastructure must be optimized (research topic) to support more dynamic and higher-density computing environments.

The complexity of greening existing datacenter increases with the level of ambition. Low-hanging fruit is easy to pick, but higher ambitions require research into system innovations. There are many factors that play a role and the best results can only be obtained when greening is done on various fronts within the datacenter. The good news is that many solutions and techniques are available. Moreover, the greening process of existing datacenters cannot be forced because of the "installed base" or because of budgetary reasons and has to be done in steps to ensure continuity of the operations, minimize risks and consolidate gradual improvements. The strategy of discarding existing datacenters is far from green as it leads to high capital investment losses with a large already made carbon footprint.

However, improvements can only be truly assessed if both the energy consumption and datacenter productivity (and therefore the benefits the energy consumption provides) can be adequately

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[14]http://bits.blogs.nytimes.com/2008/09/07/googles-search-goes-out-to-sea/
[15]http://www.ozzodata.com/
[16]http://www.parthenondatacentres.com/
[17]http://www.informationweek.com/news/government/policy/231900242
[18]http://www.datacenterpost.com/2010/10/government-regulations-impacting-data.html
[19]http://www.datacenterdynamics.com/focus/archive/2011/12/london-2011-eu-code-conduct-helps-telecity-comply-crc
[20]https://dl.dropbox.com/u/4042336/Eindrapport%20energiebesparing%20bij%20datacenters.pdf

measured[21]. Datacenter Power Usage Effectiveness (PUE) is a first, relatively simple step in achieving this goal. PUE hides yet almost as much as it discloses[22]. New datacenter productivity metrics must therefore be developed (research topic) in order to offer a better understanding of the datacenter's carbon footprint and make comparison between datacenter sustainability levels possible. Many research activities are conducted in this area[23,24,25,26].

Research on recipes and guidelines is being published to help with the transition to a greener datacenter[27]. An example is the development of a system that accurately measures the energy consumption of individual components (e.g. servers, routers, switches, network, storage, chillers, CRACs, PDU, UPS). The energy consumption on datacenter level, or on individual rack level, can then be continuously monitored, analyzed and optimized. Cooling plays an important role to lower energy consumption within a datacenter. The heat balance within a datacenter must be accurately mapped in order to avoid hot spots, hot zones or over-cooling. Computer simulation and modeling can help in this.

Datacenter operations are dynamic and require sophisticated management tools and a holistic view of the entire facility. It also requires a much closer relationship between facilities and IT professionals. SCADA systems help in monitoring the many factors that affect consumption and offer online reporting on live data making rapid intervention possible[28]. R&D in the area of datacenter management tools helps close the gap between cooling, power, and IT systems and offer a better insight into infrastructure and IT performance, enabling automatic adaptation to real-time changes in the environment. A comprehensive energy reduction plan can then be established and be regularly reviewed and updated. A tight coupling between the individual rack consumption and corresponding applications or users should be kept in order to support and stimulate the process of optimization. The ultimate challenge is to realize a closed-loop management and optimization of the datacenter energy consumption.

In addition to careful selection of energy efficient products, optimization of air flow and cooling (using measurements and simulations), and reducing the losses of energy transport and conversion (e.g. by locating the datacenter closer to the power source), there are additional measures that make a datacenter greener. Close research collaboration with the supplier can lead to the acceptance of higher operation temperatures than strictly specified in the operation manual. A few degrees higher operation temperature means less cooling power and a longer period of the free-air-cooling[29,30,31]. Collaboration with the energy supplier may help in getting excessive hot and cold energy stored or even used by third parties. And last but not least, the measures to green an existing datacenter are only optimal when the racks within the datacenter (or portions thereof) can be standardized. Modularization is therefore one of the key concepts in modern datacenter design. Most advanced form of modularization is the containerized solutions[32] with prefabricated components deployed on-site, and optimized for the applications served. A modular approach enables a standardized, application-optimized and tested model for the datacenter, offering a flexible approach to deployment. Modularization can also be seen as part of a shift towards an

