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Sustaining ICT for Sustainability:

Towards Mainstreaming De–carbonization–oriented Design & Enabling the Energy–Efficient, Low Carbon Economy

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Abstract

The study set out to understand and demonstrate the role the ICT sector could play as a critical enabler in the transition and progress towards an energy–efficient, low carbon economy. More specifically, the study of sustaining ICT for sustainability has twofold intent: (2) to investigate the direct footprint of ICT sector and explore how it can be tackled through adopting sustainable design–based solutions; and (2) to highlight the enabling potential of ICT sector to mitigate climate change and massively improve energy efficiency across the economy, identifying and quantifying the global ICT impacts and opportunities in the context of energy and carbon emissions savings.

To achieve the aim of this study, a pertinent and extensive literature review covering theoretical, empirical, and critical scholarship was performed to investigate the phenomenon. The study draws on a variety of sources to survey the unsustainability of ICT sector pertaining to energy–intensive consumption and explore potential solutions through espousing environmental design practice, and also to examine the role of ICT in delivering energy–efficient solutions through its products and services. Validity was ensured through using quality academic and industry literature as well as relevant studies carried out by a range of eminent researchers, experts, and stakeholders (i.e. NGOs).

Findings highlight the unsustainability of ICT sector regarding energy–intensive consumption and concomitant GHG emissions associated with its products and services. Of the whole lifecycle, the use phase of ICT is the most critical. Data centers and telecom networks devour energy. Planned obsolescence entrenched in software design shorten upgrade cycle, which makes software utilities a planet killer as to energy consumption. Alternative sustainable design–based solutions entail using renewable energy and most efficient energy required over ICT's life cycle – de–carbonization strategy. Also, digitization is an effective strategy for ICT sector to slash energy use per unit. To reduce the footprint of data centers and telecom networks, design solutions vary from hardware and software to technological improvements. Designing out built–in obsolescence in software technology is a key factor in the energy equation. As for the enabling role of ICT, the findings are highly illuminating. The ICT sector must step up its efforts in reducing its direct footprint in order to claim a leadership role in an energy–efficient, low carbon economy. Although the ICT sector's own emissions will increase because of global growing demand for its products and services, the real gains will come from its enabling potential to yield substantial energy efficiency improvements and emissions reductions across the economy. The sheer scale of the climate change challenge presents smart development mitigation opportunities for ICT sector to deliver environmentally sustainable solutions. The largest identified opportunities are: dematerialization; intelligent transport and logistics; intelligent buildings; smart power supply; and efficient industrial processes and systems.

This study provides a novel approach into sustainable design in ICT, underlining unsustainable design practices in ICT sector. Review of the literature makes an advance on extant reviews by highlighting the synergic relationship between ICT design, sustainability, and the economy.

Keywords: ICT, Design, Sustainable design, Energy efficiency, Footprint, Emissions reductions, GHG, Climate change, Low carbon economy, Rebound effect, Systemic effect, Dematerialization, Digitization, De–carbonization, Transport, Buildings, Power generation, Industrial processes.

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Glossary

Anthropogenic: Caused by or attributed to the influence of human beings or their ancestors on natural systems. In this context, human induced GHG emissions that are produced as the result of human activities.

Biodiversity: The variety of living organisms and life in all forms, levels and combinations. This term includes genetic diversity, species diversity, and ecosystem diversity.

Biosphere: The whole of the Earth's surface, atmosphere, and sea that is inhabited by living things (Rooney 1999). Or, the Earth's outer shells, within which life's processes occur – air, land, and water.

Carbon Dioxide Equivalent (CDE): A metric measure, expressed as million metric tons of carbon dioxide equivalents (MMTCDE), used to compare the emissions from various GHG based upon their global warming potential (GWP). GWP is the index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of those gases without directly calculating the changes in atmospheric concentrations.

Carbon Footprint: Is the volume of GHG emissions an organisation generates. It is calculated by assessing energy usage and all components of the organisation's operations that consume power.

Climate Change: Encompasses all forms of climatic inconstancy – any differences between long term statistics of the meteorological elements calculated for different periods but relating to the same area – regardless of their statistical nature or physical causes (Mitchell et al. 1966).

Data Center (or Server Farm): Is a dedicated facility used to house ICT equipment, such as data storage systems, servers, telecom network and devices, in addition to backup power supplies, redundant data communications connections, security devices, environmental controls (i.e. air conditioning, fire suppression), etc.

Dematerialization: The substitution of digitized (low carbon alternatives) products and services for their physical equivalents (high carbon activities). It also refers to the absolute (immaterial) or relative reduction in the quantity of materials needed to manufacture ICT products.

Design for Environment: Is design that seeks to eliminate potential negative environmental impacts before a product is made (Greenpeace 2005).

De–carbonization Strategy: Entails the exploration of renewable energies and designing less carbon–hungry or low power ICT equipment.

Economy: Generally refers to the system (synergies, behavior, inputs, outputs, processes, methods, energy, boundaries, etc.) of production, distribution and consumption of goods and services.

Ecosystem: A complex system of interaction between living organisms (plant, animal, fungal, and microorganism communities) and their associated non–living environment as an ecological unit.

Energy Efficiency: Rational (efficient) use of energy to achieve an intended application performance. Technically, it is the minimum quantity of energy required to deliver a functional output from an ICT device.

Energy Intensity: Ratio between the consumption of energy to a given quantity of output.

Environmental Impact: Any change to the environment whether adverse or beneficial, wholly or partially resulting from an organization's environmental aspects (ISO 14001 2004).

Direct Effects: Arise from the design, production, distribution, maintenance, and disposal of ICT products and services by the ICT industry (MacLean and Arnaud 2008). Accordingly, the impact of ICT on climate change is related to the GHG emissions that result from the energy used to produce materials, operate facilities, transport goods, provide services, etc. (Ibid).

Global eSustainability Initiative (GeSI): Is formed in 2001 as an international strategic partnership of ICT companies and industry associations committed to fostering global and open cooperation and creating and promoting technologies and practices that foster economic, environmental and social sustainability and drive economic growth and productivity.

Global Warming: Is the gradual heating of the Earth earth's atmospheric air and oceanic temperatures due to GHG, leading to climate change; a process that raises the air temperature in the lower (near–surface) atmosphere due to heat from infrared radiation trapped by GHG.

Greenhouse Gases (GHG): Any gas that absorbs infrared radiation in the atmosphere. It acts as an insulator (with heat–trapping properties) that helps trap the sun's rays (ultraviolet radiation) passing through the Earth's atmosphere to warm the planet's surface. GHG include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), ozone (O_3), and chlorofluorocarbons (CFC), perfluorinated carbons (PFCs), hydrofluorocarbons (HFCs), etc.

Greenhouse Effect: Produced as GHG allow incoming solar radiation to pass through the Earth's atmosphere to warm the Earth's lower and near–surface atmosphere, but prevent part of the outgoing infrared radiation from escaping into outer space (radiating some back towards the surface). In this context, infrared radiation refers to the heat energy emitted by the Earth's surface and its atmosphere.

Holistic: Involving all aspects of something (characteristics, traits, behaviors, patterns, relationships, cause–effect, dynamics, etc), for example, including somebody's physical, mental and social conditions, not just physical symptoms, in the treatment of illness (Rooney 1999).

ICT Industry: Is typically broken into three sectors: hardware, software, and services and includes: electronics, microelectronics, ICT applications, information systems, and telecommunications.

Intelligent Transport Systems: Is the application of technologies to transport operations, including satellite navigation tools; location finders and routers; advanced driver assistance systems; freight and fleet control; guidance and management; safety systems; etc.

Life cycle: Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources through use to the final disposal (ISO 14040 2006).

Logistics Industry: Provide warehousing, help clients integrate their supply chain, provide transport and IT services and make deliveries (GeSI 2008).

Nanoparticles and Nanotubes: Are 'ultra small pieces of material that are free rather than fixed to or within a material.' (Dowling 2005)

Nanotechnology: Is the study of the control of material on an atomic and molecular scale and generally deals with structures of the size of nanometer, and involves developing materials or devices within that size. Nanotech involves the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanometer scale (Dowling 2005).

Planned Obsolescence: Is the process of a product becoming obsolete after a certain period or amount of use in a way that is designed or planned by the manufacturer.

Radio Frequency Identification Devices (RFID): Is an object (tag) that can be applied to or incorporated into a product or person for the purpose of identification using radio waves (Madden and Weißbrod 2008).

Rebound Effect: Counterproductive effect of an otherwise effective measure, i.e. an improvement in energy efficiency that is absorbed by a resultant increase in demand for energy service because of final price decrease due to higher efficiency of the production of the service.

Renewable Energy: Energy harvested or generated from natural sources that are essentially inexhaustible and renewable (naturally and continuously replenished), which minimizes environmental impact. Renewable sources of energy include biomass, geothermal, wind, ocean, photovoltaic, and solar thermal energy.

Indirect Effects: Arise from the use and application of ICT throughout the economy and society, in government, public institutions, and research and academic communities (MacLean and Arnaud 2008). In this case, the impact of ICTs on climate change derives from the GHG emissions resulting from the energy required to power and cool data centers and network devices in the myriad applications that characterize the information society (Ibid).

Smart Building: The term smart or intelligent building involves a suite of technologies used to make the design, construction and operation of buildings more efficient. It entails the introduction of new technological innovations that have positive environment impacts.

Smart Grid: 'A set of software and hardware tools that enable generators to route power more efficiently, reducing the need for excess capacity and allowing two–way, real time information exchange with their customers for real time demand side management (DSM).' (GeSI 2008)

Smart Motor Systems: Devices that convert electricity into mechanical power (GeSI 2008). A motor is 'smart' when it can be controlled to adjust its power usage to a required output, usually through a variable speed drives (VSD) and intelligent motor controller (IMC), a piece of hardware controlling the VSD (Ibid). VSDs are devices that control the frequency of electrical power supplied to the motor, thereby adjusting the rotation speed to the required output.

Strategy: Logical and generic guidelines to inform the process and implementation of a long term plan of action designed to achieve a particular goal.

Strategizing: To plan and devise a strategy or course of action.

Sustainability: A state where the four 'sustainability principles' (Robèrt et al. 1997) are not violated.

Sustainable Design: Its philosophy is to design technologies that comply with the principles of environmental sustainability. It is also referred to as 'eco–design' (Papanek 1995).

Sustainable Development (SD): Defined as the ability 'to meet the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). It is a process of change in which the exploitation of resources, the direction of investments, and the orientation of technological development are all in harmony (Ibid).

Sustainable Technologies: Technologies that use less energy, do not deplete natural resources, do not pollute the environment, and can be reused or recycled at the end of their useful life (Ji and Plainiotis 2006).

Telematics: Refers to the fusion or integration of several technologies that are mainly covered by the terms telecommunication and informatics or ICT. More recently, this term has been associated with the connotation of automotive telematics where the use of computers and telecommunications is aimed at enhancing the functionality of motor vehicles.

Systemic Effects: Arise from changes in economic and social structures and behavior enabled by the availability, accessibility, and application of ICT goods and services (MacLean and Arnaud 2008).

Upstream Solutions: Solutions that address root causes of issues, rather than symptoms.

Acronyms

BMS: Building Management System

CO_2e: Carbon Dioxide Equivalent

DSM: Demand Side Management

EDGE: Enhanced Data rates for GSM Evolution

EPA: Environmental Protection Agency

GDP: Gross Domestic Product

GeSI: Global eSustainability Initiative

GHG: Greenhouse Gases

GIS: Geographical Information System

GSM: Global System for Mobile Communications

GtCO2e: Gigaton of Carbon Dioxide Equivalent

ICT: Information and Communication Technologies

IEA: International Energy Agency

IPCC: The Intergovernmental Panel on Climate Changes

ITU: International Telecommunications Union

LCA: Life Cycle Assessment

MtCO2e: Million ton of Carbon Dioxide Equivalent

NGA: Next Generation Access

NGN: Next Generation Network

PUE: Power Usage Effectiveness

RFID: Radio Frequency Identification Devices

SOA: Service Oriented Architecture

T&D: Transmission and distribution

TWh: TeraWatt Hour

VSD: Variable Speed Drives

WCDMA: Wideband Code Division Multiple Access

WWF: World Wide Fund

C H A P T E R   O N E

I N T R O D U C T I O N

1. Introduction

This introductory chapter provides an insight into the research area, sustaining ICT for sustainability. It contains the motivation and justification, problem discussion, purpose, research questions, scope and finally the outline of the study.

1.1. Motivation and Justification

The evidence for global warming is compelling without a shred of doubt as backed up by climate scientists; some skeptics argue that this type of rhetoric is a hyperbole notwithstanding. 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.' (IPCC 2007) The most recent results presented by climate scientists are alarming as the accumulation of GHG in the atmosphere is growing faster than originally predicted (GeSI 2008). That said it is appropriate to shift the climate change debate from whether it is occurring or not, to what can be done to preclude the atmospheric levels of GHG from exceeding the so called 'safe' threshold – estimated as 450 parts per million (ppm). However, this is not universally accepted, according to King and Walker (2008) and Hansen et al. (2008). Further, evidence (Mittelstaedt 2007; IPCC 2007) shows that the anthropogenic (human–induced) factor is behind disturbance to natural systems which accelerates climate change. Stern Review (2006) predicts that failure to combat climate change could cause possibly irreversible economic disruption on a scale similar to those associated with the economic depression. To address this looming issue, global transformation to an efficient, low carbon economy has become unavoidable. Exploring the possible convergences between industrial and technological logics and environmental instances can play a key role in enabling systemic solutions that consider environmental externalities of the economic growth. That said ICT–based innovations could play a key role in improving energy efficiency and thus mitigating climate change. Besides, ICT are increasingly recognized as the strongest change means humanity has to its disposal, and, at this time, must be mobilized and directed at promoting sustainable economic development. Our contention is that, as ICT become more sophisticated and more embedded in our social and organizational structures, we are in a better position than ever before to make sustainable development work (Alakeson 2003). In addition, considering the huge impact of ICT on the economy, it is certainly of strategic value to call to mind the urgency of strategizing ICT design with sustainability in mind.

Climate change is an overarching and a multi–dimensional issue that affects all parts of the society with strong links to key economic issues pertaining to energy–and carbon–intensive industrial processes and inefficient systems that negatively impact on the environment. Stern Review (2006) highlights dire consequences of climate change if we do not take action to reduce carbon emissions. However, the current trends are unsustainable and if nothing were to change, final energy consumption is generally predicted to increase with a substantial rise in GHG emissions – the main culprit of global warming. Years of scientific study and political debate have led to worldwide consensus on the deleterious effects of GHG emissions and the consequent need to radically reduce it in the medium–to longer–term (MacLean and Arnaud 2008). Nothing less than a major shift from a high to a low carbon global economy is needed and ICT appear to offer the unsurpassed way to accelerate the transition towards a global sustainable economy. As Madden and Weißbrod (2008) point out, ICT can help to reduce the environmental footprint of what we do. There is evidence demonstrating that the ICT sector is a key player in creating a low carbon economy and could do a lot more to help push the world in this direction by 2020 (Neves 2008). Indeed, the combined energy and climate debate is now at the top of the international political agenda. And energy efficiency is deemed to be the primary focus where the ICT can be mobilized to make the most substantial contribution. Otherwise, failure to rationalize energy use may have a snowball effect on the economy and the environment. There is a tremendous untapped potential for adding intelligence to ICT components, products, and services to address economic and environmental challenges. ICT not only constitute a sector in their own right but they also pervade all sectors of the economy where they act as integrating and enabling technologies. Thus, they have a key role to play, not just in reducing the sector's own footprint but also enabling emissions reductions across the economy. Besides, if the carbon emissions from ICT were to double or triple under a transition period due to a dramatic increase of resource efficiency solutions, this would obviously be very strategic, and something we should consider (WWF et al. 2008).

Although the huge potential of ICT to reduce GHG emissions in other sectors, the sheer scale of the challenge involved in stabilizing the climate signifies that the sector also needs to step up its efforts in reducing its direct footprint (GeSI 2008). ICT sector is both energy–intensive user and a potential foundation of the economy's efficiency resolve for which the ICT sector might face an absolute increase in emissions that will have a significant bearing on expectations in that it should commit to absolute reductions. However, it is clear how ICT's impacts on our economy have developed to the point of complete dependence for which we are paying a penalty, principally in terms of their externalities in energy usage (Forge 2007). The acuteness of the situation calls for the ICT sector to give primacy to use all of its creativity and skills to improve energy efficiency of its own products and services. Given their pervasiveness, ICT could improve the situation, reinforcing positive effects in the environment, or they could worsen the situation (GeSI 2008). ICT have a number of potential risks and uncertainties that we need to understand when placing high expectations on ICT (Plepys 2002). The performance improvements in ICT as well as their growth and increased use have led to increased consumption of ICT products and services, which has numerous environmental implications on different levels (Ibid). ICT impact on the climate change is a visible instance that exposes underlying flaws in the design of technological systems. These flaws substantiate the unsustainability of the current mainstream ICT design approach as to, particularly, energy consumption. Nonetheless, being an essential and strategic component of every economic sector, ICT must be treated as an environmental hazard factor, with new design criteria and measures (Forge 2007). To this end, it is necessary for ICT sector to espouse sustainable design practices when it comes to energy use so to address its own footprint. Overall, the sound strategy is to continue positioning the ICT sector as an effective enabler of efficient, low carbon smart solutions for other economic sectors while substantiating the sector's commitment to tackling its own footprint by managing its products, services, and processes for efficient energy use. It is obvious that this could very well be the most daunting ICT–support ticket of all, but it is very strategic and worth to consider given the associated enormous economic and environmental gains.

For a twofold aim, this study endeavours to investigate the direct footprint of ICT sector and explore how it can be addressed through adopting alternative design solutions based on sustainable design practices, as well as to highlight the enabling potential of ICT sector to mitigate climate change and massively improve energy efficiency across the economy, identifying and quantifying the global ICT impacts and opportunities in the context of energy and carbon emissions savings. The topic being addressed is a significant research area that merits further focus as it has become a mainstream theme in the debate of ICT and sustainability. Although, a number of studies have been carried out in recent years investigating the relationship between ICT and the environment (Willard and Halder 2003; Erdmann et al. 2004; Pamlin and Szomolányi 2007; Mallon et al. 2007; ITU 2007; Global Action Plan 2007), relatively little attention has been given to the potential of ICT to address the challenge of climate change from ICT design and economic perspectives, or these studies only pass reference to the role ICT could play in responding to environmental issues. There is increasing evidence that significant opportunities and threats are involved and that ICT contribution to sustainable economic development is still untapped. These deserve more research and attention, thus the motivation behind this study.

1.2. Problem Discussion

Conspicuously, the unsustainability of current economic trends is manifest by the increase of human–induced environmental degradation and the push of environmental thresholds in unprecedented ways, i.e. 'current atmospheric GHG levels stand at 430 (ppm)' (IPCC 2007; GeSI 2008; McKinsey 2007). This results mostly from economic activities – power generation and distribution, industrial processes, transport and logistics, etc. The instrumental rationality of the economy and current industrial models has completely ignored the externalities of the patterned growth leading to disastrous global climate change. However, more than ever, a swift implementation of climate solutions becomes imperative before average global temperatures move beyond where there is no return. To this end, ICT–based solutions are projected to be the sound means to stride to a low carbon economy. ICT pervade all economic sectors as integrating and enabling technologies and hence could help alleviate global warming by massively enabling energy efficiency. By many indicators, ICT will be a critical enabler in progress towards an efficient, low carbon economy. This is indeed a great opportunity to promote sustainable economic development.

Through using its long history of creativity and innovation, ICT sector can do its part to troubleshoot the planet's woes caused by its own footprint and by that of other economic sectors. That said the ICT sector should first clean up its own house through tackling its own carbon footprint. The current unsustainable ICT pose an issue regarding technological innovations, and if not taken seriously, it could worsen the world's problems. The mainstream ICT design approach needs to entrench environmental considerations to reduce ICT' impacts on climate change. These impacts derive from the GHG emissions resulting from the intensive energy from unsustainable sources consumed all through ICT's lifecycle. The focus should be given to greening ICT product and services when it comes to energy usage. To this end, sustainable design practices can play a significant role in enabling clean technology. Indeed, sustainable design approach entails increasing the use of renewable energy that is cyclic and safe and using most efficient energy required over life cycle in as well technology usage as in manufacturing processes. While the ICT sector plans, through sustainable design measures, to significantly step up the energy efficiency of its products and services, ICT's largest contribution will be to massively improve energy efficiency across the economy. Although the ICT sector's own emissions will increase because of global growing demand for its products and services, there are estimated to be five times less than the emissions that can be reduced through the enabling effect (GeSI 2008). The real gains will then come from enabling energy efficiency and GHG emissions reductions across other economic sectors, particularly manufacturing, transport and logistics, energy supply, and buildings. These sectors are recognized as significant contributor to global warming because of the huge dead losses, poor management, and intolerable inefficiencies associated with their energy systems. ICT can play a pivotal role in providing the relevant technologies and services (i.e. measurements, monitoring, control, optimization, etc.) needed to support these sectors to become more energy efficient. Explicitly, ICT applications can make transport and logistics more efficient and intelligent, rationalize energy use in buildings operations, optimize industrial processes and systems, and minimize power transmission and distribution losses. In addition, dematerialization (using ICT to replace physical products and service with digitized alternatives) holds a great potential to enable a product–to–service shift across the economy through e–substitutions, such as tele–working, videoconferencing, e–commerce, etc. Interestingly, and in support of anecdotal evidence that these e–substitutions can yield even substantial energy savings if widely implemented. The ICT sector has a unique ability to make energy consumption and GHG emissions visible through its products and services (GeSI 2008). This role makes it a key player in the equation of moving towards economic and environmental sustainability.

However, the behavioural patterns of technological innovations are unpredictable for they evolve dynamically and rapidly and are subject as well to the emergence of paradigm shifts as to failures of materialization. Uncertainty thus remains a contentious issue as to estimating absolute future economic and environmental impacts, given the capriciousness surrounding the fact that new technological innovations might not be widely adopted or fully transpire. It is also difficult to predict changes that are likely to take place within the ICT sector over a long period of time. Even for a short and medium term, there exist a number of behavioural and structural stumbling blocks that must be overcome if the full outcome of ICT enabling effect is to be realized. This is due to the issue of rebound effects – the potential for all the efficiency gains to be offset by our insatiability for consumption of ever more ICT products and services – that shouldn't indeed be underestimated. The energy efficiency gains resulting directly from the improved efficiency of ICT products or services, or indirectly in the use and application of ICT products and services may be counteracted, owing to systemic effects – how ICT–enabled changes affect behavioural choices; economic and social structures; and governance processes that, at the end of the day, determine the patterns of energy consumption. Systemic effects should be holistically examined in order to avoid rebound effects that may offset environmental gains. Coming to grips with systemic effects is an intricate task (MacLean and Arnaud 2008). These effects are enabled by a set of complex, diverse parameters, including accessibility, application, use of ICT products and services and so on. Beyond rebound effects, it is also crucial to overcome other hurdles (including financial, technological, organizational, legislative, informational, etc.) to adopt ICT–based energy efficiency and climate solutions. When putting high expectation on sustainable solutions, economic sectors should take into account an array of critical factors, such as financial wherewithal; corporate culture and vision; technological innovations capabilities; internal communication; etc. By and large, making a beneficial contribution to energy efficiency through ICT and suppressing rebound effects and other hurdles remains a complex challenge for which there is unlikely to be a panacea. Nevertheless, smart integration of ICT innovative solutions is definitely a strategic path that we should consider to move towards a sustainable economy.

1.3. Research Purpose

The study set out to understand and demonstrate the role the ICT sector could play as a critical enabler in the transition and progress towards an energy–efficient, low carbon economy. More specifically, the study of sustaining ICT for sustainability has twofold intent: (2) to investigate the direct footprint of ICT sector and explore how it can be tackled through adopting sustainable design–based solutions; and (2) to highlight the enabling potential of ICT sector to mitigate climate change and massively improve energy efficiency across the economy, identifying and quantifying the global ICT impacts and opportunities in the context of energy and carbon emissions savings. In the enabling model, the study covered the most accessible mitigation opportunities where ICT solutions could have a substantial influence on CO2 emissions, including dematerialization, transport and logistics, buildings, energy supply, and industry. The key aim is to underline the relationship between ICT design, sustainability, and the economy in that how symbiotically can one affect the development of the other and in what direction. Ultimately, the study endeavors to add to the body of knowledge and contribute to the previous research endeavours in mobilizing and sustaining ICT for sustainable development and, more importantly, present a departure for further empirical and theoretical research and development.

1.4. Research Questions

To achieve the objective of this study – investigating the ICT sector's direct footprint and its potential to deliver low carbon, energy efficiency solutions – the author set out to answer two main questions:

1. What is the direct footprint of the ICT sector and how it can be tackled through sustainable design practices?
2. What is the enabling contribution of ICT sector to an energy–efficient, low carbon economy?

1.5. Scope

The scope of this study is too broad as it deals with three sweeping areas: ICT, sustainability, and the economy. However, the author limited the research to view the above stated research questions focusing mainly on key economic and environmental issues in relation to ICT. For the purpose of this study, technical details of product design and development pertaining to ICT–based energy efficiency solutions are beyond the scope of this thesis. For the direct footprint of ICT, the ICT sector covers mainly PCs and peripherals (i.e. monitors and printers); IT services (i.e. data centres and their component servers; storage; heating and cooling); telecoms networks and devices (i.e. network infrastructure components; mobile phones; and broadband routers). Moreover, this study is concerned with all sectors of ICT industry, including hardware, software and services for they are involved in as well the unsustainability of ICT as the enabling contribution to energy efficiency improvements and climate change mitigation. Reducing the scope was an iterative process whereby the author attempted to constantly evaluate the extent, value, coherence, and relevance as key elements for achieving the final outcome of the study.

1.6. Outline of the Study

This study is divided into six chapters. Figure 1.1 visualizes the outline of the study. Thus far, the first chapter has been covered, and the discussion focuses subsequently on the remaining chapters.