[21] http://uptimeinstitute.org/wp_pdf/(TUI3009F)FourMetricsDefineDataCenter.pdf
[22] http://greenqloud.com/greenpowerusageeffectiveness-gpue/
[23] http://gigaom.com/cleantech/7-green-data-center-metrics-you-should-know/
[24] http://www.thegreengrid.org/~/media/TechForumPresentations2011/Data_Center_Efficiency_Metrics_2011.pdf?lang=en
[25] http://sameekhan.org/pub/W_K_2011_SUPE_SI.pdf
[26] http://link.springer.com/chapter/10.1007%2F978-3-642-32606-6_7
[27] https://dl.dropbox.com/u/4042336/CE_Delft_3686_Vergroenen_Datacenters_def.pdf
[28] http://www.sustainableplant.com/2011/04/data-center-monitoring-system-improves-efficiency/
[29] http://perspectives.mvdirona.com/2011/02/27/ExploringTheLimitsOfDatacenterTemprature.aspx
[30] http://www.datacenterknowledge.com/archives/2011/03/10/energy-efficiency-guide-data-center-temperature/
[31] http://www.eni.com/green-data-center/it_IT/static/pdf/ASHRAE_1.pdf
[32] http://www.datacenterjournal.com/press-release/welcome-to-the-worlds-first-data-center-container-park/

industrialized view of the datacenters. Standardization, modularization and virtualization are essential research topics for optimizing datacenter management, energy consumption, utilization factor and cooling strategy and do not stand in the way of innovation in ICT applications.

3.6 SUSTAINABILITY THROUGH VIRTUALIZATION AND CLOUD COMPUTING (STAGE III)

The move to cloud computing is one of the most dramatic ICT trends of this decade. The market for cloud computing services has continued to expand during the recession despite the decline in economic activity in most of the world. Cloud computing revenue is even expected to grow at a rate of 28.8%, with its market increasing from US$ 46.0 billion in 2009 to US$ 210.3 billion by 2015[33]. Cloud computing models – in all their diversity across public, private, community and hybrid clouds – will be the predominant paradigm for the next generation of ICT services. We are, however, only at the beginning as many cloud applications are still to be developed. New metrics and new levels of transparency are required if the impact of clouds on sustainability is to be adequately assessed.

Cloud computing is the next step beyond virtualization and grid computing. Increasing the utilization factor by sharing ICT infrastructure plays a pivotal role in greening ICT. Public cloud providers must make their datacenters as energy efficient as possible for obvious competitiveness reasons. New generations of hardware, software, and even business processes are developed in order to leverage the enormous scale of the cloud and make ICT more energy efficient. This promise can though be deceiving if the high utilization factor of mostly public clouds is not met. High availability requirements and projected economy of scale of public clouds may even play a detrimental role on energy efficiency below a certain utilization threshold[34,35].

As cloud computing continues growing, equipment suppliers and datacenter manufacturers will focus their designs on the needs of this important market segment. Energy efficiency is one of the most important among those. The green promise of clouds is in the massive investments in economy of scale and newest datacenter technologies, making clouds in general and public clouds in particular achieve industry-leading rates of efficiency, when and only when clouds are better utilized and less expensive to operate than traditional datacenters. This means higher levels of standardization, modularization, hardware optimization and virtualization. Public clouds are therefore most suitable for general purpose applications.

Community or sector-specific applications like in healthcare, chemistry or public services should be moved to community or sector clouds[36]. There is a rapidly growing need for a sector specific approach to cloud services. Public cloud services have so far focused on horizontal solutions. The business model of these services is based on maximum economy of scale, but is not always addressing sector-specific needs. In order to overcome this important limitation a sector-specific approach to cloud services is needed. Sector-specific clouds provide additional advantages over private and public clouds. They focus on those shared - and often specific - needs and facilitate business processes at the right level of privacy and security but also provide hardware effectiveness and efficiency within the sector. The implementation of sector-specific clouds will still be based on the general standard public cloud technology (open source or commercial) as underlying platform, but offers in the same time the opportunity to incorporate specific elements that are important for the sector. Common data and processing requirements can still be contracted within the public cloud, while enterprise critical data remain indoors or stored in the shared infrastructure. Sector-specific clouds are clearly complementary to the existing public and private

[33] http://www.pikeresearch.com/research/cloud-computing-energy-efficiency

[34] https://dl.dropbox.com/u/4042336/TNO%20-%20Cloud%20Computing%20-%20grijs%20of%20groen%202012.03.23.pdf

[35] http://greenmonk.net/2012/01/09/is-cloud-computing-green/

[36] http://arxiv.org/pdf/0907.2485.pdf

clouds but offer a much better fit between hardware configuration and sector specific application requirements leading to a much better application scaling than when using public clouds.

Many industrial sectors (health, creative industries, life sciences, logistics, etc.) still use physical media (disks or tapes) to exchange data, accepting all related disadvantages in terms of carbon footprint, time loss, higher costs and increased privacy, security and fraud risks. Sector clouds allow the pooling and integration of sector-specific solutions simplifying data and application sharing and creating a sector-specific cloud of users and providers with a sector-wide coverage. The ultimate goal is to develop an industry or sector specific ICT ecosystem. Another interesting advantage of sector clouds is that they can be set up in a federative way, making it possible to preserve the already made investments in local datacenter and ICT personnel. This aspect is mostly not addressed by public cloud providers, advocating a drastic outsourcing of ICT and ignoring the large scale destruction of existing private infrastructure and carbon footprint investments. Such a federative approach is still in the infancy stage and needs to be further developed (research topic).

3.7 GREEN SOFTWARE AND DATA LIFE CYCLE MANAGEMENT

The electronics industry has for years been aware of the energy challenge by the simple fact that the increasing miniaturization got limited by the cooling capacity within components and systems. The software industry must still make this turn. It is now often the case that software applications are written with Moore's Law still in mind. The direct software development costs are higher than CPU time and developers are no longer as in the eighties, interested in optimizing flops, bits and bytes. One even refers to the "Wintel" alliance: each new version of Microsoft Windows (and Office) required more CPU power. The users were consequently forced to upgrade their hardware, while they mostly only needed to buy a limited part of the functionality. Green labels for software are therefore important and research into best practices and tools for reaching that goal are very much needed. Green compilers should be developed to assess the level of energy efficiency of software developed or help with improving its carbon footprint. Tools should help the user select greener software components and commercial products for their applications. Software has a huge multiplier impact on datacenter energy consumption and developers know that a small effort of software optimization mostly leads to an order of magnitude of performance improvement, which means that much less hardware would be needed for the same performance level.

On macro-level, centralization of software will help decrease the overall footprint of applications and avoid over-sizing of hardware. The strategy of bring-your-own-device with hand held devices and thin clients or laptops, decrease the energy consumption of software and limit the footprint to the applications running in the cloud. Another interesting research area is how to decrease the data carbon footprint. The problem is the huge amount of unnecessary data duplication and transfer and the ease with which we do this to ourselves. The enormous impact on energy consumption can be reduced by using smart compression software. But the best solution is to adopt smart information lifecycle management (including the hot, cold and frozen data concept) and de-duplication techniques[37]. Smart software must ensure that data is not duplicated unnecessarily, kept online or stored for ever. Less unnecessary storage means less unnecessary energy waste.

3.8 BIG DATA AND SUSTAINABILITY

Big Data aims at exploiting advanced data storage, access and analytics technologies handling high volume and fast moving data in a variety of scenarios. These typically involve low signal-to-noise ratios, such as social media sentiment monitoring, or log file analysis, and require novel

[37]http://www.data-archive.ac.uk/media/2894/managingsharing.pdf

Big Data techniques in a user centric approach. The use of Big Data as a Green IT technology is already widely reported[38,39]. With smart phones and tablets being widely spread, apps are likely to be developed to offer the benefits big data applied in sustainability, in order to manage building energy efficiency, precision agriculture, food production, water, transportation and mobility, waste, manufacturing, and materials reuse.