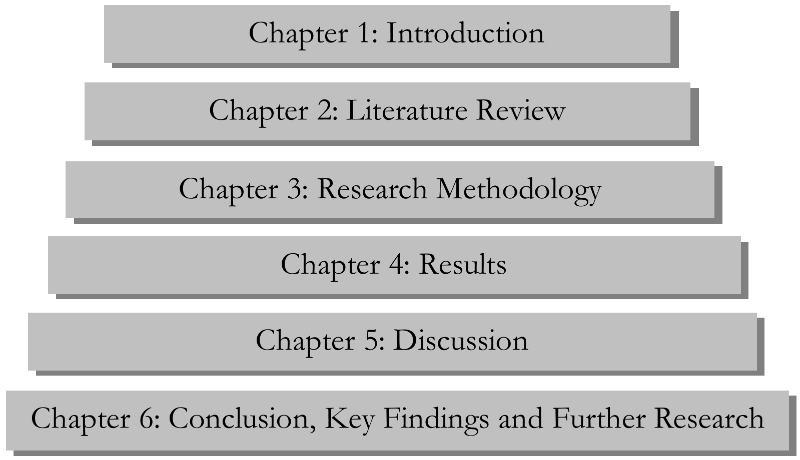

Figure 1.1 Outline of the study

The first chapter, which has already been presented, provides an introduction to the research study. More specifically, it covers: the background, problem discussion, purpose, research questions, scope, and, as a final point, the disposition of the study. The second chapter delves into the theoretical literature relating to the research study, including ICT, design, sustainability, sustainable development, climate change, and energy. This chapter gives background information required for the understanding of the entire research study. The third chapter motivates and discusses the chosen methodology. The fourth chapter analyzes and synthesizes results garnered from recent empirical, critical studies in accordance with research questions. The fifth chapter evaluates and discusses the results and highlights the findings. The sixth final chapter provides a summary of the thesis and some concluding remarks as well as key findings drawn from the results, which are given in relation to the two research questions. This chapter is ended with suggestions for further research.

C H A P T E R   T W O

R E S E A R C H   M E T H O D O L O G Y

2. Research Methodology

This chapter aims to justify and discuss the chosen research methodology. It covers the following: research approach; literature review method; purpose; hierarchical search strategy; selected theories and researched topics; organizational framework; data analysis; synthesis and evaluation; and validity.

2.1. Research Approach

To achieve the objectives set out by this study, the literature review research methodology was used to collect the relevant data. The process involved background research – identification and comprehension – followed by data analysis, synthesis, and evaluation. Data were gathered from a variety of sources to survey the unsustainability issue of ICT sector and the role of environmental design in addressing it as well as to analyze the potential of ICT to deliver energy–efficient, low carbon solutions through its products and services. Sources included relevant available theoretical, empirical and critical studies based on expertise in the field, consumer surveys and expert interviews, as well as academic and industry literature. According to Cooper (1988), the types of scholarship found in literature material may be empirical, theoretical, analytic, or methodological in nature. These studies were projected to inform the research process by providing as well statistical data as descriptive (or interpretive) information. They provided connections and contradictions between different research results and validation for intuitive reasoning and abstract concepts. Overall, the information collected was used to both provide the author with an overview of relevant previously conducted research work related to the topic under review and to answer the research questions.

2.2. Literature Review Method

Literature review is a crucial endeavor for any academic research (Webster and Watson 2002). It is aimed to provide a solid background and foundation of material for this research paper's investigation to which comprehensive knowledge of the literature is essential. Effective synthesis of quality literature enables to develop a solid foundation for a research study (Barnes 2005; Webster and Watson 2002) and better explain and understand problems that address actual issues (Yair and Timothy 2006). Hart (1998, p. 1) defines the literature review as 'the use of ideas in the literature to justify the particular approach to the topic, the selection of methods, and demonstration that this research contributes something new'. Indeed, the aim of the literature review is to find out and unfold what is previously known about the intended research topic. A literature review of a given field is the record of previous work in that field (Barzun and Graff 1977), which is the foundation upon which any future work in the field draws (Borg and Gall 1979). Therefore, initiating any research study should not underestimate the need to uncover what is already known in the body of knowledge (Hart 1998). Shaw (1995, p. 326) notes that the literature review process should 'explain how one piece of research builds on another.' In addition, Hart (1998) states that the literature review is the selection of available documents on the topic, which contains data, information and evidence, and is written from a particular standpoint to fulfill certain aims or express certain views on the nature of the topic and how it is to be investigated, and the effective evaluation of these documents in relation to the research being proposed. On the whole, the literature review remains the preferred method for data gathering as it is assumed, given the multidimensional nature of this study as well as how broadly the research questions were framed, to be an efficient way to outline the author's argument, anchored by the theories and studies explored throughout the thesis.

2.3. Purpose

The intent of this research method is to establish the case for researching the topic of ICT in relation to environmental and economic sustainability. This research method was carried out not only to provide a valuable insight into how others may have approached the subject area under inquiry, but it also ensured that the investigation was not duplicated by any previously undertaken research work, in addition to ensuring a degree of depth in understanding the concepts and theories and evaluating previous studies related to the research study being addressed. This is supported by Aitchson (1998) who views that the literature review method allows the researcher to find out what has been done regarding the problem being investigated to eliminate needless duplication. Besides, it is valuable to extend or carry on from where others have already reached. Nevertheless, it is important to remember that not all literature material is of equal rigor (Ngai and Wat 2002). As a general purpose of literature review method, the author identified and accumulated relevant information; provided the intellectual context for the research study; sharpened the theoretical framework of the research; highlighted specific arguments and ideas relevant to this study; identified gaps and weaknesses in existing knowledge; and then synthesized and evaluated the collected information in connection with this research paper's investigation.

2.4. Hierarchical Search Strategy and Sample Studies Selection

A literature search is the process of querying quality scholarly literature databases to gather applicable research documents related to the topic under examination (Yair and Timothy 2006). A broad search strategy was used, covering several electronic search databases, including ELIN (BTH library website) and Google Scholar (www.scholar.google.se). Webster and Watson (2002) suggest that the main contributions are likely to be in the leading journal articles. Accordingly, the author focused mainly on journal articles, in addition to projects outcomes, books, reports, dissertations and other research publications giving emphasis to the relevance of collected information. Webster and Watson (2002, p. 16) remarks that 'a well–organized search should ensure that you accumulate a relatively complete census of relevant literature.' A hierarchical approach was used to search for literature. According to (Garner et al. 1998; Strauss and Sackett 1998), a hierarchical approach to searching for literature entails using the following hierarchy of methods:

- Searching databases of reviewed high quality literature;
- Searching evidence based journals for review articles;
- Routine searches and other search engines; and

- Direct contact with colleagues and scanning journals.

As far as selecting a sample of studies is concerned, the following hierarchy of sources was used: well known and peer reviewed journals; less well known refereed journals; reports; books; abstracts; and personal communications (in this case, dialogue with experts in the field). When doing the literature review, the researcher should utilize sources that substantiate the presence of the topic under investigation (Barnes 2005). Doing so enables the researcher to provide a solid argument for making the case of the study under investigation as well as spot where literature fits into that proposed study (Yair and Timothy 2006).

2.5. Selected Theories and Reviewed Topics

For theory, the following bodies of literature were selected as central themes for review given their synergy and integration as well as their implications for this study. They include:

- ICT
- Design
- Sustainability
- Sustainable development
- Climate change
- Energy

Topics reviewed using the thematic approach for data collection and analysis include:

- Environmental impacts of ICT
- Unsustainable ICT
- The footprint of ICT industry
- Green ICT
- ICT and energy efficiency
- ICT and low carbon economy
- ICT and climate change

2.6. Organizational Framework

Generally, there are various ways of structuring a literature review, including chronological, classic studies, inverted pyramid, methodological, and thematic organization. In this study, the author used a combination of the thematic and inverted pyramid framework for organizing literature review. This is to provide a logical and coherent structure of literature material to bring clarity to the reader. In the thematic approach (applied in results and discussion chapters) the research is divided into sections representing the categories or conceptual subjects for the topic, and the discussion is structured into these categories or subjects (Ferfolja and Burnett 2002). While in the inverted pyramid approach (applied in literature review chapter), literature review begins with a discussion of the related literature from a broad perspective and then deals with more and more specific studies which focus increasingly on the research questions at hand. Although the thematic literature review was organized around given topics, progression of time was an important factor in the process.

2.7. Data Analysis, Synthesis and Evaluation

The process of analysis, synthesis, and evaluation of data is a critical phase in the literature review. Yair and Timothy (2006) point out that the essence of analysis entails identifying why the information being presented is of importance; the core of synthesis is to assemble the literature being reviewed for a given concept into a whole that exceeds the sum of its parts; and the essential evaluation in the literature review is to clearly distinguish among opinions, theories, and empirically established facts. The results obtained from the literature were used to answer the two research questions, formulate findings, and draw conclusions. Results were critically examined and linked to the study in an attempt to demonstrate how they supported and extended the topic under investigation – sustaining ICT for sustainability. In so doing, the author provided a critique of the research through voicing his perspective and position after gaining understanding and insight into the topic at hand, in addition to his reasonable academic and professional experience regarding sustainability and ICT. Leedy (1997) notes the more knowledgeable you get, the better you will be able to understand your problem. Further, researchers can better understand problems and solutions that address actual issues through building a solid theoretical foundation based on quality resources (Yair and Timothy 2006). Consistent with that, it is critical to indicate your own language and other authors' attitudes to the research issue (Madsen 1992). Ways of using language to do this include: technically emphatic expressions, attitude markers, relational markers, and hedging expressions (Ferfolja and Burnett 2002). Respectively, these ways concern words or phrases that relate to the strength of the claim or to your degree of confidence in what is said; indicate a writer's assessment of or attitude to an issue; indicate the writer's relationship to the audience or the scholarly community in which they are writing; and make statements about the degree of certainty or probability of a question (Ibid).

2.8. Validity

Validity is a key issue in any research approach for it brings robustness and soundness to research outcomes. It entails the quality of the evidence gathered in terms of credibility, authenticity and relevance, and not strictly the method that is only a way of gathering evidence. Barnes (2005) suggests that researchers should ensure the validity of the study and reliability of the results through making use of quality literature to serve as the foundation for their research. Hart (1998, p. 1) states that 'quality means appropriate breadth and depth, rigor and consistency, clarity and brevity, and effective analysis and synthesis.' To ensure the validity and reliability of the research approach, the content was thus based on studies containing in–depth analysis and sound data collection instruments involving stakeholders globally as well as on views shared with prominent experts and scholars in the field as reflected on the reference list from highly credible sources.

It is also important to clarify how essential the selection procedure for the chosen methodology is, as there is a potential for missteps and errors that may arise from using a biased procedure (Staley 2004). Using literature review allowed the author to evaluate the merit of previous studies in terms of relevance, accuracy, and findings. This made it possible to learn from the errors of others and avoid pitfalls and biases. Indeed, an effective and quality literature review is one that is based upon a concept–centric approach rather than author–centric approach (Webster and Watson 2002).

Research bias was addressed through critical thinking and evaluation of data as well as relevant discussions with Per Flensbury, expert in the field of ICT and related economic and environmental sustainability matters. This was intended, apart from gaining further knowledge, to feed critical perspective into the study. As far as the information is concerned, the data was collected based on a preliminary process of evaluating the quality of the documents. For that, the author used Scott's (1990) four criteria for assessing document quality:

1. Authenticity: the evidence gathered for the thesis is genuine and of unquestionable origin
2. Credibility: the evidence gathered is free from error and distortion
3. Representation: the evidence obtained is typical
4. Meaning: the evidence gathered is clear and comprehensible

CHAPTER THREE

LITERATURE REVIEW

'If I have seen a little further it is by standing on the shoulders of giants.' (Isaac Newton 1676)

3. Literature Review

The aim of this chapter is to establish the theoretical foundation for the proposed study. The author reviews relevant earlier and current theories and studies. The theoretical constructs covered in this chapter include: ICT, design, sustainability, sustainable development, climate change, and energy. Following the discussion of key definitional issues related to these domains, the author delves into the literature relating to the research study. In so doing, he begins with a broad perspective and then deals with more and more specific studies relating to the research questions at hand, following the inverted pyramid organizational framework for structuring the literature review.

3.1. Information and Communication Technologies (ICT)

3.1.1. What is ICT?

ICT is a generic term that is used to encompass all forms of technologies used to handle information and aid its communication in a digital format – creation, acquisition, processing, storage, retrieval, transmission, exchange, dissemination. ICT include hardware and software. Hardware encompasses computers (desktop, laptop, wearable), mobile phones, pen-based PDAs, printers, wireless and mobile telecommunications networks and so on. Software comprises associated applications and services, such as decision support system (DSS), service oriented architecture (SOA), enterprise resource planning (ERP), videoconferencing, e–commerce, e–learning, e–communities (i.e. virtual team), etc. ICT use spans over as diverse areas as business, industry, environment, government, communication, health care, scientific research, education, etc. Moreover, it is common that ICT is synonymous with IT as ICT is an umbrella term for information technology (IT) and communication technology. Indeed, IT is the field of engineering that involves computer and communication systems – hardware and software – used to create, acquire, process, store, retrieve, transmit, disseminate and protect information, as well as the knowledge and skills needed to use ICT securely, intelligently and appropriately in a variety of contexts. Information technology is defined by the Information Technology Association of America (ITAA) as 'the study, design, development, implementation, support or management of computer–based information systems, particularly software applications and computer hardware.' (Veneri 1998, p.3) Communication technology entails, on the other hand, the activity of designing, constructing and maintaining communication systems which are used to facilitate virtual communication between individuals or groups.

In the broadest sense, the term IT is used to refer to all of computing which is concerned, according to the Association for Computing Machinery (ACM 2006), with any goal–oriented activity requiring, benefiting from, or creating computers; it thus includes designing and building hardware and software systems for a wide range of purposes; processing, structuring, and managing various kinds of information; making computer systems behave intelligently; creating and using communications and entertainment media; finding and gathering information relevant to any particular purpose and so on. IT first started as a grassroots response to the practical, everyday needs of organizations and then evolved as computers became essential work tools at every level of most organizations, and networked systems became their information backbone (Ibid). Successful implementation of IT is typically dependent upon how appropriately the computer–based systems respond to the organization's needs regarding the integration of the infrastructure and architecture of systems and the management of the interaction of these systems with the external environment through programmatic interfaces (human computer interaction). Obviously, IT use goes beyond the organizational context as it is nowadays used by different categories of people for social, political, professional and research purposes. The premise of IT use is to meet a wide spectrum of information needs of people and organizations and enhance problem–solving capacities pertaining to computer systems as well as increase users task proficiency, accuracy and efficiency. This can be accomplished through as well the design, development, use, implementation, application and innovation of technological systems as theory about these systems and related processes. It is important to note that IT can also be considered as an umbrella term in its own right as it is a quite broad concept that covers a wide variety of areas, including: installing applications; designing complex computer networks and information databases; managing data; networking; engineering hardware; and the management of entire systems (i.e. ERP, SOA).

3.1.2. ICT and Sustainability

ICT are increasingly recognized as the strongest change means humanity has to its disposal. Recently, ICT have become a critical player in progress towards an efficient, low carbon economy. ICT have consistently delivered innovative products and services that are now an integral part of every aspect of human life. Indeed, a large part of economic growth is attributed to and continuously driven by ICT innovative solutions that are becoming an essential and strategic component of all economic sectors, such as energy supply, transport and logistics, buildings, power supply, industry, etc. ICT have, moreover, a profound effect on the environment, becoming a key driver and force of change for a low carbon economy. There are benefits from the adoption of ICT–based innovations to influence and transform the way our society works (GeSI 2008). ICT have a significant potential to enable new solutions to address environmental challenges. As environmental problems aggravate recently, ICT are being expanded beyond mere production of green products, becoming actively used in dealing with environmental issues (Forge 2007). The positive ecological dimension rests on ICT's potential to deliver greener products and increase efficiency through dematerialization, e–substitution, virtualization, optimization, etc. (Reisch 2001). This can bring enormous economic benefits and environmental gains. In 2008, the global conservation organization (WWF) suggests ten uses of ICT in other economic sectors that could each improve energy efficiency and mitigate global carbon dioxide emissions by at least 100 million tons by 2020 (Griffiths 2008):

- Smart grid: deploying smart meters and communication technologies within electricity networks.
- Smart work: use of the internet to work remotely and avoid business trips or physical commuting.
- Smart buildings: use of sensors and control systems in buildings to improve efficiency.
- Dematerialization services: use of ICT to substitute for physical products and interactions.

• I–optimization: use of ICT in production processes to improve operations and increase efficiency.

• Smart appliances: use of ICT in appliances to improve efficiency and to tailor their use with needs.

• Integrated renewable solutions: use of simulation, analytical and management tools to enable a wide deployment of renewable energy.

• Intelligent transport: deployment of advanced sensors, analytical models and ubiquitous communications to enable less polluting forms of transport.

• Smart city planning: deploying simulation software to improve urban design to optimize energy efficiency.

• Smart industry: deploying software to forecast, simulate and analyze energy use in production processes.

Software technology is deemed to be the biggest contributor to sustainability initiatives. Software technology provides the tools that allow to measure, monitor, and model environmental systems. Examples are countless in this regard, among them include: geographical information systems (GIS) (Pearson and Ross 1994; Mann and Benwell 1996); system models – nutrients (Smaling and Fresco 1993); climate change modelling (Shackley and Wynne 1995); remote sensing (Duvernoy et al. 1994); modelling complex systems (Redetzke and Van Dyne 1990); participatory modelling (Marr et al. 1998) and so on. Pahl–Wostl (2007) points out that the increasing awareness of the complexity of environmental problems and human–technology–environment systems has triggered the development of new management approaches. ICT continue to lead and bring more innovations needed to address even more complex environmental problems.

3.2. Design

3.2.1. Definitional Issues

The scholarly literature on design is as diverse as the wide range of approaches to conceptualizing design in different kinds of areas. As noted by Walsh (1996) and Roy and Potter (1993), the discussion over the meaning of design is a confusing one, not in the least because the term 'design' is used to cover different kinds of design activities, including ICT design, graphic design, industrial design, engineering design, etc. In literature and in practice a profusion of ideas exists about what design is and how it has been reinterpreted (e.g. see Wolfgang 2001). Although much has been written about design research and practice and even with a seemingly endless and ever–burgeoning discourse in this regard, there is still an ongoing debate about what design is. This apparent lack of uniformity in the definition of design reflects in part the different perspectives on the function of design, and, with it, the contribution of designers (Walsh 1996; Gemser 1999; Walsh et al. 1992). Suggestive definitional endeavors tend to frame it within what designers intend to create or solve, for what purpose, and with what problem solving method, design concept remains too intricate to be all–embracing notwithstanding. Another kind of heated debate about design is whether it is a science or not. Wolfgang (2001, pp. 65–66) states: 'design is not an art because it doesn't aim at individual expression, but instead to serve various stakeholders...Design is not technology because it deals with fuzzy, discursive criteria rather than objective criteria…Design is not science because it does not offer new explanatory models of reality, but changes reality more or less purposefully...Obviously design is something very special.' A close look at this attempt of further adding intricacy to the matter depicts that looking for an ideal definition may not help to grasp or precisely describe what design is. Design can be considered as a combination of many elements intertwined together to imply that design is merely but a concept of another kind that transcends its epistemological boundaries, not delineated from a phenomenological perspective. Cross et al. (1981) contend that the epistemology of science was in disarray and therefore had little to offer an epistemology of design. Glynn (1985, cited by Cross 2001, p. 2) suggests that 'it is the epistemology of design that has inherited the task of developing the logic of creativity, hypothesis innovation or invention that has proved so elusive to the philosophers of science.' Indeed, design theorists and philosophers have realized that design definitions remain unable to fulfill the big issues of design, owing to the complexity inherent in its subject as an expert field. Overall, design takes place in various contexts and transcends its subject as it travels beyond its boundaries to land everywhere. 'Design is everywhere – and that's why looking for a definition may not help you grasp what it is.' (Design Council)

3.2.2. What is Design?

The term design covers different kinds of design activities related to various disciplines, such as graphic design, industrial design, architecture, engineering design (i.e. ICT) etc. Generally, design refers to an inventive or creative problem solving process or activity aiming to produce artifacts to fulfill social and organizational needs. The genesis of design is to create and enhance functional and aesthetical utility and value of artifacts within the environment in which they operate. From a functional perspective, design can be characterized as: anticipative (looking ahead, in directions and time scales); generative (aiming at the synthesis of material or immaterial artifacts and patterns of behavior); integrative (neglecting disciplinary boundaries, moderating perspectives, and including its own); context aware (using cognitive, emotional, social, environmental, technological, and cultural interdependencies); illustrative (creating wholes, contexts, narratives, aiming at agency and dissemination); user–oriented (taking quality of life as its own criterion, without claiming what this is) (Wolfgang 2001).

Design is that area of human experience and knowledge translated into the ability to solve problems and, more generally, adapt the external environment to fulfill various needs. Conklin (2001, p. 15) states: 'any design problem is a problem of resolving tension between what is needed and what can be done'. It is a process that combines creativity, pragmatism, vagueness, and subjectivity as well as scientific knowledge to provide solutions to wicked problems spaces encountered by humans through their interaction with the world. Wolfgang (2001) classifies design as an attempt of seeking to categorize fuzziness. This is manifest by bringing a learning approach to each problem space using creativity, intuitiveness, expediency and so on to create a solution. Moreover, design serves far beyond its processes, artifacts, scenarios, tools, and people (designers); it contributes to human understanding, knowledge, and experience in almost every context (i.e. ICT, leadership, art, social change, strategizing, storytelling). Bearing that in mind, one would wonder how enormous the benefits could be if the design could be informed and motivated by holistic philosophies such as sustainability. Rusts (2004, p. 84) states '…,there is much wider world of knowledge and experience that they [designers] can engage with and influence, and this is as true of research as it is of the more usual forms of creative practice.'

3.2.3. ICT Design Intricacy

In ICT, this term design is often used to indicate a broad set of activities in the product design and development. ICT design entails a wide variety of aspects, including technical, environmental, social, cultural, ethical, cognitive, emotional, etc. Like all forms of design, the main objective of ICT design is to amalgamate aesthetics and functionality for increased utility. ICT design endeavour is certainly of complex nature as it is difficult and often daunting to define design problems at a certain point of time (countless experiences in ICT project design have proved this fact). However, ICT design aims at fulfilling human and organizational needs expressed by different users within different contexts. The inherent complexity of ICT design that is manifest by functionality and aesthetics specifications demanded by these users can raise many issues in the design process. This mostly relates to the appropriateness, application, and the motivation of a given design approach that can be espoused to tackle different problems. Design approaches include: designer–centric, user–centered; participatory, multi–stakeholder, context aware, (co-)design, technology or demand driven design, mono or multi methods, etc. However, no matter how knowable a designer can believe the design problems to be, instantiation of technological artefacts tend to unfold externalities or side effects in the environmental where they operate. For instance, ICT have negative impacts on the environment pertaining to energy–intensive products and services. Designing ICT should entail holistic views and act upon continuous learning and problem redefinition. It is a process of multiple steps; hence a one–off decision making situation is irrelevant as new phenomenological interpretations evolve and new considerations (i.e. environmental) emerge to add up to the problem solving process.

3.2.4. ICT Design and Design Science

Many attempts have been undertaken to scientize design. Accordingly, some design theorists have endeavored to provide related definitional implications concerning the fields whereby scientific (systematic) methodologies are applied like in engineering and applied sciences. And ICT design draws indeed from engineering and applied sciences; it is a design science. Design science refers to 'an inventive or creative, problem solving activity, one in which new technologies are the primary products.' (Venable 2006) The aim of design science is to recognize laws of design and its activities, and develop rules (Hansen 1974), which would seem to be design science constituted merely as systematic design (Cross 2001). However, Hubka and Eder (1987, cited by Cross 2001) view this as a narrower interpretation of design science than their own: design science (1) comprises a system of logically connected knowledge in the area of design, and contains concepts of technical information and of design methodology; (2) addresses the problem of determining and categorizing all regular phenomena of the systems to be designed, and of the design process; and (3) is concerned with deriving natural sciences' applied knowledge appropriate information in a form suitable for the designer's use. Design science centers on systematic knowledge of design process and methodology as well as the technological underpinnings of design of artifacts and thus refers to an explicitly organized, rational and systematic approach to design; the utilization of scientific knowledge of artifacts and design in some sense a scientific activity itself (Cross 2001). Conversely, most views of design methodologists and designers hold that the act of designing itself is not and will not ever be a scientific activity, that is, the design is itself a nonscientific or a scientific activity (Grant 1979). Design science has its roots in engineering that is related to applied science which is the application of knowledge from natural scientific fields to solve practical problems. Design science is the application (utility) of natural science (truth), that is, it materializes the generalizability and realism of the natural science theories through the usability of scientific–based designed artifacts. ICT research and development (R&D) is the manifest of engineering and applied sciences as it relies on the application of scientific knowledge and methodologies. Rather than producing general theoretical knowledge like in natural science, design scientists produce and apply knowledge of tasks or situations in order to create effective artifacts (Simon (1969), i.e. ICT.

3.2.5. Design and Sustainability

3.2.5.1. Design and the Environment

Papanek (1995, p. 32) states: 'the relationship between design and ecology is a close one.' Understanding this relationship has a central role in the design of sustainable human systems that are, in turn, essential for society to exist sustainably in the biosphere. This form of being creates balance in nature's cycles, preserves the environment, and sustains the renewal of the biosphere. However, design of human systems has for long overlooked environmental considerations which led to complex problems, i.e. biodiversity loss, resource depletion, climate change, etc. Climate change is a visible instance that exposes underlying flaws in the design of industrial and technological energy systems, which substantiates the unsustainability of the current destructive trends. Suzuki (2002, p. 2) states: 'for the first time in the 3.8 billion years that life has existed on Earth, one species – humanity – is altering the biological, physical and chemical features of the planet.' While design is seen as a human power to create artifacts that serve and fulfill individual and collective purposes, it is, with its mainstream approach, systematically degrading the biosphere; our most valuable resource whose replenishment is the condition for human survival. The prevailing design approach, which focuses on the efficiency of delivering products and services, will not protect neither sustain the renewal of the biosphere. Thus, it is time to rethink the relationship between technological design and the environment to create sustainable human systems that will pave the way for restoring environmental quality and promoting a low carbon economy. The relationship between ICT design and the environment is multidimensional due to the complex connections among the positive benefits, negative impacts, and unintended externalities that flow from the way ICT is designed.