As mentioned above, the energy consumption of data storage must be dealt with. Big Data would be adding a huge energy bill to the ICT world-wide consumption if this energy aspect of Big Data it is not adequately dealt with. Techniques for data management and de-duplication can help, but the biggest effect is expected to be obtained from Big Data technology itself. Big Data analytics are expected to give us a better insight in many socio-economic aspects that are difficult to obtain with traditional techniques of data analysis. Insight in user behavior, trends and correlations is very helpful not only in greening by IT but also in greening IT itself. Data analytics are expected to offer new insights in the use of ICT infrastructures and help improve energy efficiency of smart grids and ICT clouds.

3.9 SUSTAINABILITY AS MOTOR OF THE *NEW* ECONOMY

While most economic sectors in the world are shrinking as a result of the present global economic recession caused by the 2008 financial crisis, the so-called green economy is still growing. Transition to low carbon and energy efficient products and services offers a golden opportunity to escape the negative spiral the world is entangled in and helps deliver a sustainable economic system, with growing consumption but without destroying the climate and exhausting natural resources. Germany en Denmark's ability to resist the financial crisis has been impressive and their policies have ensured a strong position as low carbon pioneers and market leaders in renewable energy. 'Greening the economy isn't just good for the planet – it's good for the wallets, purses and pockets'[40] according to the British Deputy Prime Minister (February 2012).

The Davos 2012 Conference of the World Economic Forum, reiterated on the other hand that *water, food and energy security are chronic impediments to economic growth and social stability*. With more people, increasing consumption and fewer resources there is a growing global risk of severe tightening of water, food and energy resources to meet the demands of an increasing global population and may result in more wars and global unrest. And while ICT is part of the energy and pollution problem, ICT may be *the* most important part of the solution.

3.10 ICT AS AN ENABLER FOR THE LOW-CARBON ECONOMY

The above mentioned reports and many others[41,42,43,44,45] identify opportunities to deploy ICT to improve energy efficiency and dematerialize various goods and services. The SMART 2020 report was the first to quantify resulting carbon savings through ICT deployment. The report shows that whilst the ICT emissions are expected to increase as a result of more deployment of ICT (first order effect), this will lead to total emission reductions five times the size of the ICT

[38] http://techcrunch.com/2011/09/28/farmeron-google-analytics-for-farms-gets-investment-from-dave-mcclures-500-startups/
[39] http://gigaom.com/cleantech/using-big-data-to-make-solar-smarter/
[40] http://www.decc.gov.uk/en/content/cms/news/pn12_007/pn12_007.aspx
[41] ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/sustainable-growth/ict4ee-final-report_en.pdf
[42] http://e.mckinseyquarterly.com/W0RH00549D4B249DF830B29EECD040
[43] http://assets.panda.org/downloads/it_user_guide_a4.pdf
[44] http://www.oecd.org/site/stitff/45983022.pdf
[45] http://www.apt.int/sites/default/files/Upload-files/ASTAP/Rept-1-Introduction%20to%20Green%20ICT%20Activities.pdf

own footprint. The power of ICT is to change processes to become more energy-efficient (second order effect). According to Smart 2020, greening by ICT would enable up to 15% reduction of the global emissions by 2020 (business as usual, third order effect not included). The third order effect is that ICT teaches us about environmental effects of our behavior and enables us to rethink or change it. This third order effect, called transformative change by the WWF[46], typically an R&D area, is expected to have a factor three effect on the total reduction of global emissions (average of 45% reduction by 2020). ICT will help here to get beyond existing systems and transform linear thinking on infrastructure use, incentive models and even common values across societies and sectors.