3.2.5.2. Sustainable/Eco–Design

Sustainable design has emerged as a general reaction to global environmental crises, the rapid economic growth, and damage to ecosystems and biodiversity (Shu–Yang et al. 2004). The purpose of sustainable design is to eliminate negative environmental impacts through skillful, sensitive design (McLennan 2004) and relate people with the natural environment. For design to be sustainable, it has to stress efficiency; regeneration; resiliency; sufficiency; and mimic natural designs, patterns, processes, and rhythms. Sustainable design is also referred to as 'eco–design' (Papanek 1995). In the context of ICT, eco–design can be conceived of as a strategy that can be espoused to reduce the negative impacts associated with ICT product lifecycle. Eco–design is a promising path and a strategic approach for sustaining economic and societal development. Shu–Yang et al. (2004) contend that the practice of eco–design could potentially yield great social and environmental benefits. There is a need to think ecologically, moving from an environmentalism driven by sectoral issues involving resources and climate change, to a more integrated ecologicalism that recognizes the inherent interdependence of all life systems (Esty and Chertow 1997). Moreover, eco–design is to realize the potential of designers and benefit from their creative abilities and strengths to drive technological innovations that help mitigate environmental impacts and ultimately enable a low carbon economy. Datschefski (2001) argues that sustainability can only be achieved through design. Then, the challenge for ICT design is to embrace sustainable practices and principles for the pursuit of auspiciousness in the economy and society. Morelli (2007) suggests exploring the possible convergences between economic logics and socio–ecological instances to shift designers' activities from products to systemic solutions. He claimed that designers' perception is changing through the radical shift in the responsible role of industrial companies; the new condition implies a genetic change in the role of the industrial system and, consequently, a genetic mutation of designers' role. Awareness of designing technologies with sustainability in mind will contribute to a high quality of life for current and future generations. It is thus necessary for designers to understand how the world operates in order to take actions that support responsible design. Overall, sustainable/eco–design seeks to extend and replicate opportunities; generate new opportunities for sustainable livelihoods; and protect ecosystems and environments; and conserve and replenish scarce resources.

3.2.5.3. Sustainable Technologies

The philosophy of sustainable design is to design technologies (products and services) that comply with the principles of environmental sustainability. Design for the environment is 'design that seeks to eliminate potential negative environmental impacts before a product is made…'(Greenpeace

2005) Sustainable technologies (ICT) are technologies that are designed, produced, used, and improved based on environmental philosophy and ecological intelligence. The design of such technologies involves adopting de–carbonization strategy in both manufacturing processes and product design; reducing carbon and other GHG emission; and using sustainable measures and standards. In addition, it should promote service provision rather than ownership of physical products. This idea entails shifting the mode of consumption from product ownership to services through dematerialization. This usually provides similar functions, i.e. we buy digital alternatives instead of physical products. Such an approach promotes minimal resource use per unit of consumption (Ryan 2006), i.e. energy. Moreover, 'industry should promote a shift not only from products to services but also to services that are increasingly environmentally sound.' (Madden and Weißbrod 2008) Adding to the characteristics of sustainable design of technologies is the renewability aspect associated with optimizing materials and products transport as well as using sustainably–managed renewable sources. Table 3.1 presents examples of sustainable design principles (related to energy and emissions) from two engineering disciplines, namely product design and green design. Although some slight variations exist, similarities draw from the focus on use of renewable energy for product design and toxic emissions (i.e. carbon dioxide).

Sustainable Product Design (Datschefski 2001)	Green Design (Abraham and Nguyen 2003)
1. Solar: Their manufacture and use consumes only renewable energy that is cyclic and safe. 2. Safe: All releases to air are non–toxic. 3. Efficient: Most efficient use of energy required over life cycle.	1. Engineer processes and products holistically using environmental impact assessment tools. 2. Ensure that all energy inputs and outputs are as inherently safe and benign as possible. 3. Do not be limited by current or dominant technologies; seek fundamental change.

Table 3.1 Sustainable product design and green design

Source: Adapted from Llewellyn et al. 2005

3.3. Sustainability

3.3.1. What is Sustainability?

Sustainability is a multifaceted, dialectical, and philosophical concept that can be overwhelming due to the complexity inherent in comprehending its characteristics as a dynamic process and the specifications of the socio–ecological systems to which it is applied. It involves a holistic nature and embodies multidimensional spheres, including ecosphere, biosphere, biodiversity, society, economy, etc. The concept of sustainability has deep roots, born from the realization that human activities were endangering future life on the earth (Samuel and Lesley 2007). It has been around for a long time, but it did not become popularized until a decade after the release of the Brundtland report *Our Common Future* by the World Commission for Environment and Development (WCED) in 1987. Since then, a veritable flood of publications has defined, redefined and scrutinized the idea and applied it to most human endeavors (Molnar et al. 2001). However, the concept has been misinterpreted and misunderstood, owing to the ambiguity emanating from its complex underpinning. This includes also definitional matters as there are multiple ways to define the concept of sustainability. Murcott (1997) lists 57 definitions; a current survey would construct dozens more pertaining to a variety of contexts. Generically, sustainability refers to a characteristic or ability of a process that can be maintained or sustain itself indefinitely. More into a broad perspective, 'sustainability integrates natural systems with human patterns and celebrates continuity, uniqueness and place making' (Early 1993). Sustainability means humans consciously trying to go with the grain of nature (Foster 2001). A closer examination of these definitions depicts that at the heart of this concept is the principle that society should conduct its affairs in the best interests of the human and the natural environment as a whole.

The sustainability concept is commonly associated with three dimensions: social, environmental, and economic as it is used in connection with human and natural systems. Samuel and Lesley (2007) point out that current definitions generally include three components; society, environment, and economy, along with the recognition that 'the well being of these three areas is intertwined, not separate' (McKeown 2002). In this study, the focus is on the economic and environmental sustainability in relation to ICT. From an ecological perspective, sustainability can be defined as: improving the quality of human life while living within the carrying capacity of supporting ecosystems. (IUCN 1991) This means that sustainability is the ability of an ecosystem to maintain ecological processes, functions, biological diversity and productivity over the long haul. Rosenbaum (1993) points out that sustainable means are the methods and systems that don't harm natural cycles. From a sustainable economic development perspective, sustainability means the amount of consumption that can be sustained indefinitely without degrading capital stocks, including natural capital stocks (Costanza and Wainger 1991), i.e. energy and material resources. This must be done by using strategies and technologies (i.e. ICT) that break the link between economic growth and environmental damage and resource depletion (i.e. energy) (Ruffing 2007). In a social context, sustainability is to maintain social conditions that don't undermine people's ability or jeopardize their potential to meet their needs in the future. This can occur through promoting human rights, social justice, and a culture of peace. Overall, sustainability epitomizes well–being in a holistic sense and seeks to provide quality of life by providing a healthy, productive, and meaningful life for all people while preserving environmental quality. This occurs through using ecosystems resources in a way to meet current needs without compromising the needs of future generations. Thus, the goal is for human society to exist within the biosphere in that it does not cause imbalance in nature's cycles, nor inhibit people from meeting their needs. Sustainability involves looking at the system from a holistic perspective to make all–inclusive and astute strategic choices for societal long–term benefit.

3.3.2. The Four Sustainability Principles (SPs)

According to Robèrt et al. (1997), sustainability is a state where the four 'sustainability principles' are not violated. This definition depicts that sustainability is a state in which society does not systematically undermine natural or social systems within the biosphere. The four sustainability principles are regarded as basic principles for socio–ecological sustainability developed through scientific consensus to define the minimum requirements of a sustainable society. They are derivative from basic laws of science, including cycles of nature, conservation of matter, laws of thermodynamics, etc. and have been peer–reviewed by the international scientific community.

Sustainability has theoretical foundations from which it has grown that have recently begun to solidify into a defined science (Lee 2000). This is to articulate sustainability with methodological and scientific rigor so to be intelligible, clear and useful for analyzing, managing, and measuring overall human activities (i.e. design). A significant contribution in this line was a development of a set of four guiding sustainability principles. Those principles are based on a peer–reviewed process and a scientific consensus to provide a more clear understanding and principle–level definition of sustainability (Holmberg et al. 1996; Holmberg and Robèrt 2000; Ny et al. 2006).

…the sustainability principles should be:

- Based on a scientifically agreed upon view of the world,
- Necessary to achieve sustainability,
- Sufficient to achieve sustainability,
- General to structure all societal activities relevant to sustainability,
- Concrete to guide action and serve as directional aides in problem analysis,
- Non–overlapping or mutually exclusive in order to enable comprehension and structured analysis of the issues (Holmberg and Robèrt 2000, p. 298; Ny et al. 2006, p. 63).

The first three principles are concerned with environmental issues while the fourth is concerned with social issues:

In the sustainable society, nature is not subject to systematically increasing…

I. …concentrations of substances extracted from the Earth's crust,

II. …concentrations of substances produced by society,

III. …degradation by physical means,

and in that society…

IV. ...people are not subject to conditions that systematically undermine their ability to meet their needs.

Table 3.2 Four sustainability principles

Source: Holmberg and Robèrt 2000; Ny et al. 2006

This scientific definition of sustainability clarifies how to avoid the destruction of the biosphere (Holmberg et al. 2000; Robèrt et al. 2002; Ny et al. 2006). Scientific principles are the foundation of our understanding of the biosphere and how it operates. By means of understanding the cycles of nature, the conservation of matter, and the laws of thermodynamics scientists have come to concur that:

- Neither matter nor energy disappears;
- Natural processes disperse matter and energy;
- The value of materials exists in their concentration, structure and purity;
- Photosynthesis is the primary producer in the biosphere; and
- Humans are a social species.

3.3.3. Implications of Sustainability Principles for Design and Society

The four sustainability principles are aimed to be incorporated into decision–making, strategies, processes, activities, systems, and policies etc. as attempts to promote sustainable practices that help restore and preserve environmental quality and meet human needs. This objective can be achieved through establishing and maintaining the environmental and social conditions over the long haul. It is important to recognize that sustainability encompasses both social and environmental dimensions as we cannot achieve one without the other. To achieve sustainability, it is required to design human systems (i.e. ICT) that maintain the potential evolutionary quality of the ecosphere and don't compromise its ability from supporting all life forms, levels, and combinations. Datschefski (2001) contends that sustainability can only be achieved through design. The goal of sustainability is for society to exist within the biosphere in a way that it does not cause imbalance in nature's cycles, nor impede people from meeting their needs. And for this to occur, humans should, according to Walker & Salt (2006) and Princen (2005), design systems that stress adaptability, efficiency, harmony, regeneration, resiliency, and sufficiency, and mimic natural designs, processes, patterns, and rhythms. From a social perspective, to enhance and maintain social conditions, it is necessary to support fairness and equitable distribution of resources and power; provide equal opportunities and healthy working conditions; produce social environment where human needs can be met; and promote prosperity of individuals, communities, and organizations through receiving an adequate and fair return on their investments. Nothing less than this is worthy of our inventiveness and humanity.

3.4. Sustainable Development

3.4.1. What is Sustainable Development?

This concept was introduced and came into widespread acceptance after the release of Brundtland report in 1987 where it was defined as a development that 'meets the needs of the present generation without compromising the ability of future generations to meet their own needs'. This is one of the most widely used and broadly stated definitions. However, this definition is not universally accepted and has undergone various interpretations (Kates et al. 2005). Most well–established definitions do not clarify specific human and environmental parameters for measuring sustainable development, nor do they provide further explanation of the needs or the implications of the state of not being met; hence they can be interpreted as statements of fact or value. In the same vein, the idea of sustainable development is viewed as an oxymoron because development inevitably depletes and degrades the environment (Redclift 2005). From a different critique angle, Anderson (2002) argues that the real purpose of sustainable development is to contain and limit economic development in developing countries and control population. This view stems from the fact that while developed countries inflicted environmental damage during their industrial growth, they now encourage developing countries to mitigate the environmental damage, which sometimes impedes economic growth. Most critiques in this regard was raised when Agenda 21 set up the global infrastructure needed to manage, count, and control all of the world's assets and resources.

However, Foster (2001, p. 153) states: 'learning to understand the natural world and the human place in it can only be an active process through which our sense of what counts as going with the grain of nature is continuously constituted and recreated.' The active process of sustainable development is a vision and an approach to development for achieving the goal of sustainability – 'going with the grain of nature'. It can be viewed as a process of working toward a state of economy that equitably embraces the realization of qualitative potentialities and quantitative value; a pattern of using the ecosystem and its resources to achieve the sustained economic development within society. It is described by (WCED 1987) as ‘a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.’ It endeavors to conciliate and relates to the continuity of traditionally misperceived contradictory forces – economic development, social justice, and environmental integrity. Economists now view the economy and the environment as a single interlinked system. Wilson (2003) contends that sustainable development balances the need for economic growth with environmental protection and social equity. The whole philosophy behind sustainable development is to meet human needs; enhance social standards; and protect and preserve the natural environment needed by future generations. The premise rests on understanding the interdependence and equal importance of the natural environment, the economy and society. To pursue this pathway, both ecological and social systems must not be systematically degraded by economic activities. Sustainable development Sustainability interfaces with economics through the social and ecological consequences of economic activity (Daly and Cobb 1989). It seeks to change the current developmental path ensuring that environmental sustainable protection does not preclude economic development which, in turn, must be ecologically and socially viable now and in the long run.

3.4.2. Strategic Sustainable Development (SDD)

Sustainable development is an approach to achieve sustainability. While there are many approaches to sustainable development, the strategic approach is guided by a shared understanding of sustainability principles that embody the end goal for achieving sustainability. From an environmental perspective, to be strategic in moving towards sustainability requires a clear understanding of sustainability principles concerned with environmental issues which are employed to set the minimum requirements of an environmentally sustainable society. According to (Holmberg et al. 1996; Ny et al. 2006), sustainability principles define an end–goal for sustainability to plan strategically and holistically for socio–ecological sustainability in the biosphere. Strategic sustainable development (SDD) is a planned development that addresses environmental and social issues in a rigorous, meaningful and scientific way to achieve sustainable society. This can occur through addressing the root causes that are resulting in the current systematic decline in the potential of the planet so to help develop upstream and socio–ecologically informed solutions needed to sustain the design of human systems (i.e. ICT). SSD entails a back casting from basic sustainability principles approach to sustainable development whereby a vision of a sustainable future is set as the reference point for devising and planning strategic actions. This is necessary to shift our thinking paradigm in a way to act proactively, think strategically, on a larger scale, and of future generations. SSD is about an alternate way of thinking to solve the escalating environmental problems and mitigating the negative impact of the current path of our economic development. This path is inflicting serious environmental issues, including climate change, rapid resources (i.e. energy, material) depletion, pollution, etc. As an alternative approach, SSD seeks to guide and help individuals, organizations, governments, and institutions to agree upon concrete ways to take action together to implement sustainable development on a global scale.

3.5. Climate Change

3.5.1. Definitional Issues

Usually, multiple definitions emerge when investigating new phenomena or dealing with concepts associated with multidimensional nature such as climate change and sustainability. Such concepts are sweeping and multifaceted covering a plethora of areas and subareas, making it daunting to notionally delineate and overwhelming to interpret their definitional implications on a phenomenological level. They can therefore be defined in multiple ways based on whether the perspective is contradictory or complementary; or rather it depends on the interpretative context, i.e. business, public, media, etc. For instance, for Bärring (1993) and Pielke (2004), it is rather important which definition of climate change is used, particularly when communicating with the public and the media. In the context of climate change, the ongoing scientific and political debates have fueled many arguments leading to relatively diverse unsettled facts. This has paved the way for more misinterpretations and misunderstanding emanating from the different implications of the concept.

Consistent with that, for some 'inconstancy' is considered an inherent property of the climate system. According to Mitchell et al. (1966), the term 'climate change' encompasses all forms of climatic inconstancy – any differences between long–term statistics of the meteorological elements calculated for different periods but relating to the same area – regardless of their statistical nature (or physical causes). The climatic inconsistency and inconstancy aspects emanate from the fact that the Earth's climate is never static due to the significant change from one climatic condition to another. In addition to definitional issues, climate change is broadly defined by IPCC (2007) as any change in climate over time whether as a result of human activity or due to natural variability. While the United Nation's Framework Convention on Climate Change (UNFCCC 2004) defines climate change as 'a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, and that is in addition to natural climate variability over comparable time periods'. The BALTEX Assessment of Climate Change for the Baltic Sea basin (BACC 2008) adds explicitly, following the IPCC–definition, 'anthropogenic' to the term 'climate change' when human causes are attributable, and to refer to 'climate variability' when referring to variations not related to anthropogenic influences. On the whole, climate change is a field of study that deals with variations and their possible causes (human or natural) in climate on many different time scales (from decades to millions of years) but relating to different areas across the whole Earth. It is also important to realize that climate change may unpredictably occur at any time, and in a specific geographical area or across the whole Earth.

3.5.2. Climate Change, Global Warming, GHG and Greenhouse Effect

The term 'climate change' has been used interchangeably with 'global warming' given, perhaps, the causal relationship between them as climatic processes. However, there is more to the distinction between them from a scientific perspective. Climate change results from the buildup of man–made GHG gases in the atmosphere that trap the sun's heat (that would otherwise bounce off the planet back into space), causing changes in weather patterns on a global scale. Climate change responds to different external forcing (processes external to the climate system) whether natural or anthropogenic. More specifically, apart from natural factors or influences, such as changes in solar activity, volcanic eruptions, long–period changes in the Earth's orbital elements, natural internal processes of the climate system (EPA 2008), climate change can occur as the result of anthropogenic forcing attributed to human activities such as increasing atmospheric concentrations of carbon and other GHG through fossil fuel combustion, deforestation, and industrial processes (IPCC 2007). Natural variations such as solar radiation and volcanoes that produced most of the warming from pre–industrial times to 1950 had a small cooling effect afterward (Hegerl et al. 200). On the other hand, global warming is the gradual heating of the Earth's atmospheric and oceanic temperatures due to GHG, which leads to climate change. In other words, global warming is a process that raises the air temperature in the lower atmosphere due to variation in the atmospheric (unsafe) concentrations of the GHG that capture infrared radiation reflected back from the Earth's surface.

GHG contributing to the greenhouse effect and to a rise in global temperatures include: include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), ozone (O_3), and chlorofluorocarbons (CFC), halogenated fluorocarbons (HCFCs), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs), etc. GHG are produced from both natural and human–made sources and deemed as the culprit of global warming. GHG are gases that absorb infrared radiation in the atmosphere. They act as insulators (with heat–trapping properties) that help trap the sun's rays (ultraviolet radiation) passing through the Earth's atmosphere to warm the planet's surface before being reflected back into space as infrared radiation. This process is known as the greenhouse effect which is, in fact, a natural phenomenon that helps maintain a stable temperature and climate on Earth. Without the latter, the Earth would be too cold to support life.

Unquestionably, no one knows exactly what climate change will do. But there are some pretty good theories that put in the picture what some unintended consequences might be. Concentration of infrared radiation captured in the atmosphere may cause: increases in global average air and ocean temperatures; disrupted ecosystems (i.e. rainfall pattern shift, hydrological flow change, changes in what grow where and when, changes in which species die or thrive); melting of glaciers; rising global average sea level; severe droughts and floods; increased intensity of windstorms; new pathways for disease; habitat loss; heat stress; displaced people and environmental refugees; etc.

3.5.3. Atmospheric GHG Levels: Causes, Effects and Potential Solutions

No issue looms larger in terms of potential strategic impact on the economy than the climate change. This issue has become at the top of political agenda given its contentiousness pertaining to the dilemma surrounding the involved high cost of addressing the issue or not addressing it. Indeed, the British government' Stern Review (2006) suggests that failing to tackle climate change could inflict economic damages (the overall costs and risks) equivalent to losing at least 5% of global gross domestic product (GDP) each year. Under severe scenarios, not acting now would incur a wider range of risks and impacts; and the estimates of damage could, according to Stern (2006), amount to as much as 20% of global GDP or more. In contrast the costs of reducing GHG emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year (Ibid).

The concentration of GHG has increased dramatically as a result of human activity, i.e. fossil fuel combustion, deforestation, industrial processes, etc. In 2007, IPCC declared human induced global warming 'unequivocal'. More infrared radiation is being trapped in the atmosphere due to variation in the concentrations of the GHG causing global temperatures to increase and climates to change. The concentrations of CO_2 have increased by 148% since the mid–1700s (EPA 2008). Carbon dioxide accounts for 70 % of the problem that comes from the burning of fossil fuels (Easty and Winston 2009). Rising temperatures and provoking unpredictable weather patterns could affect a broad range of industries and livelihoods given the overarching aspect of climate change issue. Indeed, beyond the direct effects of global warming and the related weather's unpredictable patterns, all economic sectors will face the indirect effects of climate change, particularly as stringent policies (already in place in Europe) to control GHG emissions kick in. For economic sectors (such as logistics and transportation, industry, power supply, and buildings), energy efficiency will be very critical and new technological innovations will be needed to overcome this hefty challenge.

Current atmospheric GHG levels stand at 430 parts per million (ppm) and are rising at about 2.5ppm every year, leading us beyond levels of 450–500 ppm (IPCC 2007; GeSI 2008; McKinsey 2007). Recent analysis suggests that 450ppm may be too high (what can be considered safe are not universally accepted) and that we should be aiming to reduce emissions more quickly (King and Walker 2008; Hansen et al. 2008). The build–up of GHG in the atmosphere beyond those levels required to maintain a stable temperature and climate to support life on Earth will result in irreversible economic disruption and other catastrophic changes. Climate change is fundamentally altering the planet: the earth will warm more in coming decades due to past emissions and climate change will likely have a devastating impact on ecosystems and economies (GeSI 2008). According to Stern (2008), society currently needs to reduce emissions to about 20 GtCO2e per year by 2050, and to reduce emissions by 20 GtCO2e per year. However, carbon emissions will continue to grow at 2–3% per year under a BAU scenario given that the current underlying rate of decrease in carbon intensity (defined as the relative amount of carbon emitted per unit of energy or fuels consumed; quantified in tons of carbon dioxide equivalent (tCO2e)/GDP), is 1% per year and that the world economy continues to grow by 3–4% per year (GeSI 2008). Thus, to reduce emissions by 20 GtCO2e per year implies that a drastic change is needed in production and consumption patterns (Stern 2008). To address the climate change, the most promising solutions are those enabled by energy efficiency technology and, if at all possible, those endorsing the renewable energy espousal. Using ICT to enable energy efficiency in the economy, particularly transport and logistics, manufacturing, power supply, buildings, etc. is an example of ways to help avert the climate change effects. Energy efficiency improvements across the economy holds a great enabling potential to lower GHG emissions in the future, and, unquestionably, the ICT sector has a pivotal role in reaching those goals. Next section addresses energy and related issues.

3.6. Energy

3.6.1. Energy and the Economy

Energy has been a concern for all economies and societies. It drives the economic growth and enhances quality of livelihoods. However, the current unsustainable extraction, production and use of energy resources are threatening the planet through rising GHG emissions in the atmosphere partly due to the intensive consumption of fossil fuels (main energy source). Among the greatest contributors to GHG emissions are the current energy systems that power transport and logistics, industrial processes, buildings operations, power supply, etc. According to IEA (2008), of the total emissions from human activity in 2002, 24% was from the power sector, 23% from industry, 17% from agriculture and waste management, 14% from land use, 14% from transport and 8% from buildings (GeSI 2008). Taking another view of the same data, in 2005, manufacturing was 33% of end–use energy consumption; transport was 26% and households 29% (other services and construction made up the final 12%) (IEA 2008)

As previously pointed out, climate change results from anthropogenic activities and impact upon our ecosystems and quality of life. Current predictions suggest that ecosystems on Earth are likely to be impacted by storms, floods, wildfires, and species shifts which threaten our current society as we depend on ecosystems for resources such as energy and water (IPCC 2007). The current economic trends are unsustainable and if nothing were to change, final energy consumption is predicted to increase with a substantial rise in GHG emissions. Failure to rationalize energy use across the economy may lead to unintended severe externalities that are difficult to predict given the complex set of natural and anthropogenic factors involved in the process. This may accelerate or delay climate change effects but any unpredictable event will be undoubtedly widely devastating. Moreover, current energy production, supply and use are subject to complex global mechanisms and will cause not only the failure of the economy but also the deterioration of the planet. Thus, a holistic analysis approach is required to understand the conundrum of current energy production and consumption patterns in order to avert the plausible consequences of devouring energy and rising global warming under the current industrial unsustainable model.

3.6.2. Driving Forces for Energy Efficiency Technology

The threat of climate change exposes systematically increasing economic destructive trends that escalate negative environmental impacts, including the intensive use of unsustainable energy sources (i.e. fossil fuels) and the destruction of ecosystems for energy production. In order to address the looming climate change issue, global transformation to a low carbon economy has become unavoidable. And ICT–based solutions hold a great potential to improve energy efficiency and mitigate climate change. ICT could play a key role in responding to what is universally acknowledged as the most critical environmental challenge facing the globe – and which is increasingly seen as one of its more significant economic challenges – moving to a low carbon economy (MacLean and Arnaud, 2008). Energy efficiency lies at the heart of economic development. Clearly the exact path of the energy future is yet to be charted, but whatever course it takes will affect every economic sector (Esty and Winston 2009). Therefore, managing and securing energy use are important for the economy to thrive and sustain. Many industries, particularly energy–intensive users, can make use of modern ICT to move into higher energy efficiency and lower carbon footprint.

With supplies tight and fuel prices skyrocketing (spiking to over $ 100 per barrel), many economic sectors (i.e. transport and manufacturing) are required to adopt energy efficiency and climate solutions in order to gain economic advantages of energy conservation and emissions reductions. With a focus on energy efficiency and increase in renewable energy espousal due to better pricing during peak demand, ICT can be used to deliver between 2–7 billion tons of CO_2 reductions (WWF et al. 2008). This could be accomplished with existing technologies just by scaling up solutions that have been proven to work, without significant rebound effects (Ibid). However, global trends and forecasts indicate that the economy's hunger for energy will not abate and given the predictions of the decrease of oil and gas supplies in the future, it is not clear from where, and how, these supplies will come. The bottom line is that energy future will not be the same as the energy past (Esty and Winston 2009). Transforming the incentives for innovation in energy conservation and efficiency technology in today's market and climate reality will dramatically reshape the future of energy consumption profile. In fact, this has already begun to take place through focusing on ICT–based innovations and their implementation in some economic sectors, such as transport and logistics, buildings, industrial processes, etc. According to the Economist Intelligence Unit (2008), many industries have already recognized the need to manage their energy use as strategically as possible in order to reduce their carbon footprint. Further to this point, as the changing energy picture inevitably creates new competitive pressures, for economic sectors that use energy substantially like those in heavy manufacturing and transportation, energy productivity may become a point of strategic advantage (Esty and Winston 2009). The sectors responsible for producing the highest levels of carbon emissions are where ICT might well enable substantial reductions. But it is critical to foster the deployment of efficiency technology and promoting its adoption widely.

3.6.3. Rebound Effect and Energy as an Effective Measure

The phenomenon of rebound effect is well known to energy economists (Khazzoom 1980; Brookes 1990; Berkhout et al. 2000; Binswanger 2000). Traditionally, rebound effect refers to counterproductive effect of an otherwise effective measure. For example, an improvement in energy efficiency that is absorbed by a resultant increase in demand for energy service because of its final price decrease due to higher efficiency of the production of the service. In the context of ICT, rebound effect occurs when increased energy efficiency gains stimulate new demand for ICT products and services, leading to an overall increase in energy consumption that offset energy savings. To better explain that, a more energy–efficient ICT product or service would require less energy to produce, thus the cost per unit of production falls driving down the final price of a unit of product or service, which, as a result, increase demand of the product or the service. Besides, evidence from the energy sector indicates that a more efficient use of natural resources does not always reduce their absolute consumption (Plepys 2002). This occurs most likely because of systemic effects that arise from behavioural changes and social and economic structures that profile or determine the pattern and level of energy consumption.

The majority of earlier studies focused on energy consumption for transport and heating in a single–service model, which largely neglected the substitution effects among various services (Plepys 2002). But subsequent research endeavors expanded the sphere of rebound effects to different models. Thus, rebound effect concept was developed further to focus on multiservice models, which allowed for better understanding of full implications of rebound effects (Binswanger 2000). Greening et al. (2000) carried out a comprehensive literature review of the rebound effects from energy efficiency improvements and suggested a classification of rebound effects into four types: The first type of direct effects is pure price effects which occur as a consequence of increased energy efficiency, which reduces the price of energy utilities by decreasing the amount of fuel needed to produce a commodity and, subsequently, reduces its final price. The second type of direct effects is substitution and income effects where a consumer will not increase the use of the 'bargain' (Plepys 2002), commodity indefinitely until the limits of satiation or budgetary tradeoffs with other expenditures. The consumption pattern and level will be determined by other factors, such as consumer's time budget, behavioural constraints, i.e. social norms, fashion or effort level (see Schneider et al. 2001). Behavioural aspect is important to remember for it is relevant to the further discussion on ICT and energy consumption. The third type of rebound effects is economy–wide effects where the argument builds on the interrelationship of prices and outputs of goods and resources in different markets, which form a unique equilibrium state. In this type, energy price determines the cost structure of many commodities, which determine supply–demand equilibriums for virtually all products and services across the economy (Plepys 2002). The fourth type of rebound effects is referred to as transformational effects in Greening's framework. It relates more to the changes of consumer preferences, altered social institutions, and organisation of production (Ibid). Greening et al. (2000, p. 399) point out that the extension of the rebound effect definition to include transformational effects is 'conceptually possible, but not analytically practical as both theory and empiric data are lacking'. This makes this type of rebound effects the most obscure and abstract given the fact that transformational perspective is much more difficult as it requires looking into the dynamics of behavioral choices and social and organizational structures involving a set of complex factors that may lead to unpredictable scenarios. It is worth noting that transformational effects concern the discussion of energy use within economic sectors where ICT can enable energy efficiency. This revolves around the fact that it is widely assumed that increased energy efficiency of the economy through ICT applications will result in economic and environmental gains, which may not necessarily happen due to a phenomenon known as 'efficiency paradox' (Rubin 2007) in which technology improvements allow for energy savings that are lost to greater consumption. Further to this point and at different level, transformational impacts of ICT on the environment are difficult to be controlled and measured given that ICT–enabled changes affect behavioral, social, and economic parameters, such as consumers attitudes, accessibility, availability, application and use of ICT as well as organizational structures, production, distribution, service processes, etc.

C H A P T E R   F O U R

R E S U L T S

4. Results

4.1. Overview

This section analyses and synthesizes the results based on the literature review research methodology. The author obtained pertinent information covering empirical and analytic scholarship found in as well industry literature as recent relevant studies carried out by a range of eminent researchers, experts, and stakeholders (i.e. NGOs, research centers). This is to answer the two research questions outlined in chapter introduction, section 1.4.2. Extensive literature review helped to gain knowledge of the phenomenon under investigation. To provide a logical and coherent structure of the literature material and bring clarity to the reader, the author used the thematic approach – the results are divided into sections representing the subjects for the topic of this study. These results are presented in two sections that are, in turn, divided into subsections based on the issues explored to answer the research questions:

1. ICT's direct footprint and the role of sustainable design in reducing it.
2. The role of ICT in enabling an energy–efficient, low carbon economy.

4.2. ICT's Direct Footprint and the Role of Sustainable Design in Reducing it

The results are presented in relation to key environmental issues pertaining to intensive energy consumption and GHG emissions, and then to the role of sustainable design (de–carbonization strategy) to reduce the footprint of ICT sector. The ICT sector is unsustainable – design practices don't comply with environmental sustainability principles – as it has generated negative impacts on the environment. Considering the ICT's impacts on climate change, it is apparent that the ICT sector overlooks the externalities relating to direct and indirect effects of the total ICT product lifecycle as to energy consumption and GHG emissions. ICT have become a global environmental issue from manufacture, through use to disposal, especially when it comes to uncontrollable use of energy that increases GHG emissions. According to Forum for the Future (FF 2006), the effects of ICT on climate change are of three types: direct, indirect, and systemic. Direct effects arise from the design, production, distribution, maintenance and disposal of ICT products and services by the ICT sector, and that the ICT's impact on climate change is related to the GHG emissions that result from the energy used to produce materials, operate facilities, transport goods, provide services, etc. (MacLean and Arnaud 2008). Indirect effects arise from the use and application of ICT throughout the economy and society, and that the ICTs impact on climate change derives from the GHG emissions resulting from the energy required to power and cool data centers and network devices (Ibid). Systemic effects are created by the aggregated effects of large numbers or groups of people (individuals or organizations) using ICT over the medium to long term. They arise from changes in economic and social structures and behavior enabled by the availability, accessibility, application and use of ICT goods and services (Ibid).

4.2.1. ICT Product Lifecycle

4.2.1.1. Energy Use and GHG Emissions

4.2.1.1.1. Direct Effects

Analyst Gartner (2007) estimates that the manufacture, use and disposal of ICT products contribute around 2% of global GHG emissions. GHG emissions of ICT are comparable with those of the aviation industry, although the ICT sector is larger and aviation emissions have a greater effect on climate as they are released in the upper atmosphere (Griffiths 2008). The carbon generated from material extraction and manufacture is about one quarter of the overall ICT footprint, the rest coming from its use (GeSI 2008). The total footprint of the ICT sector – including (PCs) and peripherals, telecoms networks and devices and data centres – was 830 MtCO2e, about 2% of the estimated total emissions from human activity released in 2007 (Ibid). Currently it is estimated that consumer technology (including PCs, cell phones, printers, etc.) produce 40% of the ICT sector's GHG emissions (MacLean and Arnaud 2008). In 2002, the combined carbon footprint of PC and monitors was 200 MtCO2e and this is expected to triple by 2020 to 600 MtCO2e – a growth rate of 5% per annum (pa) (GeSI 2008).

Because of growth in demand for ICT products and services, mainly from emerging economies (i.e. China and India), and the rapid adoption in the developed world, the ICT industry's own carbon emissions are expected to increase, under BAU scenario, from 0.53 billion tonnes (Gt) carbon dioxide equivalent (CO2e) in 2002 to 1.43 GtCO2e in 2020, three times what it was in 2002 (Ibid). In developed countries, the total electricity demand consumed by ICT is between 5% and 10% which contributes with 1%–3% to worldwide CO2 emissions (WSIS 2003, 2005). One recent report estimates that direct effects of ICT provision account for 20% of ICT–generated GHG emissions (Griffiths 2008). The production of electronics (i.e. semiconductor) requires a high amount of energy and other natural resources (WSIS 2003, 2005). Studies show that the energy used to manufacture ICT equipment has also critical impacts on the environment (Madden and Weißbrod 2008). Computer components – screens, keyboards, circuit boards, batteries, and so on – are normally manufactured separately before being assembled, hence different locations and companies are involved in the process (Ibid). A study of the product group personal computers (PCs) in the EU Eco–label Scheme shows that production phase of a PC requires 27% of energy, releases 29% of GHG, and generates 22 % of waste compared to use and disposal phases (IPU/AC 1998). Another study shows that the production of one PC requires, among other resources, more than 5000 kWh energy, the emission of the production of one piece include 1850 kg carbon dioxide, 2 kg sulfur dioxide, and 1 kg nitrogen oxide (Grote and Rechnung 1996).

4.2.1.1.2. Indirect Effects

A recent report estimated that indirect effects might account for 80% of ICT–generated GHG emissions (Madden and Weißbrod 2008). Micro–level estimates can be helpful in visualizing the scope of the issue, i.e. a single Google search uses as much power as an energy–efficient 11–watt light bulb in 15 minutes to one hour (MacLean and Arnaud 2008). Speaking of micro level, the actual power consumed by each processor which varies with its computing power and memory is around 265 W and cooling overhead adds another 135 W (equivalent to 51 percent), for a total of 400 W of which 34 percent is power for cooling (Forge 2007). The microprocessor consumes a major part of the total power. Thus, the use phase of technologies remains the most significant of the whole lifecycle of ICT in terms of energy use and GHG emissions (Madden and Weißbrod 2008). A study carried out, using life cycle assessment (LCA) methodology, found that for a generic PC, the use phase of ICT has the largest environmental impacts as they are strongly related to fossil fuels (IPU/AC 1998). ICT–generated GHG emissions are likely to increase despite improvements in energy efficiency. As estimation, ICT will be responsible for 3% of global emissions by 2020 (Griffiths 2008). A study using the ecological footprint methodology shows that total footprint of the energy use for an analyzed PC turned out to be 1000 times larger than the footprint of resource consumption from the rest of the life cycle (Frey and Harrison 2000). Of the whole life cycle of ICT, the use phase is the most significant in terms of energy use and GHG emissions. Indeed, a study of the product group PCs in the EU Eco–label Scheme shows that the use of ICT requires 73% of energy and releases 68% of GHG of the whole life cycle (Ibid).

Also, energy consumption is likely to be increased by the development of faster communication lines as it is likely to contribute to the demand of faster computers (Kelly 1999). Communication lines and other power demanding equipment – servers, routers, filters, and storage devices are required when it comes to computer networks. A heavily debated study shows that in 1999 the Internet equipment consumed roughly 8% of the total electricity in the United States, with a prediction to grow to 50% within a decade (Mills and Huber 1999; Mills 2000). Regarding GHG emission, this study shows that in the USA it takes 1 kg of coal to produce enough energy to send 5 MB of data over Internet. However, the results were criticized by a number of peers suggesting a reduction of the estimate by at least 88% (Koomey et al. 1999; Koomey 2000). The correction was valid based on the fact that the initial power requirements of Internet hardware were overestimated by more than a factor 10 (Plepys 2002). Nevertheless, the corrected numbers didn't look optimistic given that the Internet traffic doubles every 6 months (Roberts and Crump 2001). Moreover, putting the ICT infrastructures (fiber optic) cable in place involves sizeable construction activities, and their environmental impacts may be substantial (Plepys 2002). The complex ICT infrastructure requires a reliable power supply, which forces dot–com companies to install huge systems of batteries, flywheels, magnetic superconductors, UPS, and back–up generators (Ibid).

4.2.1.2. Reducing the Footprint of ICT Products

The green solutions to design flaws of ICT products aim to mitigate the impacts on the environment. The ICT sector needs to tackle its footprint so to claim a leadership role in a low carbon economy. This can be achieved through de–carbonization strategy which entails the exploration of renewable energies and developing less carbon–hungry or low power ICT equipment. Sustainable product design is solar: use consumes only renewable energy that is cyclic (Datschefski 2001). Failure to address its own carbon footprint through sustainable design practice, the ICT sector can, due to its rapid growth, results in an increased overall energy demand and GHG emissions. Currently, one of the issues drawing the most interest environmentally is global warming. Some sustainability initiatives are in place to ensure that the ICT sector can address its own carbon footprint. Such efforts are focused on the reduction of energy consumption through design and production of low power consumption–type ICT products as well as improvement of ICT manufacturing process (Lee 2009). In line with that, WWF et al. (2008) point out that current attempts are largely focused on increasing the energy efficiency of ICT devices, components, and systems. Currently, a great deal of the research focuses on the impacts created by the ICT design processes (Madden and Weißbrod 2008). The Electronics Industry Code of Conduct (EICC) outlines standards to ensure manufacturing processes are environmentally responsible (Arbogast 2006). New technology trends in the ICT sector such as clouds and grids using Web based technologies (i.e. SOA) and virtualization, combined with zero–carbon data centres co–located with renewable energy sources, are enabling the possibility of the ICT sector adopting a zero–carbon strategy which is essential (MacLean and Arnaud 2008).

Sustainable design or design for the environment seeks to eliminate potential negative environmental impacts when a product is designed – before it is made. Sustainable design is becoming increasingly oriented towards service provision rather than ownership of physical products. This idea entails shifting the mode of consumption from product ownership to service provision. Sun Microsystems offers access to the dematerialized world of computing with its 'thin client' product range (Madden and Weißbrod 2008). The Strategic Health Authority for London replaced 400 of its 100–watt PCs with Sun Microsystems 'Sun Ray' ultra thin client, which only use 4 Watts each (Ibid). The positive ecological dimension rests on ICT's potential to deliver greener products and increase energy efficiency through dematerialization and ecological product life optimization (Reisch 2001). ICT plays a pivotal role in enabling the shift from physical products to services, i.e. the move to 'virtual goods' (Forge 2007). A similar dematerialization transition has already taken place in the telecommunication sector as most people do not own an answer phone and instead use a voicemail service offered by their network providers (Madden and Weißbrod 2008). Likewise, in the music industry the more adventurous labels and distribution channels now use no materials whatsoever, and instead replace a material product with a digitized/virtual alternative (Ibid). Cortese (1999) points to the notion of 'products of service': 'a key to resource efficiency is to understand products as a means to deliver a service to a customer. For example, people do not want energy; they want the service it provides such as heat or light'.

From a nanotechnology perspective, alternatives to silicon–based electronics are being explored, such as plastic electronics for flexible display screens (Dowling 2005). The focus is also on quantum dots, semiconductor nanoparticles that can be tuned to emit or absorb particular light colors for use in solar energy cells (Ibid). In the longer term, it is hoped that nanotechnologies will enable more efficient approaches to ICT manufacturing that will produce a host of multi–functional materials with reduced resource use (Ibid). However, it is important that claims of potential environmental benefits are assessed for the entire lifecycle of a material or product (Ibid).

4.2.2. Data Centers

4.2.2.1. Energy Use and GHG Emissions

Due to digital economic growth, data centers are expected to increase in order to respond to new business demands associated with the need for storage, computing, and other information technology services. If economic growth continues in line with demand, the world will be using 122 million servers in 2020, up from 18 million today (GeSI 2008). In 2002, the global data centre footprint, including equipment use and embodied carbon, was 76 $MtCO_2e$ and this is expected to increase more than triple by 2020 to 259 MtCO2e – making it the fastest growing contributor to the ICT sector's carbon footprint, at 7% pa (Ibid). At this point, volume servers will represent more than 50% of the data centre footprint (174 MtCO2e) and cooling systems alone will amount to 4% of the total ICT footprint (Ibid). Data centers are considered to be the hungriest energy users and the great generators of GHG emissions. This is a flaw owing to the design faults of ICT equipment with regard to energy usage. The energy consumption in data centers has become an issue because of high electricity costs and problems with power supply capacity (Griffiths 2008). A Swiss study shows that the connection power of data centers is between 20 and 40 MW (Aebischer and Huser 2000). In terms of national consumption, the UK had total electricity generating capacity of some 77.4 GW in 2005–06 (Forge 2007). The UK has around 1,500 data centers, the largest data centers may consume directly between 7 and 14 MW each, perhaps on average some 10 MW (Ibid). They account for about a quarter of ICT's emissions, and 2–3% of the UK's total electricity capacity (Griffiths 2008). According to UK Renewable Electricity Sources (UKRES), data centers consume around 5% of the country's maximum generation capacity, which is a figure comparable with the total generated by all forms of renewable energy in the UK, some 3.5 GW (Plepys 2002). Moreover, power consumption by servers doubled between 2000 and 2005 (McKenna 2008) and server farms concentrate the use of large amounts of energy (Madden and Weißbrod 2008). The charity Global Action Plan (GAP 2007) mentions that the growth in data storage overtook the growth in the airline industry, as in 2006 the number of plane passengers grew by only 3%, while 48% more data storage capacity was sold in the UK than in 2005. Since 1996 the number of servers in service globally has increased 400 %, from 6 million to 24 million (Forge 2007). Over the same period, average server power consumption has also increased 400 % from 100 to 400 watts (Ibid).

4.2.2.2. Server Idleness and Behavioural Barriers

The problem for most data centers is in having too many commodity servers idle that needlessly use electricity, generate heat, and drive up CO2 emissions – perhaps 6 to 10 times too many in comparison with their potential capacity (Forge 2007). Most of the energy going in to data centers is lost to inefficient servers, cooling systems, power supplies, and subsequently a small fraction converted to useful output (Griffiths 2008). Today, from 15 % to 35 % of the operating budget of data centers goes on cooling energy – power supplies (Forge 2007). Also, a great amount of the electricity used by ICT equipment is consumed when it is switched off or is not performing its main function (Madden and Weißbrod 2008). An important fraction of the electricity is consumed by ICT equipment when it is switched off or is not performing its main function (WSIS 2003, 2005). According to Plepys (2002), the energy consumption by ICT is likely to remain significant because this is linked to several behavioral factors, such as the power management functions of computers are underutilized (Kawamoto et al. 2001); growing access to broadband networks encourages heavy downloads, so users are likely to leave computers on during nights or weekends pursuing lower rates and larger network bandwidth; increased connectivity requires more and more computers to stay on–line operating 24 hours a day, etc. A survey conducted by the National Energy Foundation (NEF 2007) shows that 18% of office staff never switch off their PC at night and weekends, and a further 13% leave it on some nights each week. This behavior to energy use produces about 700,000 tons of CO2 emissions, equivalent to the annual emissions of a typical gas–fired power station (Ibid). At present, these standby losses are of the order of 50% of the electricity used by ICT (Madden and Weißbrod 2008; WSIS 2003, 2005). Standby losses may increase dramatically in the future due to the general trend of interconnecting different types of ICT equipment and services (WSIS 2003, 2005). ICT equipment used in a network can often not be fully disconnected and if no low–power mode is provided, (rather actually applied by the end–user), then full electric power is used no stop independently of the service needed (Ibid). Overall, the data center is a GHG generator due to the huge energy it devours, which contributes to global warming.

4.2.2.3. Reducing the Footprint of Data Centers

4.2.2.3.1. De–carbonization

Sustainable ICT design entails producing low energy consumption–type ICT products. Direct attention should be given to the ICT product design stage as to how to avoid environmental externalities (carbon emissions). This could be accomplished by promoting related demonstration projects that involve actors from the entire life–cycle chain in finding sustainable solutions for ICT design. However, sustainable product design is solar and efficient. Solar: manufacture and use consumes only renewable energy that is cyclic and safe, and efficient: most efficient use of energy required over life cycle (Datschefski 2001). It is quite conceivable that new interface, more energy efficient devices (such as the Apple iTouch or the RIM Blackberry) can be solar powered or use human body movement for their energy sources (MacLean and Arnaud 2008). Green design ensures that energy inputs and outputs are as inherently safe and benign as possible (Abraham and Nguyen 2003). Green ICT is about adding the green concept to ICT design and production basis by cutting energy consumption and thus reducing carbon emissions to alleviate global warming. This is to mitigate the impact of ICT on climate change, which could be achieved through espousing de–carbonization strategy. These criteria are to be considered in the design process of sustainable ICT products that require less energy or ideally use renewable energy.

It is forecast that ICT equipment and consumer electronics together will make up 45 % of all appliance–related electricity use in the UK home (Owen 2007). Widespread diffusion of ICT will increase substantially electricity demand so there are two strategies to consider: one is to limit this increase and cope with an unreliable power supply by designing efficient laptop technology, and two is to avoid up to 50% of this new demand by eliminating unnecessary standby losses in ICT equipment (WSIS 2003, 2005), especially in data centers. In addition, progress in micro– and nano–electronics is still governed by Moore's law (1965) who observed that the density of transistors in integrated circuits was doubling every 18 months. This phenomenon has continued to the present day meaning that the energy consumption per bit of information processed or transmitted has fallen by many orders of magnitude. However, quantum and optical computing could also have a substantial impact upon how ICT products can consume energy in efficient way. Indeed, there are emerging nanotechnology applications such as quantum and photonics–based systems, which promise considerable computing power for a fraction of today's power consumption in ICT products. Reding (2008) argues that the focus should not only be on reducing the energy intensity of ICT components, sub–systems and products but also to explore quantum and photonic–based technologies which could reduce energy consumption for lighting by 30 to 50% by 2015. Nevertheless, such technologies have not been factored into the carbon emission calculations because their impact within the timeframe is uncertain (GeSI 2008). There could also be breakthrough technologies that would transform how PCs use energy, for example, solid state hard drives which could reduce energy consumption by up to 50%, choleristic LCD screens that reduce monitor energy consumption by up to 80%, and direct methanol fuel cells that can deliver 20% savings for power supplies (Ibid). Moreover, for green grid data centre efficiency metrics, solutions are diverse but the data centre infrastructure efficiency (DCiE) and the power usage effectiveness (PUE) (is defined as the total power going into a data center divided by the power used by the ICT equipment) are considered two of the most effective solutions as metrics to quantify improvements in the data center. They can help operators improve efficiency and reduce costs (GeSI, 2008). The US Environmental Protection Agency (EPA) suggests that by 2011 PUE could be reduced to 1.2 by implementing state–of–the–art technologies (energy efficient) considering data centers have a PUE greater than 2, although values vary widely according to the configuration of the data center and requirements on its availability (Griffiths 2008).

4.2.2.3.2. Solving the Dilemma of Data Centers

Solutions to the problems of energy intensity in data centers range from hardware and software to data center design. That said it is possible to return, in the short term, to some of the basic principles in hardware design to produce energy savings in data center. Among these principles are: power to the server impacts on data center physical footprint; reducing the voltage; re–engineering (redesign) the CPU and software for lower energy usage; and powering the data center with renewable energy that does not emit GHG (see Appendix A for clarification). Further, Griffiths (2008) suggests three main areas where the energy efficiency of data centers can be improved: the facility itself; the ICT equipment housed there; and how that equipment is used (see Appendix B for detailed explanation). At operational level, Forge (2007) suggests a combination of hardware and software solutions to achieve a radical improvement in energy usage in data centers. This can occur through consolidation of servers to run fewer servers, using the concepts of virtual servers – virtualization – for each application environment; rationalizing the portfolio of applications down to the minimum necessary to run the business; and systems management for effective 100 % utilization of computing, storage and network resources. The steps in consolidation of servers and whole data centers for enhanced energy and emissions efficiency include: dynamic applications management across servers (resources can be dynamically provisioned depending on a variable workload); proactive systems management solutions; and storage systems software (see details in Appendix C). The steps are aimed at reducing their total number, and if planned with care, this move will avoid over–concentration of equipment.

In addition to the above, other technological improvements are feasible to cut energy consumption in data centers. Such improvement include: using more efficient components, such as multi–core processors that save energy; applying or automating power management; replacing desktops with laptop computers; using multi–functional devices like the printers that include scanning, copying and fax functions, which is more efficient than running several separate devices, etc. (Griffiths 2008) (see Appendix D). Moreover, other changes may relate to simple technological adjustments. For example, many ICT systems are prevented from entering their standby mode by local area network traffic, which means that many PCs and systems run at full power constantly (Madden and Weißbrod 2008). In 2004, the United Nations University in Tokyo suggested the redesign of network cards to allow PCs to go to sleep and power up again only in the event of any important network traffic (Ibid). They estimated that Australia alone could reduce emissions by three million tons of CO2 by using presence–detecting services that turn off devices that are not being used (Mallon et al. 2007). In an attempt to cut energy consumption, Data–hosting company Ultraspeed said it had reduced its energy use by 40% through the implementation of two big changes to equipment operation: firstly, the company switched from alternative current power to direct current power, which cut energy use by 30%, and the second change was the introduction of diskless servers – virtualization. (Madden and Weißbrod 2008). Distributing low voltage direct current into the data centre could eliminate uninterruptible power supply units and the need for mechanical back–up, (GeSI, 2008). The principle of virtualization is being widely used to reduce energy use in ICT equipment. A driver for this improvement is that heat inefficiency has become a big problem for process power (WWF et al. 2008). As a more effective solution in this regard, new business model solutions such as SOA and other web based technologies enable companies to access key business applications such as all kinds of databases or collaboration tools via a web browser, with no need to host their own data centre facilities. Such centralized and highly scalable services could lead to further capacity to consolidate resources with breakthrough gains in energy efficiency (GeSI 2008). In addition, in climates where the outside temperature allows, simply directing external air into the data centre can save energy cooling and reduce GHG emissions. 24% reduction in energy consumption from cooling is possible by allowing the temperature of the data centre to fluctuate along a broader operating temperature range (ibid). Additional emission reductions are possible through complete adoption of the cooling technologies available today as it would result in additional savings of 65 MtCO2e in 2020 (Ibid). Cooling and virtualization (servers) are two key elements in energy efficiency when it comes to data centers. Indeed, higher adoption rates of virtualisation architectures and low energy cooling technologies would help achieve step changes in efficiency (Ibid). It is likely to achieve 86% efficiency in one data centre by more efficient virtualisation architectures and changing the data centre location to reduce cooling needs (Ibid). Only about ½ of the energy used by data centres powers the servers; the rest is needed to cooling systems (45%) and run back–up, uninterruptible power supplies (5%), and, by 2020, it is predicted that these measures could achieve about 18% reduction (55 MtCO2e) in consumption (Ibid). Nevertheless, powering the data center with renewable energy remains the most effective means to eliminate GHG emissions. Some of the largest users of data centers (i.e. Google, Fujitsu) are turning to emissions–free power sources for data centers, for instance, Google has installed a 1.6 MW solar roof power supply on one data center building (Forge 2007).