Analysis of above mentioned Greening by IT initiatives does not provide a strict recipe how to deploy ICT to green the various sectors of the world economy. Most initiatives are just emerging from the pioneering phase and reveal many green business opportunities and regulatory issues. They provide also valuable insights on potential benefits (second order) of different IT applications. Third order effects are more difficult to capture, especially when socio-economic behaviors need to be predicted over a longer period of time. Various R&D attempts to systematically map the potential impact of ICT at a global scale show that most benefits can be obtained in the transport sector, smart buildings, smart industry, smart grids (dealt with in Part-I), e-commerce and dematerialization. The effects of greening those areas are best guesses and their priorities and potential impact will change substantially with technology and society.

3.11 TRANSPORT SECTOR

ICT has a major direct impact on greening the transport of people and goods in many ways. The role of ICT in optimizing transport logistics improving filling rates and transportation routes is well-known. Deploying sensing and control techniques, big data analytics, online management tools, GPS and mobile communications helps provide relevant information to the users, optimize traffic control, facilitate smart parking, improve public transport fill rate and quality of service, reduce traffic congestions and journey duration and implement dynamic road pricing scheme, minimizing as a result the total transport carbon footprint.

Another area of interest is minimizing employee home-work commutation by promoting work mobility (using BYOD[8], internet and cloud services) but also promoting concepts like smart work centers[47] (office centers in residential areas, shared by various employers and offering employees professional work environment close to their homes). Techniques like virtual presence (permanent video link with colleagues) help coping with many disadvantages of distant working like social isolation or degradation of team cohesion. Investments in next generation video conferencing techniques (High definition video, life-sized images, spatial audio, imperceptible latency and ease of use) help improve the quality of conferencing making external meetings less necessary and decreasing the company's travel carbon footprint. Saving commuting costs is also a hot item in education. Open and distance learning help to provide localized content to students in their native communities, save travel costs and increase availability of specialized knowledge.

A transformative impact of ICT is to rethink current transportation systems. Smart grids can lead to a new model where vehicles (electric cars with generators on board for instance) can be seen as mobile energy generators, where energy could be produced and used locally when not in use on the road. Such a shift could transform residential areas in people and goods transportation nodes. The same line of new thinking applies for datacenters, where putting datacenters in residential areas helps to minimize data transport costs and provides local energy production facilities as well.

[46]http://assets.panda.org/downloads/fossil2future_wwf_ict.pdf
[47]http://www.connectedurbandevelopment.org/connected_and_sustainable_work/smart_work_center

3.12 SMART BUILDINGS

ICT supports a wide range of technologies to improve efficiency of buildings and connect those to the internet and the clouds. Traditional technologies, such as Heating, Ventilation, and Air Conditioning (HVAC) are mature. Building Energy Management System (BEMS) and Building Information Modeling (BIM) are relatively new. Both are evolving rapidly and revolutionizing the usually conservative building sector. Proprietary BEMS solutions have already been around for several years but the trend is to push the concept one step further, offering an open platform for building management and modeling and for hosting users and third-party developers of application[48]. Building owners and occupants will then be able to tap data from their building system and other data sources (weather, energy providers, municipality, utilities, etc) and co-develop their own community building management system (prosumer approach). Social media communities help deployment of crowd sourcing for sharing best practices and funding the further development of smart buildings.

Smart controls have already been available for decades, but they have not yet been used in conjunction with a wide range of other data sources. With smart controls, smart buildings are able to offer efficient and natural lighting, better electrical appliances and cooking facilities and environmental heating and cooling systems. BEMS connected to internet and the clouds offer the users and operators a dynamic and precise insight into building energy consumption and assistance in saving energy. Cloud-based solutions connected to a wide range of real-time big data sources can offer the users, operators and managers recommendation for cost-effective energy efficiency measures to reduce costs and building carbon footprint.