4.2.3. Software Technology

4.2.3.1. Energy Use and GHG Emissions

While software technology is projected to play a pivotal role in decelerating climate change and reducing GHG emission, it seems that it produces less efficient software in terms of energy requirement as hardware speed and memory size increase. Larger software utilities (i.e. operating systems) mean more systems hardware is required to host it and more of it is wasted on software upgrade (Forge 2007) whose cycle is fueled by the phenomenon of planned obsolescence embedded in software design and engineering more generally. The software industry has ignored the externalities of its poor software engineering and the continuing descent in its performance achievements regarding the parameters that really matter (Ibid). The concept of planned obsolescence has been around for decades and was introduced by (Packard 1960). In ICT industry, planned obsolescence has potential benefits for ICT manufacturers because the products or applications fail and the consumers become under pressure to purchase again, and then, manufacturers by hiding the real cost per use from the consumer, they can charge a higher price than consumers would otherwise want to pay. Increasingly ICT are becoming like other consumer durables and selling more of software technology substantiates unsustainable design practices that induce consumers to update to the latest, greatest, and most powerful. Planned obsolescence generally concerns all ICT equipment, including laptops (3 years) or desktops (3–5 years) along evidently with their software applications. In 2007, the chairman of Microsoft when speaking of the Vista introduction stated: 'you've always got to obsolete your old products' (BBC2 2007).

Operating system upgrades are a planet killer that few seem to be aware of (Forge 2007). The upgrade of larger software utilities devours energy. Usually, upgrading to a new generation of an operating system drives up overall power demands because CPU and memory requirements may treble, taking applications with them. For instance, migrating from the operating system Windows 98 to Vista means that memory should go up 40 times and CPU power and speed (and related heat) 15 times (Ibid). This implies that hundreds of thousands of PCs and possibly attached hardware such as printers and scanners, networking and storage systems may all be junked to make room for the new path of the new operating system (Ibid), which is certainly unsustainable. The upgrade of operating system may also make the applications and utilities obsolete as incompatibility may prevail which is an issue that should be addressed by rethinking the mainstream software design approach.

4.2.3.1.1. Reducing the Footprint of Software Technology

To overcome the environmental adverse effects of software technology associated with energy consumption and GHG emissions, it is necessary to extend the upgrade and replacement cycle by averting or designing out the built–in obsolescence from software technology. Software design needs to consider environmental considerations by adopting sustainable design practices. Otherwise, policy measures may be effective to preclude producers from embedding obsolescence criterion in service design of software applications. Indeed, the growing use of free software is a trend that tries to combat this problem on the software side (WSIS 2003, 2005), in an attempt to discourage producers from releasing large software utilities as they deliberately tend, for profit purposes, to entice the acquisition of new devices and render obsolete previously serviceable devices. As to the software incompatibility issues, new directions in software technology are being called for in terms of ways to make applications constantly and consistently compatible with older versions (Forge 2007). But heightened awareness of energy consumption and climate change associated with software technology can play a key role in changing people behaviors and attitudes towards frantic consumerism. No doubt rising awareness and incentivizing efforts in this regard is the path towards overcoming the complexity of systemic factors in the current consumption culture.

4.2.4. Telecoms Devices and Infrastructure

4.2.4.1. Energy Use and GHG Emissions

As a part of ICT industry, telecom devices and infrastructure have also a visible footprint. The energy demands of running telecommunication networks are significant. They typically account for over 70–90% of a telecommunications company's total energy use, which is likely to increase in future years as take–up of broadband increases and mobile networks grow (GeSI 2008). In terms of total ICT footprint, although it continues to grow, the telecoms footprint will represent a smaller share of the total ICT carbon footprint in 2020 because efficiency measures will balance growth and data centres will rise to take a larger share of the total (Ibid). Further, the increased demand of telecom devices will obviously drive the increase of telecoms infrastructure in order for telecom providers to respond to the ever–growing demand in digital society more generally. The telecoms devices global footprint was 18 MtCO2e in 2002 and is expected to increase almost threefold to 51 MtCO2e by 2020 (Schaefer et al. 2003; Bertoldi 2007) driven mainly by rises in the use of broadband routers and IPTV boxes (system where a digital television service is delivered using internet protocol over a network infrastructure) (GeSI 2008). Similarly, the telecoms infrastructure footprint, including ongoing energy use and carbon embodied in the infrastructure, was 133 MtCO2e in 2002, and this is expected to more than double to 299 MtCO2e by 2020, a growth rate of 5% pa (Ibid). This is because of the escalating growth in mobile users. Indeed, there were 1.1 billion mobile accounts in 2002, and this is set to increase to 4.8 billion in 2020 and is the largest source of global telecom footprint emissions (Ibid). Fixed–line, narrowband and voice accounts are expected to remain fairly constant overall, but the number of broadband accounts – operated by both telecoms and cable operators (Cable accounts providing broadband but not cable TV) – will more than double 2007–2020 and mobile accounts (including a range of technologies, GSM, WCDMA, 3G, etc) will almost double during the same period (Ibid). This will, as a result, further increase the footprint of ICT sector. Increased access to broadband will also have an impact – the number of routers will grow from 67 million in 2002 to 898 million in 2020; from 2002, the growth in telecoms emissions has grown from 150 MtCO2e in 2002 to 300 MtCO2e in 2007 and is expected to reach 350 MtCO2e in 2020 (Ibid). Figure 4.1 shows the global telecoms footprint (devices and infrastructure) where the mobile network will come to dominate the overall telecoms footprint.

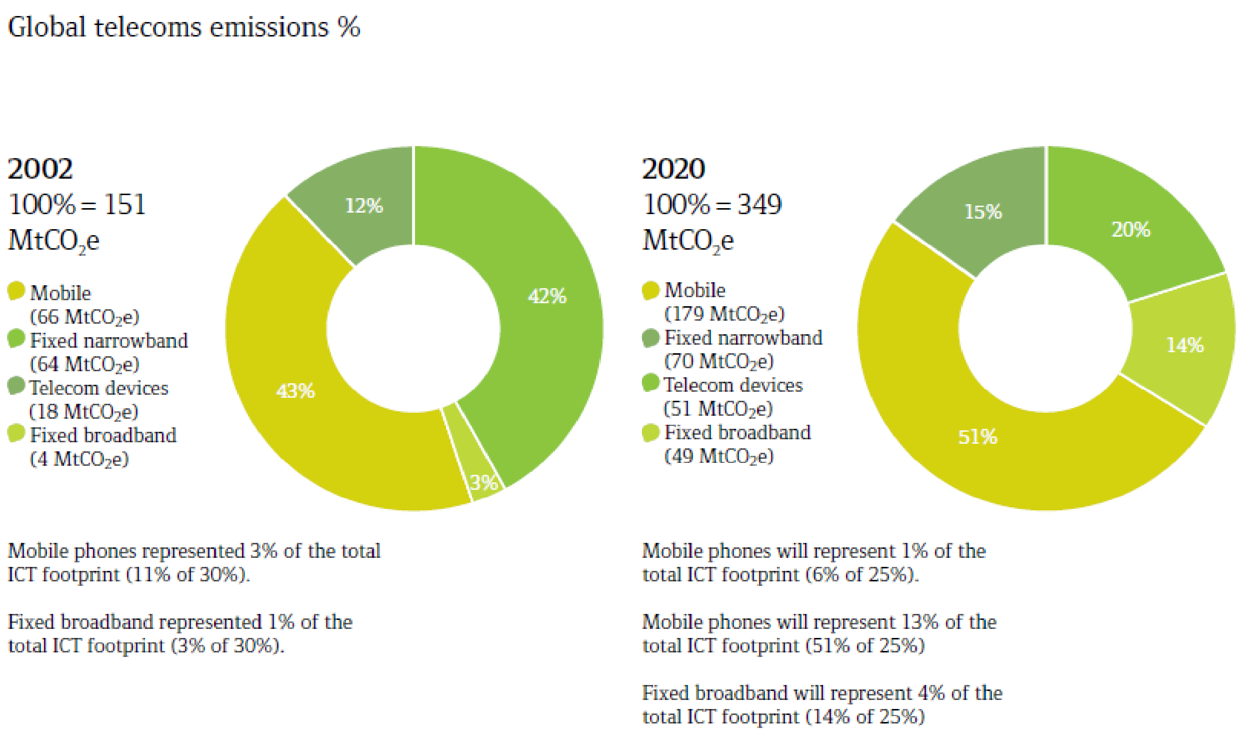

Figure 4.1 Global telecoms footprint (devices and infrastructure) Source: GeSI 2008

At present, the majority of emissions from mobile devices come from standby mode, the power (known as phantom power) used by chargers that are plugged in but not in use (Ibid).

4.2.4.2. Reducing the Footprint of Telecom Devices and Infrastructure

4.2.4.2.1. Telecom Devices

Sustainable design (or eco–design) seeks to mitigate ICT's environmental impacts and manufacturing facilities. Sustainable ICT design involves producing low energy consumption–type telecom devices and improving telecom manufacturing infrastructure. In their most far–reaching designs, especially Japan – the Sharp LCD factory Kameyama, with its own 5 MW photovoltaic system to reduce energy demands and the Fujitsu ITC production facilities built in 2004 in Japan (Plepys 2002). Green ICT design is intended to substantially cut energy consumption and thus reduce emissions to alleviate global warming. Abraham and Nguyen (2003) point out that green design ensures that energy inputs and outputs are as inherently safe and benign as possible. This can be achieved through espousing de–carbonization–based design strategy. New criteria are to be embedded in the design process of telecom devices that require less energy or ideally use renewable energy. Technological innovations in power consumption reductions from smart chargers and standby modes will certainly contribute to reduction of mobile phones' footprint as 'the majority of carbon emissions from mobile devices come from standby mode' (GeSI 2008). Besides, as telecom devices are dominated by electricity consumption, the best way forward is to use and deploy renewable energy to generate electricity and, therefore, do away with emissions. The footprint of telecoms devices can be reduced further if devices produce fewer emissions in manufacturing, or if greener electricity is used by the device during its lifetime (Ibid).

4.2.4.2.2. Telecom Infrastructure

There are current attempts by telecom companies to improve energy efficiency of telecom networks. Significant improvements are expected in the energy efficiency of base stations, routers, switches and other network equipment are unlikely to compensate for the increase in overall demand (GeSI

2008). Figures from one European telecoms company show that electricity use per information unit decreased between 2003 and 2005 by 39% pa but this has been more than negated by an increase in bandwidth requirements of 50% annually (Ibid). This is due to the increased demand for telecom services (growth in users) which inevitably would lead to more energy use and thus concomitant GHG emissions. Additional emissions reductions could be achieved by changing the network design (customer and network) to optimize overall network usage by rolling out current accessible innovations in energy and carbon–efficient network architecture. Effective long–term strategies are needed to achieve energy efficient integrated networks in terms of equipment; planning and management in access; energy consumption measurements; and technologies enabling power saving. It is projected that next generation networks (NGN) if rolled out before 2020 could bring about major shifts in terms of energy reductions, which essentially means providing faster fixed–line access over fibre optics, rather than copper, all the way to customer premises (Ibid).

Mobile infrastructure technologies currently available include network optimisation packages which can reduce energy consumption by 44% and solar–powered base stations, which could reduce carbon emissions by 80%, advanced standby power management which can reduce energy consumption by 15% reduction in energy consumption possible, night battery operation which can reduce energy consumption by 50% reduction in energy consumption possible, and more efficient base station amplifiers which could reduce carbon emissions by 9% (Ibid). Adoption of such measures will enable telecom companies to plan for significant energy efficiency improvement. The expected adoption of these measures by 2020 could lead to the avoidance of almost 60 MtCO2e in 2020 (Ibid). Intelligent network equipment relating to energy use can deliver desired outcomes regarding capabilities of data collect, monitoring, and control. Indeed, telecom operators have begun to use new network management solutions to better understand the distribution of energy consumption within the telecoms network with regard to the impact of the adoption of interconnected devices and the network services they deliver (Ibid). In addition, telecom service providers are best placed to collaborate and partner with energy suppliers and network equipment manufacturers to launch joint projects supporting energy efficiency. Also, they can share network for optimum use and tracking the energy consumption reduction benefits, thereby avoiding the construction of new networks.

It is apparent that telecom infrastructure is dominated by electricity consumption and carbon footprint; the obvious way forward is to develop and deploy renewable energy solutions to generate electricity since green initiatives are the safest alternative to save energy and mitigate emissions. Telecom companies can reduce their climate change impacts through purchasing green energy from the grid and installing renewable generation on sites and by making renewable electricity integral to telecom devices and networks as well as infrastructure because ICT companies happen to own a great part of real estate such as offices and retail outlets. The ICT sector is uniquely placed to partner with power companies to optimise the existing electricity grid to allow more efficient power distribution and the use of more renewable or green power (GeSI 2008).

4.3. The Role of ICT in Enabling an Energy–Efficient, Low Carbon Economy

In order to approach the second research question, it is important to know which sectors are responsible for intensive energy consumption and high GHG levels production. It is also crucial to associate this argument with where of these economic sectors ICT are likely to enable substantial reductions as integrating technology. Bearing that in mind, based on the literature review and drawing on very recent sources of empirical and analytical material, it is conspicuous that the ICT sector's greatest potential to enable energy efficiency and mitigate emissions is in transport and logistics, buildings, industry, and power supply economic sectors as well as dematerialization.

Most extensive studies (IPCC 2007; Stern 2006; McKinsey 2007) show that significant potential exists for carbon emissions with energy efficiency measures. A number of studies (Erdmann et al. 2006; Mallon et al. 2007; Pamlin and Szomolányi 2007; Global Action Plan 2007; Neves 2008) on the overall relationship between ICT and climate change generally show that most positive effects of ICT in reducing GHG emissions are likely to result from increasing the efficiency of industrial processes and facilities management; the efficiency and flexibility of energy production, distribution and consumption; and dematerialization. Further, far from exhaustive, a number of recent studies (Laitner 2008; ITU 2008; Fuhr and Pociask 2007; Pamlin and Szomolanyi 2006), have looked at the potential of ICT, particularly broadband, IT services and mobile communications to improve energy efficiency and deliver climate change solutions. This covered among other things the ability of ICT to replace high carbon products and activities with virtual alternatives and their role in environmental sustainability. As for ICT sector's impact on the global footprint and its enabling effect, a study has identified global emissions reduction by 7.8 $GtCO_2e$ by 2020, an amount five times larger than ICT sector's own carbon footprint (GeSI 2008; Enkvist et al. 2007). This represents 15% of emissions in 2020 based on BAU estimation and also a significant proportion of the reductions below 1990 levels that scientists and economists recommend by 2020 to avoid dangerous climate change (Stern 2008). In line with that, the ICT–enabled solutions would make possible savings of 1 ton per capita in 2020, a significant step in the right direction (Howard 2009). ICT provide the solutions that enable us to see our energy and emissions in real time (Ibid). Overall, the breadth of ICT–based solutions span over dematerialization, transport and logistics, buildings, industry, and power supply across all key economies in the world. A consensus crystallized on the focus on the most accessible opportunities for ICT to achieve energy efficiency improvements and alleviate global warming. These opportunities are covered in more detail below.

4.3.1. Dematerialization

4.3.1.1. Energy and Material Savings

Dematerialization could play a significant role in cutting energy consumption and thus mitigating carbon emissions at many levels. A study conducted by GeSI (2008) indicates that using technology to dematerialize the way we work and operate across all sectors could deliver a reduction of 500 $MtCO_2e$ in 2020, which is the equivalent of the total ICT footprint in 2002. The potential of dematerialization to reduce carbon footprint is substantial because of the spectrum of the associated technologies that include as diverse areas as economic, social, public, and private. This entails both energy and material savings through e–billing, online media, paperless office, etc. alternatives. Certain products and services (such as bills, music, books, documents, and newspapers) can be entirely digitized and transported over the Internet that hence material and energy savings can be made in production, use and distribution. Also, new flexible production technologies that are based on 'just in time' production allow resource savings (Fuchs 2009). Dematerialization could have a larger than predicted impact from other future technological breakthroughs, not yet identified, that substantially change the way people live, work, and learn (GeSI 2008). New ICT applications in e–commerce, e–government, e–health, and other social e–communities have been proven to significantly impact on reducing GHG emissions.

4.3.1.2. Tele–working and Videoconferencing

Based on most studies done on dematerialization, tele–working has been ranked as the largest identified opportunity where ICT has the potential to reduce GHG emissions. A recent report analysis done by GeSI (2008) found that although other dematerialization opportunities may come to prominence in the future, based on historic trends, tele–working would have the largest impact, up to 260 $MtCO_2e$ savings each year. Other technologies also have an enabling contribution but less than that of telecommuting. Figure 4.2 shows the impacts of different dematerialization technologies (including e–media, e–commerce, e–paper, videoconferencing, and telecommuting) on global emissions in 2020. The reason why tele–working technology is of import is because it is related to transportation – one of the economic sectors that contribute significantly to global warming. According to IEA (2004), transportation is a large and growing emitter of GHG, responsible for 14% of global emissions. Flexi–working and teleconferencing – where people work and conduct meetings from home using broadband access and wireless communications instead of commuting into an office – are positively impacting the environment. Some scientists argue that due to the fact that tele–working allows knowledge workers to overcome spatio–temporal distances the need for transport and hence environmental pollution would be reduced (Fuchs 2009). According to GeSI (2008), if 10% of the EU workforce were to become flexi–workers, this could save 22.17 million tons of CO_2 a year. Likewise, if up to 30 million people in the US could work from home, carbon emissions could be reduced by 75–100 $MtCO_2e$ in 2030 (Enkvist et al. 2007). The same argument goes for teleconferencing saying that by substituting personal meetings by teleconferences travelling can be reduced. If 20% of business travel in the EU was replaced by video conferencing, this would save 22.3 million tons of CO2 (GeSI 2008). The key way that ICT can contribute to sustainable development is that working 'down the wire', holds out the prospect of people moving less (Madden and Weißbrod 2008). As digital communications improve, people will increasingly be able to experience 'being there' without having to move (Ibid). Through using voice over IP (VoIP), videoconferencing capabilities can help to reduce the GHG emissions by replacing business travel and daily commutes with services. Commuting accounts for around 1/5 of all miles travelled (Ibid). A UK Department of Transport study found that tele–working reduces the commuting car mileage travelled by teleworkers by 48–77% which represents an 11–19%50 reduction in both mileage and trips (GeSI 2008). In relation to energy, a study funded by the Department of Employment in Sheffield found that home–based teleworkers consumed on average half the amount of energy as their office–based counterparts, owing to large part to eliminating car journeys to and from work (Economist Intelligence Unit 2008).

However, while tele–working is one of the more established ways of reducing organizations' carbon footprint, it is still not as widely adopted as one might expect due to some hurdles (including technological, organizational, financial, and informational) which depend on the economy where this technology is introduced. Speaking of economies, the number of teleworkers is relatively low (in Europe the share of teleworkers in the total labor force ranges from less than 2 % to more than 10 % (Schallaböck et al. 2003). The UK lags behind its European competitors in allowing tele–working and benefiting from the energy savings that they can create while in Germany, Sweden and Denmark, 40 % of employers have staff involved in tele–working, compared with 20 per cent in the UK (Madden and Weißbrod 2008). At present Denmark and Ireland are the only countries in Europe with codes of practice for home working that would help business and individuals to maximize the benefits of tele–work (Ibid). From a behavioural viewpoint, in 2007, Wainhouse's survey of European business users found that more than half (56%) of respondents said their use of collaboration and conferencing technology was influenced by concerns over climate change (Economist Intelligent Unit 2008). This type of awareness is widely well needed when it comes to the adoption of all energy efficiency technologies by different consumers, individuals and companies. The attraction of videoconferencing as a carbon reduction means is increased as it is easily measurable in terms of the resulting reduction in air or car miles following its adoption (Ibid).

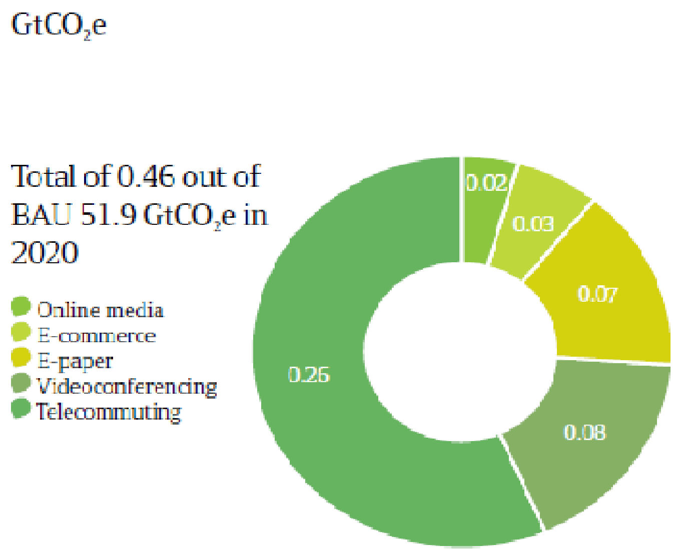

Figure 4.2 The impact of dematerialization

Source: Expert interviews, Jan – March 2008 by GeSI 2008

Examples of tele–working practices are numerous but the more quantifiable are in business sphere. Sun Microsystems has audited its 'openwork program' this year; on average each employee benefits from a 2–hour reduction in commute per week, which, over one year, results in 2 tons of carbon savings (including rebound effects). (Madden and Weißbrod 2008). Swedish company Telia has reduced its carbon emissions by 50% in three years by reducing office space, working more flexibly and eliminating all but essential business travel (Financial Times 2007). British Telecom's flexi–working program 'Options 2000' found tele–working could save 682,000 kilometers a week of car travel and 306,000 kilometers a week of rail travel (Yi and Thomas 2007). At the very least, dematerialization provides digitized alternatives, allowing individuals to control their carbon footprint in a very direct way, and that first adopters could enable the cultural shifts necessary for ICT–enabled energy efficiency to take hold in the broader economy (GeSI 2008). Overall, the way ICT can help in the short–term encompasses dematerialization where services and products can be tuned into digitized alternatives and optimization through making systems more efficient in economic sectors. The next section addresses the enabling contribution of ICT in transport and logistics, industry, power supply, and building economic sectors.

4.3.2. Transport and Logistics

4.3.2.1. Efficiency and Emission Reduction

ICT is projected to have a substantial role in reducing energy and carbon emissions in transport and logistics economic sector. The global emissions savings from smart logistics in 2020 would reach 1.52 $GtCO_2e$, with energy savings worth € 280 billion (GeSI 2008). As the majority of logistics emissions come from transport and storage, optimizing logistics using ICT could result in a 16% reduction in transport emissions and a 27% reduction in storage emissions globally (Ibid). Through a host of efficiencies in transportation and storage, smart logistics in Europe could deliver fuel, electricity and heating savings of 225 $MtCO_2e$ (Ibid). Further, ICT solutions can be used to improve logistics, where it can be used to both increase filling rates and ensure optimum travel routes (WWF et al. 2008). However, ICT might lead to more delivery movements, longer haulage distances, and more extended supply chains (GeSI 2008). This is due most likely to rebound effects but this is proportional to fuel prices rising as well as to other ICT transformational effects. Nevertheless, given the uncertainty associated with fuel pricing, logistics companies will accelerate their adoption of ICT–based energy efficiency solutions. As a result, this will have a huge impact on reducing their emissions – up to 225 $MtCO_2e$ by 2020, 27% less than BAU (Ibid). Still, to support the improvement of current transport systems, it is strategically important to ensure that future companies will build their business models around a sustainable approach to transport. Whether for environmental positioning or economic gains, efficient logistics are increasingly needed by businesses where transportation is the backbone for their reason to operate, i.e. shipping companies.

Smart logistics (ICT–based solutions) comprise a range of software and hardware tools that monitor, optimize and manage operations, which helps reduce the storage needed for inventory, fuel consumption, kilometers driven and frequency of vehicles travelling empty or partially loaded (GeSI 2008). Based on an analysis performed by GeSI (2008) which included data from expert interviews, there are a number of ways along with their specific technologies and services that could enable more efficient logistics as set out in figure 4.3 (see Appendix E). Intelligent logistics can significantly contribute to streamlining supply chains by introducing greater efficiency into a company's supply chain, which has a positive impact on the environmental. The Economist Intelligence Unit (2007) surveyed 345 executives from around the world and survey respondents selected improved efficiency of supply chains and logistics as making the biggest contribution to reducing their carbon footprint (29%), behind reducing paper use (33%) and increasing the use of virtual meetings (43%).

The transport system can become an efficient communication system where seamless solutions enable virtual or physical transportation depending on need (WWF et al. 2008). It is a set of combined complex market and technological variables that will drive transport intelligence where only unpredictable scenarios will reign. Current specific levers include intermodal shift, or moving to the most efficient type of transport, eco–driving, route optimization and inventory reduction (Ibid). More research should be encouraged to investigate other environmental and economic benefits of using intelligent systems in public and private transport. Apart from directing the research focus and allocating resources to multi–modal, seamless travel in public transport, there is also a need to widen access to ICT–supported working during train, bus, boat and plane travel and to make public transport more attractive through the use of ICT applications (such as displays at bus stops that communicate projected arrival times) (Madden and Weißbrod 2008), and developing and implementing systems for tailor–made information, such as adaptive time–tables, route–planning, and so on (WWF et al. 2008).

4.3.2.2. Telematics

Telematics have a key role in reducing energy and emissions in transport. Automotive telematics are designed to enhance the functionality of motor vehicles, for example, wireless data applications in cars, trucks, and buses. Telematics market is growing across the world. In the US, this market is expected to expand from 2.5 million units in 2007 to 5.8 million units by 2009 (Madden and Weißbrod 2008). Fleet benefits from telematics include increased productivity, dispatching efficiency, improved vehicle, driver, and cargo safety (Ibid). Telematics technologies and services are as diverse as their applications. For example, telematics can link global positioning satellites (GPS) to traffic–flow systems so to network transport means in order to reduce congestion, which can have a significant impact on carbon emissions. Wal–Mart currently uses radio frequency identification devices (RFID) to track trucks, forklifts and other mobile devices in the USA, and United Parcel Service is testing a mix of active and passive RFID to monitor vehicle movement and location (Madden and Weißbrod 2008). RFID has a wide applicability spectrum, including supply–chain, inventory tracking efficiency and management, and even people positioning. in line with that, there are some innovations emerging on a fleet management system that will use satellite navigation to plan more the optimum route routes for delivery vans (Economic Intelligent Unit 2008). In urban areas, this system minimizes the van's left–hand turns across traffic since waiting to turn involves inefficient fuel consumption. This contributes to carbon emissions and more energy consumptions that can be otherwise avoided with the use of automotive telematics technology. This new fleet management system will allow each van to be programmed at the start of a working day, and will then be fed new data on traffic conditions continually during the day so the drivers can adjust their plans accordingly (as nodes in a wireless network) as well as being the recipients of data (Ibid).

4.3.3. Buildings

4.3.3.1. Design, Construction and Operation Efficiency

Buildings sector is deemed to be one of the largest opportunities where ICT can play a pivotal enabling role in energy efficiency and emissions reductions. Globally, smart buildings technology could potentially reduce emissions by 1.68 $GtCO_2e$ and be worth €187 billion of energy savings (GeSI 2008). About 30% of projected GHG emissions by 2030 can be avoided with net economic benefit (IPCC et al. 2007). Although smart buildings include industrial, public, commercial and residential, general estimates predict that the largest cost–effective energy savings potential lies in the commercial and residential buildings. It is crucial to mainstream the adoption of smart building with regard to design, construction, and operation, so to gain substantial environmental and economic benefits. Current trends in this area provide a set of technologies to make the design, construction and operation of buildings more efficient; they are applicable to both existing and new build properties. Usually, energy consumption in buildings is driven by two factors – energy intensity and surface area – and ICT–based monitoring, feedback and optimization tools can be used to reduce both at every stage of a building's life cycle, from design and construction to use and demolition (GeSI 2008). There exist today various smart buildings technologies that can help reduce emissions at each stage of a building's lifecycle. ICT can ensure an integrated design of buildings. Intelligent meters provide feedback and control and integrated photovoltaics in buildings (WWF et al. 2008), as well as passive and active solar design for heating and cooling. Special software can be used by builders to compare energy models with actual construction in order to monitor energy efficiency and by architects to determine how design influences energy use (GeSI 2008). In line with that, architects have shown that buildings can even become net producers of electricity at little or no additional cost (WWF et al. 2008). This can be accomplished through incorporating natural heating, cooling and ventilation and daylighting strategies and by proper sitting, building form, glass properties and location and material selection (Ibid). Moreover, new ICT systems can ensure better use of existing building stock by ensuring that empty buildings are used before new ones are built and thereby reduce the need for new constructions (WWF et al. 2008). Commonly, current smart buildings focus on multiple subsystems – environment control, telecommunications, power and materials – that all converge to attain the common goal of maintaining maximum efficiency for the building. While significant energy efficiency is possible and smart planning can result in more efficient use of buildings, the big change will come when buildings become part of the solution and not users of energy as today (Ibid).

At operational level, ICT has a high potential impact on the rational use of heating energy as some 'soft measures' using ICT have the advantage of being applicable in all buildings, and could therefore have a significant effect (Madden and Weißbrod 2008). However, it is highly uncertain under what conditions soft measures (enabled by ICT) would operate effectively due to possible rebound effects associated with behavioral choices of consumers as to energy consumption level. To tackle this issue, ICT could serve as a means to raise awareness and influence the demand side by encouraging sustainable patterns of energy consumption. This is an attempt to avoid the rebound effect that outweighs efficiency gains from building operation. Heightened energy awareness is expected to positively stimulate behavioral changes both at household and organizational level.

4.3.3.2. Building Automation System

ICT applications related to smart building can provide multifunctional role in energy efficiency and emissions reductions, including highly advanced automatic systems for lighting, temperature control, security, window and door operations, efficient and natural lighting, efficient electrical appliances, and many other functions. For example, building automation system (BAS) that is a computerized intelligent distributed network of electronic devices designed to monitor and control the building system using fuzzy logic and environmental context awareness techniques keeps the building climate within a specified range, monitors system performance, reduces building energy consumption, and provides lighting based on the external environment (i.e. occupancy schedule). Speaking of lighting, apart from the adoption of high efficiency light–emitting diode (LED) technology that could substantially increase energy efficiency in lighting, embedding ICT systems through adding sensing capabilities (intelligence) to energy–efficient bulbs can enable them to automatically adjust to people's presence and the environment (natural light). In terms of emissions reductions, the broad adoption of new lighting technologies (LED and OLED) could save 30% of today's consumption by 2015 and up to 50% by 2025 leading to the corresponding reduction in CO2 emissions (Reding 2008). In addition, building management systems (BMS) run heating and cooling systems or software that monitors and switches off all PCs and servers during idleness time (when needlessly use electricity, generate heat, and drive up CO2 emissions) after users have gone home during nights or weekends. BMS provides real time monitoring and reacts to external stimuli such as the weather and related data can be used to identify additional opportunities for efficiency improvements. Generally, BMS uses smart metering and advanced visualization to continuously gather data on what is taking place in a building and how its equipment is operating, feeding it into a control system to optimize energy performance. Figures 4.4 (see Appendix F) shows how ICT can identify energy consumption and optimize for reduction in energy and emissions as well as transform current ways of designing and using the built environment. More of research and technological development endeavors should be encouraged involving researchers from ICT, energy and construction domains to support actions cutting across several disciplines, such as energy visualization and energy building management systems as well as support awareness raising and foster exchanges of information and best practices in new ICT–based relevant systems.

4.3.4. Power Supply

4.3.4.1. T&D Efficiency and Emission Reduction

Managing the production, supply and distribution of energy can bring enormous benefits to the economy and the environment. This can be accomplished by monitoring and managing power grids with smart meters and by integrating more advanced ICT applications. A study conducted by GeSI (2008) found that smart grid technologies were the largest opportunity for emissions reductions as they could globally reduce 2.03 $GtCO_2e$ by 2020; recent developments across the globe are working to turn that projection into reality. Figure 4.5 below outlines the emissions reductions opportunities for the power supply sector. This is the largest contribution to man–made GHG emissions and thus not surprising that the biggest role ICT could play is in improving energy efficiency in power T&D (Ibid). Of the total emissions from human activity in 2002, 24% was from the power sector (IEA 2008). This implies that the energy supply sector accounts for a large share of carbon emissions due to the inherent inefficiencies in generating power from raw materials and losses in distribution. It is required to deploy advanced ICT solutions for management, monitoring and control in order to mainstream or spread micro–generation (i.e. virtual power plants), and optimize user demand. Virtual power plant enabled by ICT will in the future optimize demand and production by smoothing peaks and facilitating trade between grid operators (Reding 2008). Also, demand side management (DSM) remains a critical element in the energy efficiency equation as it entails all actions that influence the patterns of use of energy consumed by end users.

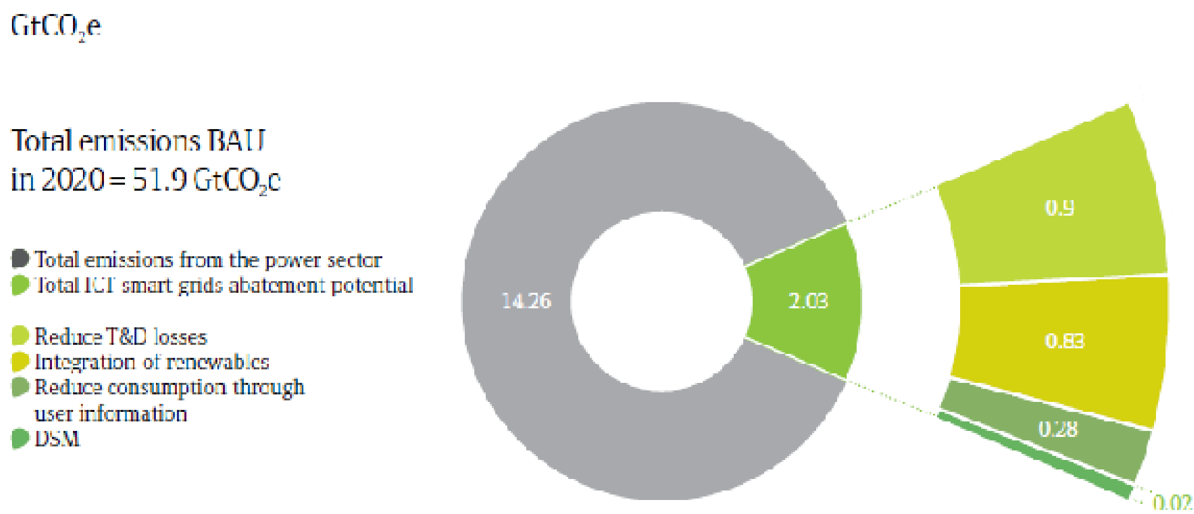

Figure 4.5 SMART grids: The global impact in 2020

Generally, smart grid aims at improving and monitoring energy efficiency and data capture across the power generation, transmission and distribution network. ICT applications could make a major contribution in energy sector through reducing losses, increasing efficiency, and managing and controlling power grid distribution network to ensure stability and reinforce security. In energy generation for example, overall potential savings of up to 40% are considered possible in the energy distribution and storage industry (Ibid). Given the potential for improvement in electricity generation (30–40%) and the considerable losses in transport (2%) and distribution (8%), it is critical to improve transformation efficiency, address losses and identify any potential problems before they compromise supply (ENF 2008). That said ICT provide a number of ways along with various technologies and services that can standardize, monitor, rethink and transform energy efficiency. Figure 4.6 (see Appendix G) illustrates the potential for ICT to reduce carbon emissions through smart grid technology. Examples include smart meters, which provide information about how much energy is used as well as automated reading of energy consumption data, helping the utility to better understand where energy is being used and more advanced grid management systems (GeSI 2008). New technological innovations are needed to address the environmental impacts associated with the energy generation, transmission, and distribution. This can, in general terms, be accomplished by fostering the exchange of best practices in new ICT–based business models for distributed generation; reinforcing technological research and development for power grid networks; supporting and deploying integrating ICT solutions for monitoring and control; and intelligent metering management of complex power systems.

4.3.4.2. Renewable Energy Integration in Grid Distribution Network

ICT can also offer renewable energy–based opportunities in smart grids for further emissions reductions. Decentralized energy production could allow renewable energy sources to be integrated into the grid, reducing coal–based generation and therefore emissions (GeSI 2008). The cost–effectiveness remains the main challenge regarding the creation of a new management system which integrated the renewable sources in the distribution grids networks (ENF 2008). However, it is critical to foster the deployment of intelligent systems that integrate power generation from renewable and consumption using the most up–to–date ICT solutions. In line with that, a very good prediction of the wind has to be feed into the system to manage the energy supply (ENF 2008). In addition, in the context of technological development, the way forward is to involve researchers from different domains (ICT, energy, renewable energy, sustainability) given that such research endeavor cut across several fields. Also, it is of import to bring together and create communication channels between producers (solar and fuel cells, wind mills, biomass, etc.), consumers, energy service providers, and network operators. Implementing ICT infrastructure for communication with producers and consumers allows for the automated control of producers and consumers (ENF 2008). It is also beneficial to incentivize efforts associated with joint projects supporting the integration of power generation and distribution grids with renewable energy sources.

4.3.5. Industry

4.3.5.1. Material Control and Reduction

The opportunities for industry in adopting ICT–driven improvements of energy efficiency and carbon footprint mitigations are clear and there. Industry might be the economic sector where the most dramatic ICT–enabled changes will materialize. ICT can be used in all industry sectors to contribute to increased efficiency though everything from material control to the design and control of engines (particularly energy–hungry industrial processes) and optimization of supply chain. For material control, the sectors with the greatest potential for efficiency solutions through ICT measures are, according to WWF et al. (2008), the iron and steel, cement, and pulp and paper industries, where small improvements can result in large gains due to the large amounts of emissions. There is considerable potential to save materials through intelligent control processes (Madden and Weißbrod 2008) using a set of available technologies designed to assess materials according to sustainable norms. Examples of absolute reduction of material (dematerialization) are the digitized low carbon alternatives. ICT' impacts have been profound in media, music and paper that are being turned from physical into digitized products and services. There is an enormous shift taking place in the economy, from industrial production to service–based intensive industries (Ibid). The portion of the economy dedicated to dematerialization is expected to grow significantly over the coming years (MacLean and Arnaud 2008). ICT can also spawn new business models in heavy industry migrating to service companies, focusing on what people want, rather than product ownership that create an ever–increasing demand for finite resources (material and energy). Such an approach promotes minimal resource use per unit of consumption (Ryan 2006). With more sophisticated ICT applications, it will also be possible in the design phase to try the global sustainability impact, not only the direct effects from the product, but also the indirect and direct effects from the services provided (WWF et al. 2008). Promoting new ICT intensive industry may well be the most environmentally sustainable route. Also, reducing the ICT industry's direct footprint through new network and distributed computing architectures is most likely the 'low hanging fruit' of an ICT strategy aimed at mitigating climate change (MacLean and Arnaud, 2008).

4.3.5.2. Efficient Industrial Processes and Motor Systems

Industrial processes and motor systems are key factors when it comes to energy consumption and carbon emissions in manufacturing sector. ICT–based intelligent devices can control and monitor energy usage in production processes and systems. Optimized motors and industrial automation would, if applied globally, reduce 0.97 $GtCO_2e$ in 2020 (GeSI 2008). Given that much of the growth in industrial energy demand has been in emerging economies like China with 80% of the growth in the last 25 years (IEA 2007), the potential for large–scale utilization of smart motor systems will be greatest there (GeSI 2008). Motor systems are instrumental in all industrial sectors. Industrial activity uses nearly half of all global electrical power generated, industrial motor systems using the majority (65%) and by 2020; motor systems will be accountable for 7% of global carbon emissions (Ibid). With motor systems and efficient industrial processes, ICT can mitigate up to 970 $MtCO_2e$ of global carbon emissions in 2020 (Ibid). Many industries have begun to respond to environmental challenges through identifying new technological opportunities for intelligent use of motor systems and optimal production processes, realizing the substantial economic savings and carbon emissions reductions. Properly sized, energy efficient motors with electronic variable speed drives (VSD) and improved gears, belts, bearings and lubricants use only 40% as much energy as standard systems (Ibid). VSD installations for the control of conveyor belts and elevators and combustion and ventilation fans used in industrial systems are the most effective means of saving energy; they can deliver energy savings upwards of up to 25–30% (Ibid). Optimization and intelligent systems are vital to the manufacturing sector for this sector demands intensive industrial energy to operate.

ICT applications in motor systems can capture and provide the data of energy usage and feed it into embedded devices whose functionality is to control the power usage depending on need. This is to make motor systems more efficient and not operate at full capacity to avoid energy loss. However, there is a lack of information about energy consumption in motor systems and where savings can be made within a factory; hence ICT's main role will be to monitor energy use and provide data to businesses so they can make energy savings by changing manufacturing systems (Ibid). ICT can bring numerous economic and environmental benefits. Further, the ICT sector has additional roles to play, for example, simulation software should be used to help improve plant and manufacturing process design and wireless networks that allow inter–machine and system communication, can improve efficiency across an entire factory (Ibid). There are a number of ways along with specific technologies and services that could enable efficiency in motor and industry system. Figure 4.7 (see Appendix H) summarizes the role of ICT in improving motor and industrial system efficiency.

C H A P T E R   F I V E

D I S C U S S I O N

5. Discussion

5.1. Overview

This section evaluates the results and discusses the key findings in relation to the research questions. First attention is given to the direct footprint of ICT sector and how it can be tackled through alternative sustainable design–based solutions. Then the discussion carries on about the role of ICT in enabling an energy–efficient, low carbon economy. In addition, the author discusses some weaknesses and strengths of this study. In this section, the thematic approach is used whereby the discussion is structured into the subjects addressed in the results section. The discussion is subsequently divided into two sections that are, in turn, divided into subsections that cover the key issues and themes that emerged in the study:

1. ICT's direct footprint and the role of sustainable design in reducing it.
2. The role of ICT in enabling an energy–efficient, low carbon economy.

5.2. ICT's Direct Footprint and the Role of Sustainable Design in Reducing it

The ICT sector is viewed as unsustainable and it continues to overlook environmental externalities. ICT design practice doesn't comply with environmental sustainability principles, owing to the resulting negative effects pertaining to energy–intensive consumption and GHG emissions. Espousing sustainable design strategy can play a key role for ICT sector to address its own footprint.

5.2.1. The Direct Footprint of ICT Sector

5.2.1.1. ICT Product Life Cycle

Energy efficiency is a key challenge when it comes to ICT product design as well as manufacturing processes. The results detailed above signify that the current mainstream ICT design approach tends to overlook energy efficiency factor (or the improvement in this regard is likely to be sluggish). Subsequently, this impacts on climate change through energy–intensive consumption throughout the whole lifecycle of ICT products. Research findings converge regarding the fact that most environmental impacts (unsustainable energy use and GHG emissions release) of ICT products come mostly from ICT use and then manufacture. Based on the life cycle assessment (LCA) methodology, it was found that the use phase of ICT has the largest environmental impacts as they are strongly related to fossil fuels (IPU/AC 1998). This shows the critical impacts of ICT use phase on climate change. Worse than that, it is predicted that the growth of ICT use will increase emissions as the energy consumption by ICT is likely to remain significant, even though energy efficiency might improve as efficient ICT products will conserve energy in the future. In line with that, it is hard to measure ICT impacts because of systemic effects associated with social and organizational structures and behavioral choices as to energy consumption patterns. By far, the energy conserved by efficiency improvements is lost to the excess of the electricity demand of new ICT services and the more intensive use and the diffusion of these services. Hence, there is a high risk that efficiency gains will be offset because of rebound effects, and that the energy demand and related GHG emissions caused by ICT production, use and disposal will grow to serious problems. Therefore, efforts to reduce ICT footprint can only be proportionate to the global share of ICT emissions, taking into account certain feedback effects associated with increased ICT deployment.

5.2.1.2. Data Centers

Certainly, data centers are energy–intensive users and GHG emissions generators due to many factors, including their complex structure, poor office management, and unsound corporate ICT strategy, in addition to human and organizational behaviors. This may pose some uncertainty issues as to whether the ICT design approach should focus on reducing total emissions from manufacture or producing new equipment that is more efficient in use. At global level, the total electricity generating capacity for data centers is huge, yet it depends on the number of data centers a country has. Indeed, different studies from UK, Switzerland, and USA confirm the same conclusion regarding the higher electricity generation capacity needed to power data centers. And this pattern is growing yearly due to both the increased demand of servers and the average server power consumption. Findings highlight that the key issue of energy–intensive consumption in data centers is the ineffective utilization of the several commodity servers idle that needlessly use electricity and drive up carbon emissions. This uncontrolled behavior of energy use in data centers contributes significantly to global warming. According to National Energy Foundation (NEF 2007), such behavior produces about 700,000 tons of CO2 emissions equivalents to the annual emissions of a typical gas–fired power station. As most findings confirm that the data centers are GHG emissions generator and energy–intensive user, it poses a real challenge for ICT sector to consider environmental factors when improving technologies to slash energy consumption in order to mitigate global warming and eventually decelerate climate change.

5.2.1.3. Software Technology

Although software technology is a key driver for economic and environmental sustainability, it was found that it produces less energy efficient applications (upgrades). The culprit of this contradiction is the phenomenon of planned obsolescence that, in fact, drives the whole design philosophy of ICT products and services towards more flaws and environmental externalities. To the built–in obsolescence, there is the potential backlash of consumers who may understand the impetus behind some ICT manufacturers investing to calculatingly make products obsolete faster. This may induce such consumers to turn to other ICT producers that offer more durable alternatives. Nevertheless, that doesn't seem to yield desired outcomes as the planned obsolescence doesn't either seem to slow down neither it will, owing to the complexity of the market game in ICT sector. The current software utilities (i.e. operating systems) upgrades are a planet killer because they devour energy. Also, the problem of software incompatibility is a contentious issue as many computer applications and utilities become obsolete once new versions or upgrades come out. Moreover, the problem of lacking compatibility among different software packages usually requires a new version of the system and then new, powerful computers or laptops, ending up in the obligation to acquire new device even if the previous one is still functionally useful. Software and hardware producers and vendors are primarily responsible for the problem. Difficulties encountered among users usually concern repairing and the lower quality of new components, which makes it difficult for consumers to resort to repair or replacements. It is more likely that both hardware and software sectors in ICT industry deviously encourage this kind of market game for maximizing profits. Suchlike, this shows that the software industry has ignored the externalities of its poor software engineering and design and the continuing decline in its performance achievements regarding the parameters that really matter.

5.2.1.4. Telecom Devices and Infrastructure

Like data centers, telecom devices and infrastructure that host complex networks are energy hungry and significant GHG emitters. Telecom industry's growth hasn't showed slowdown and the growth is exponential as telecom market continues to swell driving along intensive energy consumption to unprecedented levels. This is manifest by the increasing growth of users' accounts and mobile devices and networks. Not addressing the issue of energy consumption in telecom industry will definitely compromise the ecological dimensions (resources saving in other sectors) of the whole ICT industry. This is a complex challenge and failing to step up to it will worsen the problem of GHG emissions because telecom pervades all economic sectors as integrating technologies. Future estimates suggest that the mobile network will come to dominate the overall telecoms footprint. And at present, the majority of carbon emissions from mobile devices come from standby mode, the power (phantom power) used by chargers that are plugged in but not in use. From a conceptually different angle, the frantic consumerism of mobile phones is propelled by the throw away mentality. This encourages a mass production of mobile phones every year impacting strongly upon the environment. The prevailing planned obsolescence phenomenon in the mainstream design approach plays a central role in fueling the problem of mobile phones consumption. This is a deliberate strategy of ICT product design and service development espoused by most telecom giant companies in order to reap economic gains, manipulate consumerism and drive up throw–away mentality. What makes it even worse is that the model cycles of mobile devices are increasingly getting shorter, which remains a questionable strategy in environmental terms. New innovations and awareness rising are needed to encourage more rational consumption patterns. A sound approach could be to double the life of mobiles devices. Overall, the telecom foot print is a very complex element to control as to the total footprint of ICT industry for it is associated with an array of complex economic factors and players involving subscribers, operators, service providers, and energy suppliers. The intricacy of this value chain is related to how effective the real time information can be exchanged in the value chain to allow better efficiency measures to be implemented to cut energy use and thus reduce emissions. Indeed, the distribution of energy consumption within the telecoms network is, in general, poorly understood and the impact of further adoption of interconnected devices is unknown (GeSI 2008).

5.2.2. The Role of Sustainable Design in Mitigating ICT Sector's Footprint

This discussion section sheds light on how alternative design solutions can be devised based on the practices and principles of sustainable design whose philosophy is to design technologies that comply with environmental sustainability. This intends to reduce the footprint of ICT sector.

5.2.2.1. Rethinking ICT Design Strategy

ICT have a profound effect on the economy as a large part of economic development is attributed to ICT innovative applications; they are an essential and strategic component of all sectors. They have even become a critical enabler towards the progress of an efficient, low carbon economy as this study clearly illustrates. In order for ICT sector to claim a leadership role in a low carbon economy, it is certainly of import to call to mind the significance and timeliness of strategizing ICT design with sustainability in mind. ICT must be treated as an environmental hazard factor, with sound design criteria and practice to avoid potential risks and uncertainties. Both ICT users and producers alike need to understand this fact when placing high expectations on technological innovations.

As in all areas of design, it is necessary to rethink product design strategy in ICT in a way to ride on new emerging waves like green wave when building products and developing services. Sustainable technologies should be designed to support, improve, and conserve the environment rather than to systematically degrade the biosphere as what all human systems' designers have been doing for a long time. Thus, adding environmental sustainability principles to ICT design is an effective strategy to minimize risks and avert unplanned long effect externalities. In current economic reality, the prevailing ICT design strategy induces designers to place business expectations on ICT and overlook side effects. The majority of ICT designers have been forced to interpret their responsibility only in the context of complementing business strategies and creating corporate value, despite of the attempts of a few other proposing interesting design contributions that advocate for environmental solutions. Further, ICT producers have preferred to pursue market oriented strategies, ignoring the impacts of the looming global issues such as climate change caused by current ICT industrial paradigm. The expansion of ICT markets is based on the expansion and intensive consumption patterns of resources (i.e. energy, material). From an environmental point of view, this implies catastrophic medium and long term consequences of a continued and increasing use of natural resources (Morelli 2007).