A transformative impact of ICT on buildings is to make them part of the solution rather than part of the carbon reduction problem. Re-thinking buildings is already the trend for several years especially after the burst of the housing bubble at the end of the last decade. Energy self-sufficient houses are already available[49], and ICT plays herein a central role, with integrated BEMS solutions. Buildings will be designed with proper siting, architecture, material selection and making use of natural light, heating, cooling, and ventilation. Daylight will make it possible to use far less energy and even become net producers of electricity at little or no additional cost. Finally, deployment of high performance computing for better real-time simulations, combined with big data analytics should help both goals, rethink building design and use and dynamically manage energy resource production and consumption.

3.13 SMART INDUSTRY

The world trends in resource use and energy consumption show that current forms of industrial production are not sustainable in the long term[50]. Most heavy industries, like iron and steel, cement, aluminium, paper and pulp still follow a linear model based on extraction of natural resources, and disposal of products at the end of the lifecycle. The global footprint was 50% relative to the global bio-capacity and has doubled in 27 years. Since 1987 the world is in overshoot, currently 50%[51]. Many industries continue to be inefficient and wasteful and thereby over-consuming the limited resources of our planet. Industries need therefore to radically improve their energy efficiency, reduce resource consumption and avoid release of harmful by-products. ICT is crucial in reaching those 'must-do' goals. Industries which fail to become smarter will be less competitive and eventually lose their markets.

ICT contributes to the efficiency of industry at all stages, from the conception of products and services, to the design and control of plants, processes and production lines, to the choice

[48] http://www.pikeresearch.com/wordpress/wp-content/uploads/2012/05/SB10T-12-Pike-Research.pdf
[49] http://www.ieeeusa.org/communications/releases/2011/032211.asp
[50] www.footprintnetwork.org
[51] http://www.footprintnetwork.org/en/index.php/GFN/page/world_footprint/

of supply chain and marketing strategy. Use of IT-based controls and knowledge management systems within industrial production processes, in conjunction with access to real-time production and usage data, helps to improve operations, save energy and increase production efficiency. Software helps improving design-for-manufacturing and minimizing waste of raw material. A wealth of business opportunities is facilitated by ICT in the sophistication of product design and manufacturing processes, reducing material flows, cutting out waste in mining and manufacturing and dematerializing when possible. Dematerialization is gaining ground within the smart industries and the impact so far has been profound on the photo, music, film and paper industries.

Rethinking the current industry business models with ICT will migrate the industries closer to becoming service companies, focusing on what people want, rather than on mass-manufacturing products based on an ever-increasing demand for our planet's finite resources. ICT is indispensable in evolving the traditional industries into cradle-to-cradle service companies and producing stuff is a low-margin commodity business. Products will last longer— and with the support of ICT be recovered, reused, repaired, remanufactured, and recycled. This rethinking of the smart industry will create major new business opportunities with lower energy needs and better customer-oriented services. Customers buy light from Philips and not the light bulbs, and HP offers printing services instead of selling printers. Open ICT platforms for gathering customer information on products and services and involving customers in co-design[52], will make it possible to tap into the experiences, skills and ingenuity of millions of consumers around the world and involve them in the new generation of sustainable products (prosumer model).

3.14 ICT FOR DEMATERIALIZATION

The Telstra[53,54] and above mentioned GeSI Smart 2020[6] reports describe how ICT can help the global transformation towards dematerialization for a more energy-efficient and low-carbon economy. In 2012 GeSI, the Yankee Group and ACEEE published a more recent study[55] about the potential carbon reduction from broadband deployment for eight household activities: teleworking, e-news, e-banking, e-commerce, music and video streaming, e-learning, e-mail and digital photography. Although telecommuting (see also transport paragraph above) is responsible for the largest carbon reduction (85%) among the eight selected activities, the study shows that dematerialization plays a relatively growing role in carbon reduction of household consumption. Large energy savings will be made through the use of ICT for service delivery, substituting physical products with digital content (i.e. 'use bits instead of bricks'[56]).

On the other hand, waste management can be seen as a variant of dematerialization as it allows delivering products without the need for new raw materials. The race towards more processing power on one chip, characterized by Moore's law[57] leads to accelerated obsolescence of silicon systems and generation of rapidly growing e-waste. ICT should be deployed for the registration and recycling of electronic systems, avoiding the need to extract increasingly scarce raw materials, especially highly energy intensive such as rare earths. Recycling should ultimately lead to a sustainable consumption of natural resources and safe disposal of e-waste, reducing GHG emission and providing sustainability of supply to the industry.

[52] http://www.trendwatching.com/trends/customer-made.htm
[53] http://www.climaterisk.com.au/wp-content/uploads/2007/CR_Telstra_ClimateReport.pdf
[54] http://www.telstra.com.au/business-enterprise/download/document/business-industries-sustainability-executive-whitepaper.pdf
[55] http://www.telework.gov.au/__data/assets/pdf_file/0005/156668/Global_eSustainability_Initiative.pdf
[56] http://www.wwf.se/source.php/1183711/it_user_guide.pdf
[57] http://www.mooreslaw.org/

3.15 FINALLY, A WORD ABOUT THE NECESSITY OF AVOIDING RE-BOUND EFFECT

Are energy-saving light bulbs left on more than incandescent bulbs? Would the purchase of a fuel-efficient car lead us to use it more frequently than before? Examples of an often-overlooked rebound effect: when something costs less, we start to use it more. A report published by the Breakthrough institute[58] surveyed the literature on the rebound effect in energy efficiency measures and the implications effects for climate change mitigation policy. Multiple rebound effects seem to operate at various scales, having their greatest magnitude at the macroeconomic level with the potential to substantially erode much of the realized carbon reductions.

Literature shows that there is enough evidence of a rebound effect on an individual level. The Breakthrough report shows that 10–30% of energy savings from efficient cars and homes are lost by more use. Why this occurs is not well researched. Greater efficiency in buildings for instance doesn't frequently lead to the expected savings because of some unexpected socio-economic behavior of the tenants. But the highest rebound in energy use from green measures occurs in industry and commerce[58]. Improving the energy efficiency of production of raw material leads to lower prices, greater demand, more production, and consequently a rebound in the energy use as a compound result of the energy efficiency improvements. So, successful strategies for carbon reduction with ICT must include life cycle assessments in order to ensure that the new green system is really reducing carbon emissions. Another way of getting out of this vicious circle could be found in pushing people to consume less energy or, a more realistic approach, on using renewable energy sources so that it doesn't matter how much we consume. The lesson learned is that a systemic approach must be adopted when dealing with carbon reduction policy.

3.16 CONCLUSIONS

The world use of energy and raw material has been overshooting the limits of planet capacity since several decades and must be made sustainable in order to avoid threatening economic, social and environmental stability and deprivation of future generations. ICT is well positioned to help in this but a halt has to be put to the exponential growth of energy use by ICT itself. Besides putting a lot of effort into the development of energy-efficient ICT systems and equipment life cycle management, greening IT requires greening the datacenters, as the majority of carbon emissions of ICT are produced there. ICT can be made sustainable at three stages of the power loss chain: integrating the datacenter within the power grid, improving energy efficiency of the datacenter itself, improving software and data use of infrastructure and deployment of virtualization and cloud services. Research into smart grids and the development of innovative datacenter concepts as part of the energy ecosystem are worth pursuing, with interesting related areas like green software, sector clouds, Big Data analytics and related applications and services. ICT is essential to maintain growth and prosperity without conflicting with sustainability requirements. The focus should however shift from energy efficient linear processes from raw material to waste onto energy self-sufficient cyclic processes where raw materials are reused. Interesting research areas are ICT solutions for decentralization of energy production and deployment of sustainable energy sources, and the use of innovative ICT solutions for smart transport, smart buildings, smart industry and dematerialization. A systemic approach for deployment and use of ICT prevents a rebound effect of energy usage triggered by improved efficiencies brought up by ICT. This will lead to an energy efficient future where growth and prosperity will be possible without running the risk of a burst in an economic bubble caused by the exhaust of planet natural resources.

[58] http://thebreakthrough.org/blog/Energy_Emergence.pdf