ICT have become a significant global environmental issue from manufacture through use to disposal because of the throw away mentality and frenetic consumerism fueled by the phenomenon of planned obsolescence integrated in ICT design strategy. Rather, ICT design strategy needs to revisit the current tactics and rethink current practices. And any new design alternative should be directed towards better environmental performance. ICT design, operation, and disposal constraints form a significant corporate concern for both ICT–enabled organizations and ICT producers. General movement towards green ICT design has started springing up in every center of ICT manufacture. This is visible in the EU through energy efficiency programs and adoption of sustainability measures and indicators for reducing GHG emissions. Environmental concerns are forcing a new ecological responsiveness in the ICT industry whereby impacts are seen in three main directions (Forge 2007):

1. ICT processes – reduction in GHG emissions, energy consumption, and transport.
2. Product design – lower energy consumption in use and production.
3. Manufacturing facilities – reduced energy consumption and GHG emissions, powered by renewable energy sources with zero emissions.

Next, the author discusses the results regarding the role of sustainable design in tackling the footprint of ICT sector.

5.2.2.2. Digitization

Since quite long, digitization initiatives have been undertaken by ICT sector, including Sun Microsystems, IBM, HP, Nokia, Ericsson, Microsoft, etc. through offering access to the dematerialized world of computing with a range of new products and services. Dematerialization potential is the most important opportunity ever enabled by ICT. ICT have proven to optimize processes and products as regards their material and energy efficiency and organize innovative services that can replace material products in many occasions. However, reducing the demand for ICT, whether for physical products or their virtual equivalents, remains a critical factor for dematerialization strategy to bring fruitful outcomes. The demand for ICT products and services is projected to grow exponentially in the future, which might compromise the environmental dimension of dematerialization and ICT more generally. Progress in the direction of dematerialization is only a necessary, but not a sufficient, condition for approaching the goal of sustainability (WSIS 2003, 2005). Planned obsolescence that stimulates frenetic consumerism is also a crucial factor that ICT sector should capitalize on when developing dematerialization strategies. It is necessary to adopt sustainable ICT design practices in order to combat planned obsolescence and enable more rational consumption patterns of technological products and services. From a nanotechnology perspective, some material applications present a great opportunity to revolutionize ICT approaches to manufacturing in terms of miniaturization, material properties, shapes, and sizes. This applies to design, production, and application of structures, devices and systems at the nanometer scale. However, to the exciting possibilities offered by nanotechnologies, there are some risks and uncertainties associated with applications involving the properties of nanoscale particles. Most nanotechnologies pose no new risks, but there are uncertainties due to lack of evidence about the potential effects on the environment of deliberately manufactured nanoparticles and nanotubes – ultra small pieces of material that are free rather than fixed to or within a material (Dowling 2005). Moreover, radically new strategies are currently under demonstration and exploration to harvest and locally store energy below the micro level scale, including kinetic energy in the form of chemical energy, random fluctuations, ambient electromagnetic radiation, and so on.

5.2.2.3. De–carbonization

5.2.2.3.1. ICT Product Lifecycle

Energy efficiency and use of renewable energy sources are potential solutions to alleviate global warming. Again, the ICT design has to explore new opportunities to make efficient products, or rather consider sustainably–managed renewable energy sources in their operation and production processes. However, the whole life impact of ICT equipment is much more difficult to measure than the in–use energy as it is spread through a long supply chain (Griffiths 2008). ICT indirect impacts are significantly higher than direct impacts and much more difficult to measure at the macro level (MacLean and Arnaud 2008). The seemingly straightforward calculations of direct ICT energy consumption are not easy and can be inconclusive. Nonetheless, to focus efforts on increasing energy efficiency, the design should support life cycle thinking as to which stage of the product life cycle the product will consume the most energy and where possible to improve the overall system performance in respect to energy efficiency outcomes.

De–carbonization initiatives remain potential solutions to mitigate the impact of ICT on climate change. Concrete applications of these solutions depend on sustainable practices – ICT de–carbonization–oriented design strategy. Besides, energy efficiency brings economic benefits to both ICT users and producers; hence there has to be a compelling reason why ICT sector should embrace this opportunity and strive to turn it into reality. Explicitly, this emanates from the incentive to maximize business profits by satisfying consumer demands as to lowering energy spending. Findings suggest that carbon emissions savings must come from efficient energy use, as ICT equipment tends to have a large share of energy consumption and is expected to increase in the future along with electricity demand, despite tremendous improvements in electronics.

5.2.2.3.2. Data Centers

In the domain of energy efficiency, the focus has been on the redesign of data centers along with the housed ICT equipment. As detailed in the results section, a wide spectrum of design solutions are suggested to deal with the issue of CO_2 emissions resulting from intensive energy use in data centers. These design solutions are of both short and long term nature, and consist of hardware, software or a combination of the two. Such solutions are practically implementable and can contribute significantly to energy saving in data centers if intelligently used rather than simply assembling a collection of improved components that will not necessarily result in effective outcomes of energy saving. But concrete initiatives to implement new solutions depend on the priority given to the energy efficiency of data centers by corporate ICT strategy. That said change has begun to take place in ICT–enabled organizations across the globe and consequential energy saving is tremendous. But powering the data center with renewable energy is still at its early stages with a few recent implementations, though it remains the ideal solution to energy problem.

More research in ICT design innovation and technological change is underway in EU, USA, Japan, UK to develop upstream solutions to solve the data centers dilemma, especially to the problem of ICT equipment's idleness and inefficient utilization that directly contribute to GHG emissions as showed by different studies. Legislation on data centers within EU countries have had great impacts on encouraging manufacturers to design ICT products with whole life environmental impacts in mind – setting and complying with minimum standards for energy efficiency in order for ICT products to be eligible for sale in the EU. Those initiatives can play a pivotal role in forcing ICT sector to consider environmental considerations in the design processes instead of just taking voluntary actions (CSR) which is not as effective as corporate accountability. Rather than trying to change corporate behavior, it may be more effective to enforce such measures. Thus, it is necessary to set measures (i.e. mandatory emissions trading scheme) restricting the total carbon emissions for both ICT producers and consumers due to their greater impact than ICT–specific legislation.

5.2.2.3.3. Telecom Devices and Infrastructure

Like data centers, the focus has been on the redesign of telecom devices and networks in a more sustainable way through producing low energy consumption–type telecom devices and improving telecom infrastructure operation. Here, de–carburization strategy is crucial to achieve better efficiency outcomes, especially the exploration of renewable energies in both powering mobile phones and networks. In terms of mobile devices, technological development initiatives tend to be sluggish as most studies show that power consumption reductions from smart chargers and standby modes is still at its infancy. Anyhow, the focus should be directed more at devising solutions to integrate and deploy renewable energy solutions (green power) to generate electricity since telecom devices and infrastructure are dominated by electricity consumption. For telecom infrastructure, sustainability initiatives are being more explored by telecom companies to improve energy efficiency of networks and their component devices. Though, the increase in overall demand for telecom services and bandwidth requirements is likely to counterbalance the efficiency gains. This inevitably leads to more energy use and concomitant GHG emissions. No matter how workable quick fixes (downstream solutions) can be, they have been proven to be inadequate. The sound approach is rather to devise innovative upstream solutions by, for instance, redesigning the network to optimize overall network usage by rolling out current accessible innovations in energy and carbon–efficient network architecture. Moreover, effective long–term strategies are needed to achieve energy efficient integrated networks in terms of equipment; planning and management in access; energy consumption measurements; and technologies enabling power saving. That said it is imperative for telecom operators to better understand the distribution of energy consumption within the telecom networks, particularly the network services they deliver. Indeed, telecoms providers often don't know the energy consumption of specific services; the lack of information about the emissions impacts of products and services, especially in the context of complex configurations is a challenge to overcome for achieving further efficiency gains in ICT sector (GeSI 2008).

5.3. The Role of ICT in Enabling an Energy– Efficient, Low Carbon Economy

This section discusses key stumbling blocks to the realization of the full potential of ICT to improve energy efficiency and mitigate carbon emissions. They include behavioral and structural hurdles (rebound effects); economic barriers; and governance challenges (policy and regulation). The role of ICT in enabling sustainable behavioral and structural change is also touched upon.

5.3.1. Rebound Effects

It is abundantly clear that ICT can be an enabler for an energy–efficient, low carbon economy. But there are a number of stumbling blocks that must be overcome if the full outcome of ICT enabling effect is to be realized. This issue relates mostly to the rebound effects that shouldn't be underestimated – the potential for all the efficiency gains to be offset by our insatiability for consumption of ever more ICT products and services. The energy efficiency gains resulting directly from the improved efficiency of ICT products or services, or indirectly in the use and application of ICT products and services, are more likely to be offset due to systemic effects; how ICT–enabled changes affect behavioural choices; economic and social structures; and governance processes that, at the end of the day, profile or determine the patterns of energy consumption. Systemic effects should be holistically examined in order to avoid rebound effects that may counteract environmental gains. Coming to grips with systemic effects is an intricate task (MacLean and Arnaud 2008). These effects are often caused by a set of intertwined parameters, including accessibility, availability, affordability, and use of ICT products and services.

The increased efficiencies will not necessarily translate into reduced GHG emissions because of a phenomenon known as the Khazzoom–Brookes Postulate or the Jevons Paradox (Ibid). In a recent report, economist Jeff Rubin (2007) describes this phenomenon as an 'efficiency paradox' in which technology improvements allow for energy savings that are lost to greater consumption. That said improving the efficiency of ICT equipment directly or increased energy efficiency using ICT, paradoxically, may result in greater GHG emissions but not less (MacLean and Arnaud 2008). Therefore, successfully addressing the challenge of climate change through the development and application of ICTs will likely require changes in producer and consumer behaviors and economic and social structures (Ibid) as well as in governance processes. To put the ICT enabling potential at the core of energy efficiency endeavor (resolving the Jevons Paradox) may require a more holistic analysis of the direct, indirect and systemic effects of ICT on the environment. The way forward is to heighten awareness among all involved stakeholders in order for ICT producers to create well informed solutions; for users to understand and consider environmental implications of ICT use;

and for policymakers to design relevant comprehensive emissions–containing policy frameworks that contribute concretely to the transition to a low carbon economy. If we are to better use ICT technology to move away from existing energy intensive consumption habits and lifestyles, we need policy innovations, incentives for companies and the active participation of consumers (GeSI 2008). However, rather than being a relatively straightforward matter of increased energy efficiency and a reduced carbon footprint in the ICT sector, the relationship between direct, indirect and systemic effects is actually rather complex (MacLean and Arnaud 2008). Overall, making a beneficial contribution to energy efficiency through ICT applications and suppressing rebound effects remains a complex challenge for which there is unlikely to be a panacea.

5.3.2. Environmental Adverse Behavioural Changes

Far from exhaustive, a few examples of environmentally adverse behavioural changes that compromise the environmental dimension of ICT are presented below.

5.3.2.1. Virtual Mobility

As previously mentioned, digitized alternatives have enormous economic and environmental benefits. Companies reduce offices and parking space and transport congestion (less daily commuting) and save energy. However, due to systemic effects, gains from alternative virtual solutions (such as teleworking and videoconferencing) are often lost to greater energy consumption. Rebound effects counteract energy savings. To avoid this scenario, tele–working should be accompanied by a reduction in office spaces and, at the same time, the adoption of rational use of energy (i.e. heating) in home's alternative office. Energy saving depends on the amount of time teleworkers spend at home, considering that the extra energy required in the home for tele–working is small compared to that in the office. But this depends on how energy intensive different homes can be; hence additional energy may be required for home offices heating and cooling. A study carried out in 1997 by the Swiss Federal Office of Energy reported that if one household member was working at home, a 30% household energy increase (Aebischer and Huser 2000). Besides, teleworkers normally don't work full time at home because they need to stay connected personally and face to face with their social work environment (Fuchs 2009). About 5 % of the labor force in Europe can be considered as teleworkers, roughly 10 % of the workdays of the complete European labor force can be regarded as home–based telework (Schallaböck et al. 2003). New ways of working will not necessarily displace traditional ways of working.

Due to the low number of teleworkers (in Europe the share of teleworkers in the total labor force ranges from less than 2 % to more than 10 %) (Ibid), travelling to work produces only a relatively small share of total carbon emissions, and working from home doesn't automatically imply less transport because online work can produce new contacts that might generate the need for meeting people personally (Fuchs 2009). Online meetings facilitate more long–distance business connections and may lead to an increase in a number of face–to–face meetings (Plepys 2002). More generally, internet communication makes it easier to connect people globally and to initiate and maintain new social relationships and hence it can raise the desire or need to meet people face to face frequently (Alakeson 2003). This create more travelling and therefore more carbon emissions generated from transport (airplane is the worst case which happens more often). A study shows that 'homeworkers are spending more time travelling than conventional workers' (Piercarlo et al. 2004). Some studies have suggested that the effect of ICT on GHG emissions in tele–working is likely to be minor in the absence of measures to alter demand because of the central role the movement of people plays in the economy (Willard and Halder 2003; Erdmann et al. 2004)

In addition, tele–working should not encourage latent demand such as private travel (leisure drives) because of flexi work saving: money, fuel, and time (i.e. daytime journeys undertaken by the telecommuter for different social purposes). Otherwise, these side–effects would counterbalance ICT's environmental gains. To help address this issue, public transport may have the potential to support home workers and further encourage companies to pursue such sustainability initiatives. However, current employee discounts tend to cover longer periods of time and to favor staff travelling five times per week but an alternative could be discounted public transport tickets valid for any 10 journeys within a 30–day period (Alakeson et al. 2003). Nevertheless, people may still be driven by need, for example, when they can't go shopping on the way home from work, so they might take an extra trip by car to supermarkets. But with heightened awareness and behavioural change inducement, people can consciously choose to avoid unnecessary travelling and transport. Given the divers arguments about rebound effects in ICT and efficiency equation, the heated debate on the environmental gains seems to remain unsettled as the issue involves a set of amalgamated and dynamic factors that are subject to unpredictability. The European reality seems to be that there are rebound effects from online communication on the increase of travelling and that teleworking and teleconferencing are simply too unimportant for impacting on transport savings (Fuchs 2009).

5.3.2.2. Digital Media and Office Paper

The environmental gains of digital media are typically linked to the behavior of humans and organizations as to its use. Plepys (2002) argues that it is the intensity of use that determines the environmentally positive substitution effect of the digital media. A comparative Swiss study of three ways of delivering information through TV, newspaper, and Internet shows that with the Swiss electricity mix, the environmental impacts from receiving the same amount of news through Internet and TV was equivalent to a newspaper after 20 and 85 minutes, respectively (Reichart and Hischier 2001). However, if a user decides to print the news, the Internet impact is even bigger assuming around 70–80% of all PCs are sold together with a printer (Hilty et al. 2000). This will trigger another rebound effect known as re–materialization which is associated with virtual information products (articles, books, music, video, etc.) that are accessed via the Internet and then printed out or burned onto a CD or DVD. For office paper, there is a common agreement that ICT has contributed to creating paperless office. However, this theory doesn't hold true given what the statistics reveal. Contrary to most expectations, the experience of the past decades shows that the ICT did not create the 'paperless office' rather the actual paper consumption has increased several times with the advent of desktop publishing (Plepys 2002). The increase in the United States between 1960 and 1997 was fivefold (EIA 2002). Further, Estimates suggest that the demand of world paper will grow by 30% to the year 2010, reaching over 420 million tons (Jaakko Pöyry Group 2001). The 'paperless' office has failed to materialize (GeSI 2008).

5.3.2.3. E–Commerce

Business–to–business (B2B) commonly refers to online commerce transactions, involving products, services, or information between two businesses or parties, as opposed to that between businesses and consumers (B2C). As a digitized alternative, this close–to–zero transaction model is the area where ICT is has dramatically changed the way we do business. From a sustainability perspective, this business model has a great potential to, with supply chains, reduce industrial emissions and waste; boost storage and optimize transport because of mass customer delivery; reduce warehousing space; etc. However, there are environmentally adverse behavioural changes associated with e–commerce. For example, in e–commerce where the savings due to more efficient storage and reduced transport, purchasing can be shifted to the distribution line is not sustainable (WWF et al. 2008). Therefore, when developing strategies for short–term reductions with ICT, it is essential to conduct LCA in order to ensure that the new service is really reducing CO2 (Ibid). Further, in order to respond to the needs of growing customers regarding on–line orders, companies have to accelerate the delivery of goods. This increases transportation for delivering courier, express, and parcel services, leading to more energy consumption and driving up emissions. Consistent with that, e–commerce that make freight and passenger transport more time efficient will immediately create more traffic and possibly more energy consumption (Casal et al. 2005). There is no empirical evidence for assuming anything but a strong price rebound effect here, which could have severe environmental externalities in terms of energy use and GHG emissions (Ibid).

Studies indicate that some key parameters, such as population density, shipping or delivery distances, load rate of vehicles, and shopping allocations have a decisive role for the environmental impacts of e–commerce, and it is the consumer who decides on order sizes, supplier locations, product returns, and delivery time (Plepys 2002). A Swedish study of household shopping show that if one e–commerce delivery replaces 3.5 traditional shopping trips, if more that 25 orders are delivered at a time, and if travel distance is longer than 50 km, the environmental savings are reached (Jonson et al. 1999). E–commerce reduces the need for the excess packaging used to sell many products from supermarket shelves (Madden and Weißbrod 2008). However, by e–commerce changing the structure of shipped freight towards smaller units, packaging has increased (Fichter 2001). In terms of B2C, e–purchases can be highly customized, which reduces the efficiency of vehicle load volume and requires nonstandard size packaging (Plepys 2002). Like digital media, the environmental effect of e–commerce depends on how well it is optimized and used for specific conditions. For example, e–commerce has a great potential to cut the shopping related travel, but the habits leading to the current environmental effects deeply originate in consumer behaviour (Ibid). Although a few of them consider environmental implications, e–shoppers often make purchasing decisions based on price and delivery time (overnight door–to–door deliveries), which have large fuel intensities (Ibid). Due to the complexity of parameters inherent in the phenomenon of e–commerce in relation to consumer behavior that has a very important role in determining these parameters, the impact of the e–commerce on the environment remains uncertain. In contrast, a Japanese study on e–shopping concluded that traditional retail has less environmental impacts in dense urban areas (Williams and Tagami 2001).

5.3.2.4. Transport and Logistics

The environmental gains from ICT's efficiency improvements in transport and logistics are substantial. But the saving in this sector can, due to rebound effects, be lost to increased consumption of transport products and services. Improved transport efficiency by ICT applications could result in lower manufacturing costs, lower prices, greater purchasing power and, consequently, increased demand for products and services (Plepsys 2002). Lower costs and prices of products and services tend naturally to stimulate demand and motivate insatiable consumption. The rebound effects are likely to be triggered by factors such as increased demand resulting from lower prices (Willard and Halder 2003; Erdmann et al. 2004). The conundrum is how to induce the change of these behavioural patterns to sustainable practices. Any direct energy savings or carbon neutral plan may be undermined by the Khazzoom–Brookes postulate; therefore greater incentives (or disincentives) are required to encourage businesses and consumers to adopt practices that reduce GHG emissions. This is supported by a research done by (Casal et al. 2005) that indicates that internalizing environmental externalities, in particular raising energy and fuel prices, could bring demand down to a level where transport is no longer linked to economic growth.

Usually, the ICT enabled efficiency improvements (time, energy) are counteracted by an increasing demand of products, services, passenger and freight transport. Intelligent transport systems provide day to day operations management with real time data, optimized distribution network design, information for optimal routes, time reduction, and network capacity. This stimulates demand for transport, unless measures are taken to limit growth. Some studies have suggested that the effect of ICT on GHG emissions in transport and logistics is likely to be minor in the absence of measures to alter demand (MacLean and Arnaud 2008). Or, changes in consumption patterns and working practices through heighted awareness enabled by ICT may change the equation as people would gain better knowledge about sustainable practices and take green decisions. But trends in the development of new behaviors amongst organizations and consumers are likely to be very complex.

5.3.3. Economic Stumbling Blocks

Beyond rebound effects, it is crucial to overcome other hurdles in order to adopt and deploy ICT–based energy efficiency and climate solutions. When putting high expectation on innovative sustainable solutions, economic sectors should take into account an array of factors, including financial wherewithal; corporate culture and vision; technological innovations capabilities; internal and external communication; etc. For all types and scales of companies to respond to sustainability calls and adopt sustainable business practices, there are generally challenges to face. For example, to avoid the barriers to dematerialization adoption (how to widely implement and deploy digitized alternatives) it is necessary to provide affordable related solutions (internet service to all consumers); build telecom infrastructure; raise awareness of the options and benefits of new emerging technologies, etc. In 2005, only 1–2% of the US workforce teleworked (Gartner; Matthews and Williams, 2005), and many employers remain unsure about the technology (GeSI 2008). According to a survey by TelCoa (2003), 46% thought tele–working made it harder to manage employee performance and 54% of companies thought it made it difficult for employees to collaborate. Many companies are still reluctant to adopt digitized alternatives at higher rates because it requires adopting new ways of working with significant organizational changes. Nevertheless, there are some initiatives being undertaken to change behaviors towards the adoption of tele–working and teleconferencing as beneficial technologies. These technologies should be mainstreamed in digital economy. Indeed, the Economist Intelligence Unit (2008) recently launched a report based on a series of interviews with businesses highlighting the low instance of integrating ICT in climate change strategies, though the report is optimistic that in the near future this could change dramatically new approach from businesses and governments are adopted.

There are a number of barriers preventing companies in transport and logistics, industry, buildings, and power supply sectors from adopting technological solutions and realizing full emissions savings opportunities. Some hurdles preventing the widespread adoption of energy efficiency measures in these economic sectors are presented below (adapted from GeSI 2008):

Transport and Logistics

- Fragmentation of road freight market creates natural inefficiencies and hampers capital investment in energy efficiency technologies.
- Logistics operators tend to take a short–term approach to investment in improving efficiency.
- Outdated existing infrastructure makes it hard for wholesale changes to be implemented.
- Interoperability issue between the many different systems that currently exist within the logistics industry due to the lack of industry standards.
- Anti–competition regulations often prevent cooperation between companies.

Industry: Smart Motors

- Lack of investment capital in the integrated automation and required ICT–based innovations.
- Poor awareness of the business case for reducing energy use through efficiency measures.
- Reluctance to implement technology for fear of disrupting production processes and jeopardizing revenue.
- Lack of capacity and skills to operate advanced automation technologies.
- Lack of standardization or certification.

- Outdated infrastructure that can't run new systems.

Buildings

- Poor design of buildings makes it difficult to implement automation systems and apply common standards for efficiency and operations.
- Lack of incentives for architects, builders, developers to invest in smart building technology from which they will not benefit.
- Lack of incentives for energy companies to sell less energy and encourage efficiency.
- Reluctance of building owners and operators to accept too much built–in automation.
- Unclear business case for investing in energy efficiency: energy consumption is a small part of building cost structure, yet building automation costs can be high and payback periods are long.
- Lack of skilled technicians to handle complex BMS.
- Interoperable technologies exist but are not uniformly deployed, although many experts advocate an open standard as the most effective way to enable further innovation.

Power supply

- No proven commercial viability for large–scale smart grid rollouts.
- Financial barriers affect the levels of investment in new technology.
- Low awareness of technological developments as to both options and benefits.
- Fragmentation of the industry with no standardisation between companies.

To overcome the above hurdles, there are as diverse actions as to the equivalent barriers. They overall include: standardization, industry partnership, funding schemes, voluntary actions, innovations support, and awareness rising. But the most effective solution to realize the full potential of the best available technology today is through designing innovative policies: develop strong frameworks to encourage consumers to adopt technologies; provide incentives for consumers or other types of policy intervention; raise awareness of the benefits of climate solutions; etc. However, the current environmental discourse focuses on 'problems', resulting in NGOs, politicians and media running after the problems and creating legal structures that only focus on the problems and overlook solutions (WWF et al. 2008). Next section looks at policy and regulation in detail.

5.3.4. Policymaking Challenges

5.3.4.1. The Role of Policies in the Emerging ICT Role

To enable technological innovations to materialize and avoid the failure of the enabling potential of ICT to embrace the opportunity to tackle climate change, rebound effects should be addressed by all policies, especially by ICT and environmental policies. Policies should be strategically analyzed and holistically designed to ensure that the implementation of ICT–based innovative solutions make a concrete contribution to the environment and, at the same time, avert rebound effects. In point of fact, current policy tools such as carbon taxes and carbon offsets should be reviewed, and any new policies that aim to encourage or require the use of ICT to mitigate climate change should be analyzed carefully in terms of their ability to absolutely reduce GHG emissions on a global basis, not merely to slow down their rate of increase (MacLean and Arnaud 2008). To fully assess the potential role of ICT in supporting emissions reduction, it is necessary to come to grips with systemic effects by systematically identifying the kinds of changes in individual behavior, economic and social structures, and governance processes as well as the main policy issues associated with these changes with a focus on the role of ICT–enabled innovation (Ibid). Appropriate policy frameworks can provide the incentive to act and innovate to save energy and reduce carbon emissions as well as generate new economic opportunities for ICT sector. Policies that aim at maximizing the benefits of ICT in relation to sustainable development could have powerful policy carrying over effects in other economic sectors, yielding a potentially significant return on the investment of policy resources. However, realizing these benefits will likely require major changes to economic and social structures and behaviours enabled by ICT, which is blatantly a daunting challenge given the complex dynamic interactions between ICT, socio–economic system, and sustainability. Indeed, the question of how to instigate such changes has not yet been fully and systematically explored by either sustainable development or ICT policymakers (Ibid). However, making such changes entails well defined steps, commitment, and follow–up. It will likely require coordinated policy responses in a number of different areas; deployment of a range of policy tools that are likely to include both incentives and prohibitions through a mixture of regulation, co–regulation and self–regulation; top–down and bottom–up approaches to policy development and implementation; and governance arrangements that engage all stakeholders in their roles as citizens and consumers; etc. (Ibid). That said policymakers may need to adopt a more open philosophy of how to design new policies that dynamically direct technological innovations at promoting sustainable economic development. For example, an approach that would more rigorously and systematically analyze the positive and negative impacts of ICTs on the environment, identify rebound effects and trade–offs, and anticipate the unintended externalities that often give rise to the most interesting policy challenges (Erdmann et al. 2004). In 2004, a study carried out by Joint Research Centre of the European Commission (using sophisticated modeling techniques to analyze the potential impact of ICTs on GHG emissions) shows that political decisions made with regard to ICT or sustainable development must be based on prospective analysis of the positive and negative effects of ICT as well as on the dynamics both of the development of ICT and of its impacts on the socio–economic system and its interactions with the environment (Hilty et al. 2006).

5.3.4.2. Specific Sector Policy Design

Analysing where energy efficient solutions could have the most impact in different economic sectors and providing governments with the information they need can be critical to design effective policy to promote these solutions. Designing policies that encourage the adoption of sustainable ICT solutions and promote sustainable economic development needs to be appropriate in responding to specific economic sector where ICT permeate as enabling technologies. Of course, some policies can be comprehensive should they concern the whole economy or society. For example, to address the rebound effect requires an emissions–containing framework (such as emission caps linked to a global price for carbon) to encourage the transition to a low carbon economy (GeSI 2008). In contrast, for sector specific policies, the conception should entail as diverse factors as possible to yield a potentially significant return on the investment of policy resources in these sectors.

For dematerialization, policymakers should, for example, focus on:

- Building and promoting broadband and wireless infrastructure;
- Incentivising efforts by businesses and consumers that adopt ICT solutions;

- Rewarding ICT producers for innovation breakthroughs;
- Supporting advanced collaboration technologies; and
- Subsidizing innovation projects that facilitate access to technologies.

For efficient industrial processes and systems, to overcome the barriers for ICT adoption, policymakers should:

- Create subsidies for best–in–class energy efficiency technology adoption;
- Develop ICT standards for integration of efficient industrial systems and processes;
- Encourage low–interest funding schemes for energy efficiency; and
- Support technological development involving researchers from ICT, industrial automation, sustainable development, and energy domains.

To enable the full enabling potential of ICT in transport and logistics, policies should center on:

- Encouraging businesses and consumers to use vehicles equipped with telematics;
- Raise awareness of the options and benefits of intelligent transport systems;
- Create incentives for early adopters of such technologies; and
- Apply disincentives to alter demand for carbon intensive vehicles;

As far as buildings are concerned, a number of policies could be designed, including:

- Subsidization of design projects that support efficiency technology adoption;
- Reward of the best–in–class buildings' owners and operators;
- Development of green building assessment tools;
- Regulating the green and automation measures application in the construction of buildings;
- Creation of strategic alliances between governments and related industries; and
- Providing funding schemes that encourage owners to invest in building automation systems.

Finally, for power supply, policies are essentially concerned with:

- Supporting projects of smart grid technologies;
- Subsidizing projects that accelerate efficiency technology adoption;
- Allowing decentralization of energy production;
- Encouraging energy production from renewable sources;
- Promoting multiplication of grid distribution networks; and
- Subsidizing renewable energy integration in power distribution network;

It is evident that the policy making can play a pivotal role in easing the process for producers and consumers to overcome a great bulk of hurdles. 'At the end of the day, policy–makers will need to discover what it will take to get producers and consumers to use ICT in a manner that supports reductions in GHG emissions to levels that are economically, environmentally and socially sustainable' (MacLean and Arnaud 2008, p 7). Besides, ICT can't act in isolation to mitigate climate change, nor can sustainable practices become widespread with free will. Legislation is a crucial factor for any transition in time or paradigm shift to materialize.

5.3.5. Mobilizing ICT for Sustainable Behavioural and Structural Change

To enable ICT to achieve the full potential to mitigate climate change, it is necessary to address rebound effects by overcoming behavioral, economic, and social hurdles. Again, ICT could play a pivotal role to heighten energy and climate change awareness. Changes to economic and social structures and behaviors enabled by ICT may well have the potential to help reduce our carbon footprint (MacLean and Arnaud 2008). ICT could address this issue by influencing consumers' attitudes towards more sustainable patterns of energy consumption. They can easily become a powerful engine of consumerism if used intelligently. Due to their pervasiveness and wide integration, ICT can change energy consumption habits across the economy and society. Information to consumers (individuals and businesses) about making less carbon–intensive choices and sustainable purchasing decisions is an area with great potential. By this means, the ecological dimension of ICT would deliver twofold potential enabling effect in digital economy: energy efficiency and energy awareness. That said Internet communications can facilitate consumer environmental education for adopting and understanding the benefits of sustainable practices through heightening energy and climate change awareness. Undeniably, the Internet is a powerful marketing channel, which is able to target specific consumer groups and affect perceptions and lifestyles (Reisch 2001) and alter the consumption culture of energy–intensive products and services.

In digital society, sustainable solutions can have a multiplier effect as they pervade business and consumer networks. Information about the role of ICT in enabling a low carbon economy can potentially empower consumers to make green purchasing decisions with regard to efficiency technology adoption. Consistent with that, ICT have changed the way businesses interact with their consumers and also supported the emergence of green consumerism – it is easier online to track down sustainable products that are not widely available (Madden and Weißbrod 2008). More informed choices can steer behavior for people to only consume or use a product or a service when necessary or not at all (WWF et al. 2008). Moreover, as people, companies and governments can track their own and each other's impact and how they affect the world around us, new solutions can come sooner than expected (Ibid). All stakeholders can take part as they gain more information to actively participate in sustainable initiatives and make green choices. For example, OneClimate, a not–for–profit initiative, is a net that provides innovative spaces and useful tools to enable people to communicate their experiences, insights, questions and answers about climate change where almost all the content is provided by users (Madden and Weißbrod 2008).

In addition, innovative, incentive–based approaches to changing consumer and business behavior could be of great value to respond to the global imperative of GHG emissions reduction through ICT–enabled solutions. For ICT to make organizational and social behaviors more sustainable, there has to be awareness at the outset when introducing new ways of working (i.e. tele–working, videoconferencing); doing business online (i.e. e–shopping, e–commerce); streamlining supply chain (i.e. smart logistics); generating and distributing energy efficiently (i.e. smart power grid); living efficiently (intelligent residential buildings); operating smartly (intelligent industrial buildings); and designing well informed policies (dynamic interaction between ICT, economic system, and sustainability); etc. Individuals and organizations should be supplied with sufficient information to take environmentally aware decisions when acquiring new technologies. What is more needed to enable ICT to embrace the opportunity to raise awareness of the environmental benefits of efficiency technology is to develop specialized ICT innovative solutions that encourage consumers to reduce their carbon footprints. For example, companies like Google, Yahoo, Microsoft, Apple, and Amazon, with their close and wide consumer relationships, could significantly impact on carbon emissions by partnering with energy companies to develop bundling strategies that encourage consumers to reduce their carbon footprint in exchange (MacLean and Arnaud 2008). Overall, to increase the visibility and advance the understanding of the ICT role in alleviating global warming, all stakeholders (industry, consumers, governments, academia and research institutes, etc.) need to get involved and work together.

5.3.6. Weaknesses and Strengths of the Study

Like other research methods (i.e. qualitative and quantitative) literature review has advantages and disadvantages. Below main strengths and weaknesses of this study are discussed with consideration to how they affected the overall outcome.

5.3.6.1. Weaknesses

- The topic is extremely complex as it involves technological, environmental, social and economic dimensions.
- The phenomenon embodies intricate dynamic connections between direct, indirect, and systemic effects of ICT impacts on climate change.
- Likelihood of getting overwhelmed by the information flow when reviewing literature, which may affect the course of the research.
- The researcher can bog down in the literature review process and not move forward as quickly as he should.

- Effective literature review requires a high level of skills in seeking and analyzing the sources to identify relevant and credible information.
- Not all literature material is of equal quality and rigor.

5.3.6.2. Strengths

- Results are garnered from credible, recent studies and both academic and industry literature.
- Studies are carried out by eminent researchers, experts, and stakeholders (i.e. NGOs)
- Sources include three types of scholarship: theoretical, empirical, and analytic/critical.
- Literature review is an efficient data collection method.
- Literature review allows pointing to the unknowns and discovering connections and contradictions between different research results by comparing various investigations.
- Researcher' prior knowledge on the topic is crucial in overcoming biases and missteps regarding the evaluation of results and the selection of studies samples.

CHAPTER SIX

CONCLUSIONS, KEY FINDINGS AND FURTHER RESEARCH

6. Conclusions, Key Findings and Further Research

6.1. Conclusions

The principal aim of this study was to investigate the direct footprint of ICT sector and explore how it can be tackled through adopting sustainable design–based solutions as well as to highlight the role ICT sector could play as a critical enabler in the transition and progress towards an efficient, low carbon economy. To collect the relevant data, the author performed an extensive and pertinent literature review covering theoretical, empirical, and critical scholarship, using mainly scientific journal articles, recent research studies, and international project outcomes. To provide a logical and coherent structure of the literature material and bring clarity to the reader, the author used a combination of the thematic and inverted pyramid organizational framework for literature review. The results were synthesized, evaluated, and discussed to draw a more consistent picture of the challenges ICT sector has to take up in order to claim a leadership role in an energy–efficient, low carbon, economy. Given the sweeping nature of the research area, various relationships, implications, and synergies between ICT, sustainability, and economy were identified, which broadened and enriched the study. The emphasis was on illustrating the relationship between ICT design, sustainability, and the economy in that how symbiotically can one affect the development of the other and in what direction.

The sheer scale of the challenge involved in stabilizing the climate signifies that the ICT sector needs to step up its efforts in reducing its direct footprint. Nevertheless, ICT hold a great potential to yield substantial energy efficiency improvements and emissions reductions in other economic sectors. But rebound effects and other hurdles might be stumbling blocks to the realization of the full potential of the projected gains. The effectiveness of the ICT enabling contribution will depend on behavioral changes, social structures, and governance processes. Rebound effects should be acknowledged and addressed by policymakers, especially ICT and environmental policies. Also, the behavioural patterns of technological innovations are unpredictable for they evolve dynamically and are as well subject to the emergence of paradigm shifts as to failures of materialization. Uncertainty thus remains a contentious issue as to estimating absolute future economic and environmental impacts, given the capriciousness surrounding the fact that new technological innovations might not be widely adopted and fully transpire. While the future remains volatile, individuals, organizations, governments have choices to make, and the sum total of those choices will, at the end of the day, shape how ICT development as projected will evolve to achieve a sustainable economy.

Although other researchers have acknowledged the relationship between ICT and sustainability, it is undeniably valuable to approach the topic from design and economic perspectives and find threads, through analysis and discussion, to link ICT with sustainable design and economic development while providing relevant and comprehensive review. This can contribute as a stepping stone to further empirical and theoretical research and development. Indeed, this is a potentially exciting area for investigation with many intriguing questions and extensive multidisciplinary work (involving ICT, sustainable development, energy, climate change, ecological economics) awaiting future scholarly inquiry. The time is ripe for pairing ICT and environmental and economic sustainability research for achieving the goals of a better future. It is hoped that the current study provides a step towards that goal. Since the research was exploratory in nature and the area is multidimensional, it is obvious that conclusions are preliminary and open for discussion and qualification.

6.2. Key Findings

Findings highlight the unsustainability of ICT sector pertaining to energy–intensive use and GHG emissions associated with its products and services. This was established through the following facts:

- Of the whole lifecycle, the use phase of ICT is the most critical in terms of the impact on climate change.
- Data centers and telecom networks devour energy and emit huge amount of GHG.

- Planned obsolescence inherent in the design of software technology is the culprit of frequent upgrades that make software utilities a planet killer with regard to energy consumption.

To address the footprint of ICT sector, alternative design solutions can be devised based on sustainable design practices that entail using most efficient energy required over ICT's life cycle and renewable energy that is cyclic and safe – de–carbonization strategy. Digitization is an effective strategy for ICT sector to slash energy use per unit. To reduce the footprint of data centers and telecom networks, design solutions vary from hardware and software to technological improvements. As for software technology, designing out built–in obsolescence is a key factor in the energy equation.

As for the enabling role of ICT, the findings are highly illuminating. The ICT sector must step up its efforts in reducing its direct footprint in order to claim a leadership role in an energy–efficient, low carbon economy. Although the ICT sector's own emissions will increase because of global growing demand for its products and services, the real gains will come from its enabling potential to yield substantial energy efficiency improvements and emissions reductions across the economy. The sheer scale of the climate change challenge presents smart development mitigation opportunities for ICT sector to deliver environmentally sustainable solutions. The largest identified opportunities are: dematerialization through e–substitutions (i.e. tele–working, videoconferencing, e–commerce); transport and logistics (i.e. route optimisation, load efficiency, fleet control); buildings (i.e. smart design and constuction, automation systems); power supply (i.e. efficient T&D, excess capacity reduction, renewable energy integration); and industry (i.e. material control and reduction, efficient industrial processes, smart motor systems).

6.4. Suggestions for Further Research

It is acknowledged that the study is preliminary, although it delivers a differentiated picture of both the unsustainability and the enabling effect of ICT. Also, as uncertainty surrounding future ICT development, adoption, and use still exists, further research is necessary for a fuller understanding of the role of ICT in enabling an energy–efficient, low carbon economy. Special emphasis may be given to the rebound effects given the associated externalities as well as to policy design, especially the dynamic interaction between ICT, sustainability, and the economy. Based on prior discussions and conclusions, the author suggests the following future research investigations:

- Build further linkages and sequences between environmental instances and dynamics and technological and industrial logics to create more systemic solutions.
- Combine energy economy (rebound effects), ICT, policymaking, and cognitive and behavioural psychology for devising measures and schemes that effectively influence behavioural, social, and organizational patterns of consumption (i.e. energy, services).
- Intelligent transport systems' impact on shifting to wide use of public transport.
- Open innovation in renewable energy integration in power distribution networks.
- Partnership between technology and energy companies to develop strategies to encourage consumers to reduce their carbon footprints.
- Innovation in policy design focusing on dynamic interaction between ICT, sustainability, and socio–economic systems.
- Strategy development based on life cycle assessment (LCA) for ensuring the effectiveness of e–substitutions as to emissions reductions target, especially tele–working and e–commerce.

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Appendix A: Basic Principles in Hardware and Data Center Design to produce Energy Savings (Forge 2007)

Impacts on data center physical footprint
Data center design requires a payoff between reducing the surface area needed and creating hotspots which require disproportionately more intense cooling and also may be a source of failure and unreliability. Thus there is a payoff between denser racks and reliable operation. Poor data center layout will increase cooling power required and can increase downtime.

Power to the server
More energy–efficient servers would also help. For example, part of Google's strategy has been to work with component vendors to achieve this. One avenue is power supplies which typically are 70 percent efficient. Google pays extra for DC power supplies which have 90 percent efficiency–but they pay back in energy costs in a few years. Also, most motherboards have three DC voltage inputs, for historical reasons, but the microprocessor actually works at a different voltage to all three, which is highly inefficient. Power savings come from having just one DC voltage. Naturally, if it is possible to have regular programmed shutdown or standby quiescent power levels, so that either no, or minimal, currents are drawn, the concept of a whole machine needing to be powered up to be in constant readiness may be discarded.

Reducing the voltage
Voltage levels used in the processor circuits also have dramatic effects, since power consumed is proportional to the square of the voltage. This is a solution only open to the original designer of the microprocessor. So user pressure has to act at the level of the components and the system. New processor designs may also help and the microprocessor manufacturers are moving to newer low energy architectures.

Re–engineering the CPU and software for lower energy usage
There is a wide range of techniques that could lower energy usage. Apart from new semiconductor technologies, they include shutting down parts of a processor when not in use and going much further – adiabatic computing – looking at state transitions in semiconductors to reduce energy consumed by optimizing the operations which take power, which requires analysis of hardware responses to the software at bit–level. Various energy consuming components such as DC power supplies and fans can be improved, e.g. active cool fans (from HP and others) which give four times the cooling for 30 percent of the usual energy. The big paybacks however are in backlighting of displays (for laptops 80 percent of total consumption). One possible solution is to replace the display with new organic LEDs or other technologies that cut power by eliminating backlighting.

Powering the data center with renewable energy that does not emit greenhouse gases
Some of the largest users of data centers, such as Google, Fujitsu and others are turning to emissions–free power sources for data centers and attached offices. For instance, Google has installed a 1.6 MW solar roof power supply on one data center building.

Appendix B: Technical Ways to increase Data Center Efficiency (Griffiths 2008)

Improvements to Data Centers

There are three main areas where the energy efficiency of data centers can be improved: the facility itself; the ICT equipment housed there; and how that equipment is used.

The facility

Around half of the electricity going into a standard data center is used just to cool the equipment inside it. The layout of the building has a big impact on the efficiency of the cooling systems. It should avoid as much as possible the mixing of hot and cold air. Some advanced facilities use liquid cooling or 'fresh–air' cooling, which uses air from outside the facility to cool the inside rather than re–circulating air internally.

The equipment

Components of the servers used in data centers, such as processor chips, are becoming more energy efficient. Power supply units have also become much more efficient with initiatives such as the 80 PLUS program (funded by electric utility companies), which certifies power supplies that are more than 80% efficient. New solid state data storage devices can be operated at a wider range of temperatures than hard disks, though they are more expensive and not suitable for all applications.

The workload

In traditional data centers, the servers are used inefficiently. For example, a server will still draw around 70–90% of its maximum power usage even when doing no useful work. A technology called virtualization allows applications that would otherwise be run on several different servers to share one, and in the longer term applications will be rewritten to run naturally using shared resources. This means that servers can run closer to their maximum capacity, which is more efficient. Redundant servers can then be removed.

Appendix C: The Steps in Consolidation of Servers and Whole Data Centers (Forge 2007)

Dynamic applications management across servers – virtualization and grid technology

Here the strategy is to reduce server numbers by sharing servers across applications rather than dedicating servers by application. There is no longer one application to one server as is too often the case today. This may also require dynamic scheduling to optimize throughput. There are several possible approaches. The first, using virtualization software, is also the cheapest and simplest today, hosting many environments on one server or a server cluster on an 'as–needed' basis, either from the systems vendors or a package from an independent software vendor (ISV). Virtualization enables the running of different operating systems and applications in partitions on the same physical server, to reduce hardware, power, cooling and data center space. A more sophisticated approach, now coming to market, is to dynamically orchestrate the allocation of servers as they become free to host the next application. It relies on developments from grid computing which efficiently orchestrate and load a whole environment on one server or a group to run an application (Forge and Blackman 2006). For this to run smoothly, job scheduling also requires intelligent management, to ensure that the resources coming free are adequate for the next job, in terms of processor power, storage and input/output access.

Pro–active systems management solutions

The systems management function of the future has to take on a new role – server economy. The aim is to manage applications to meld batch and real–time interactive loads into a job stream that saves on total processors required – to spread the load across fewer servers. It should also minimize those servers required for backup, on hot standby. This demands a systems management utility having advanced functions for ease of reconfiguration by the systems operator, combined with an advanced dashboard showing current energy consumption figures with historical logs. But the key tool is a running assessment of the optimal configuration to follow an energy economy strategy. For operational energy management, future systems management may need to add electrical power measurement with sensors at mother board/server level, under the umbrella of the industry–standard for management, Simple Network Management Protocol (SNMP).

Storage systems software

Compacting data using advanced compression techniques on disk and tape volumes on large storage area networks (SANs) and tape installations can be both a further energy and a space saver. New techniques for massive archives are especially effective.

Appendix D: Basic Improvements in the Office to reduce Energy Consumption (Griffiths 2008).

More efficient components

The micro–processors within electronic equipment require energy both to operate and for cooling fans. Advances in chip design (such as 'multi–core' processors) can save 30–60% of the energy used by the processor if software is written to take advantage of this capacity.

Power management

Almost all computers now have a low power mode which they can enter automatically after a period of user inactivity. In such modes they will consume very little power but can often be woken up within seconds. Power management options are sometimes enabled as a default.

Laptop computers

These can sometimes use as little as a third of the energy of a desktop. Some organizations are replacing desktops in the office with laptops. Similarly, flat screen monitors are much more efficient than old–fashioned cathode ray tubes.

Thin clients

These are terminals that do not do processing themselves, but allow the user to connect to central servers and display the output. The German Fraunhofer Institute estimated that a thin client configuration is twice as energy efficient as using desktop PCs though these findings have been disputed as underestimating the cost of the increased power usage of servers needed to support the clients.

Multi–functional devices

Printers now often include scanning, copying and fax functions, which is more efficient than running several separate devices. The number of printers per person can also be reduced, and printers can be set to enforce double–sided printing to save paper and use of the printer.

Appendix E: Figure 4.4 SMART Logistics: The Role of ICT (GeSI 2008)

Standardise, Monitor and Account

• Tag and track inventory, stock and other items throughout the supply chain

• Track local terrain and information for understanding of optimal routes

• Information systems to provide the driver with real time information about the vehicle's efficiency and behaviour

Technologies and Services

• Radio frequency identification (RFID) for asset tracking

• Geographical information systems (GIS) to combine sensing with geographical terrain

• Data recorders for vehicles

• Onboard driver information and data logging

• Real time fleet tracking

• Global Positioning Systems (GPS)

Rethink

• Increase communication between devices and between logistics providers and suppliers

• Optimise and control inventory to reduce vehicle miles in delivery or returning stock to the manufacturer

• Model and optimise distribution network design throughout supply chain design

• Conduct stock repair tasks on behalf of the manufacturer

• Manage day to day operations with real time data

• Track efficiency against business performance

Technologies and Services

• Broadband networks

• Messaging platforms enable notifications between system components

• Telematics

• Supply chain design and modelling software

• Real time route optimisation (RTRO) software

• Collaborative planning, forecasting and replenishment (CPFR) systems

• Installed base management platforms

• Vendor managed repair (VMR) platforms; also known as maintenance, repair and operating (MRO)

• Business and operational support systems (BSS) (OSS)

Transform

• Vehicle and load management systems to identify unused capacity within the supply chain

• Reverse logistics to allow the back–loading of vehicles on the network and for the return of unsold or damaged goods to the supplier

• Apply systems thinking from production to consumer to end of life

Technologies and Services

• CO_2e emissions tracking platforms

• Electronic freight exchanges (EFX) to allow for the "auction" of spare space on vehicles

• Reverse logistics platforms

• Protocols for system interoperability

• CO_2e route optimisation standards and software

• E–commerce and other e–services

Appendix F: Figure 4.5 SMART Buildings: The Role of ICT (GeSI 2008)

Standardise, Monitor and Account

• The ability to change the local conditions based on occupant behaviour

• Occupancy–based lighting

• Demand control ventilation

• Correction of hardware controls

• Measuring building performance/networking

• Modelling and simulating energy consumption

• Daylight control systems

Technologies and Services

• Sensors for remote monitoring and measurement

• Chips and controllers for BMS

• In–building network systems

• Building equipment (e.g. LED lighting)

• Building automation solutions (e.g. occupancy–based lighting)

Rethink

• Re–commission to find inefficiencies in BMS. The two areas of the greatest impact are lighting and HVAC

• Improve engagement and involvement from users

• Building and energy management control systems (EMCS)

• Removal of software errors

• Remote building management

• Improvements to operations and maintenance

• Energy modelling from design through building use

Technologies and services

• Building design and simulation software (e.g. temperature modelling, fluid dynamic modelling)

• BMS

• Implementation of building automation (e.g. shade control systems, motion–based refrigerator case lighting)

• Interconnectivity between building systems (e.g. EMCS, lighting, security systems)

• Appliance interconnectivity and networking and remote appliance control

• Operations and maintenance of building communication systems

Transform

• Create a connected urban environment such that buildings are adjustable to human behaviour

• Improved human–to–machine interface

• Software to design the built environment systems from transport through to building use

• Tele–working and collaborative technologies to reduce need for office space

Technologies and Services

• Open standards for interoperability between different technology sets

• Automated whole building control systems (AWBCS) and automated whole building diagnostic systems (AWBDS)

• Maintenance of energy generation services (e.g. photovoltaic energy supply)

• Automated building code checking services

Appendix G: Figure 4.7 SMART Grids: The Role of ICT (GeSI 2008)

Standardise, Monitor and Account

- Better information for consumers and producers of power
- Remote monitoring and measurement
- Improved energy accounting
- Improved billing services

Technologies and Services

- Sensors for remote measuring, chips and controllers for monitoring
- Smart meters (advanced metering infrastructure (AMI) or automatic meter reading (AMR))
- Energy accounting software
- Smart billing software – IP–based billing or prepaid metering

Rethink

- Better planning and forecasting
- Improved asset management
- Improved network design
- Remote grid management
- Preventive maintenance
- DSM

Technologies and services

- Grid management systems (e.g. supervisory control and data acquisition (SCADA) and output management system (OMS))
- Asset inventory and network design systems (e.g. GIS tools)
- Load analysis and automated dispatch software
- Workflow management systems for the grid
- Performance contracting applications

• Demand response software that allows automated load maintenance

Transform

• Support for and integration of renewable and distributed generation

• Intelligent dispatch

• Captive generation integration

• Grid–to–vehicle solutions

Technologies and services

• Protocols for grid–wide system interoperability

• Operations and maintenance of grid communications systems

• Advanced telecommunications to allow distributed energy producers to pool resources and to handle spikes in supply and demand

• New platforms (e.g. Emission Trade Scheme (ETS))

Appendix H: Figure 4.8 SMART Motor Systems: The Role of ICT (GeSI 2008)

Standardise, Monitor and Account

• Monitoring of energy consumption and energy savings

• Central repository of energy consumption data

• Transfer of energy consumption data to local and central governments for regulatory compliance

• Analysis of energy consumption data

Technologies and Services

• Chips and controllers for VSD intelligence

• Digital meters and components for real time information

• Database collection of energy audits integrated with business software

• Central collection of real time energy data

• Interface with monitoring agencies

Rethink

• Optimisation of motor systems by using information on required output of motor system

• Optimisation of industrial systems by receiving information at the factory level on actual output of all motor systems in real time

• Remote and centralised control of VSDs (central intelligence providing instructions to VSDs)

Technologies and Services

• Simulation of systems by plant designers and operators

• Manufacturing process design technology

• Wired/wireless communications between VSD and central control system

• Wired/wireless communications between VSD and rest of the plant

• Software to analyse and optimise design of motor and industrial system

Transform

• System intelligence and integrated control of devices across the plant and the wider business

• Integration with sales and logistics

Technologies and Services

• Protocols for system communication and interoperability

• Servers and storage to support integrated control of devices

• Wireless protocols for machine–to–machine communication (e.g. TCP/IP for industrial systems)

• Device integration in company and/or plant

• Tailored optimisation solutions for different sectors