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ICT Design Unsustainability & the Path toward Environmentally Sustainable Technologies

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Abstract

This study endeavors to investigate the negative environmental impacts of the prevailing ICT design approaches and to explore some potential remedies for ICT design unsustainability from environmental and corporate sustainability perspectives. More specifically, it aims to spotlight key environmental issues related to ICT design, including resource depletion; GHG emissions resulting from energy-intensive consumption; toxic waste disposal; and hazardous chemicals use; and also to shed light on how alternative design solutions can be devised based on environmental sustainability principles to achieve the goals of sustainable technologies. The study highlights the relationship between ICT design and sustainability and how they can symbiotically affect one another.

To achieve the aim of this study, an examination was performed through an extensive literature review covering empirical, theoretical, and critical scholarship. The study draws on a variety of sources to survey the negative environmental impacts of the current mainstream ICT design approach and review the potential remedies for unsustainability of ICT design. For theory, central themes were selected for review given the synergy and integration between them as to the topic under investigation. They include: design issues; design science; design research framework for ICT; sustainability; corporate sustainability; and design and sustainability.

Findings highlight the unsustainability of the current mainstream ICT design approach. Key environmental issues for consideration include: resource depletion through extracting huge amounts of material and scarce elements; energy-intensive consumption and GHG emissions, especially from ICT use phase; toxic waste disposal; and hazardous substances use. Potential remedies for ICT design unsustainability include dematerialization as an effective strategy to minimize resources depletion, de-carbonization to cut energy consumption through using efficient energy required over life cycle and renewable energy; recyclability through design with life cycle thinking (LCT) and extending ICT equipment's operational life through reuse; mitigating hazardous chemicals through green design - low or non-noxious/less hazardous products. As to solving data center dilemma, design solutions vary from hardware and software to technological improvements and adjustments. Furthermore, corporate sustainability can be a strategic model for ICT sector to respond to environmental issues, including those associated with unsustainable ICT design. In the same vein, through adopting corporate sustainability, ICT-enabled organizations can rationalize energy usage to reduce GHG emissions, and thereby alleviating global warming.

This study provides a novel approach to sustainable ICT design, highlighting unsustainability of its current mainstream practices. Review of the literature makes an advance on extant reviews of the literature by highlighting the symbiotic relationship between ICT design and environmental sustainability from both research and practice perspectives. This study adds to the body of knowledge and previous endeavours in research of ICT and sustainability. Overall, it endeavours to present contributions and avenues for further theoretical and empirical research and development.

Keywords: ICT, ICT design, Sustainable design, Environmental and corporate sustainability, Environmental impact, Dematerialization, De-carbonization, Recyclability, Resource depletion, Energy consumption, GHG emissions, Climate change, Toxic waste, Hazardous chemicals, Product lifecycle, Planned obsolescence, and Data centers.

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Glossary

Auspiciousness: Refers to the favorable quality of strongly being promising of or indicating a successful, thriving, prosperous outcome. Auspicious means conducive, favorable to future success.

Biodiversity: Generically refers to 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.

Business Ethics: Is a form of applied ethics that examines ethical principles and morals that arise in a business environment. Business ethics is, if not an oxymoron, an imprecise and vague term (Orlitzky 2000). Business ethical issues reflect the degree to which business is perceived to be at odds with non-economic social values.

Corporate Communication: Defined as the process through which stakeholders perceive the organization's image and reputation that are formed through the interpretation of the identity cues presented by that organization (Balmer and Gray 2000).

Corporate Citizenship: The extent to which companies are socially responsible in meeting legal, ethical and economic responsibilities placed on them by shareholders. It is about the company's sense of responsibility towards the community and environment in which it operates.

Corporate Governance: Broadly refers to the rules by which companies are operated, regulated, and controlled in relation to internal and external stakeholders.

Corporate Social Performance (CSP): Is defined as 'a business organization's configuration of principles of social responsibility, processes of social responsiveness, and policies, programs, and observable outcomes as they relate to the firm's societal relationships.' (Wood 1991, p.691)

Critical System Heuristics (CSH): 'is a framework for reflective practice based on practical philosophy and systems thinking…the aim is to enhance the "critical" (reflective) competence… reflective practice cannot be secured by theoretical means only but requires "heuristic" support in the form of questions and argumentation tools that make a difference in practice..."systems" thinking can provide us with a useful starting point for understanding the methodological requirements of such an approach to reflective practice.' (Ulrich 2005, p.1)

Dematerialization: Refers to the substitution of virtual products and services for their physical equivalents (MacLean and Arnaud 2008). In this context, dematerialization refers to the absolute (immaterial) or relative reduction in the quantity of materials needed to manufacture ICT products or using digitized alternatives.

Downstream Solution: A solution that addresses symptoms rather than causes of issues.

Earth's Crust: The thin outermost layer of the Earth, approximately 1% of the Earth's volume, that varies in thickness from 30-70 km below the continents to 6-8 km below the oceans (Rooney 1999).

Energy efficiency: Generally refers to rational (efficient) use of energy to achieve an intended application performance. In this context, it is technically the minimum quantity of energy required to deliver a functional output from an ICT device.

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

First Order or 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).

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.

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).

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).

Rebound Effect: Refers to 'an effective increase in the consumption of an energy service after its price decreases due to higher efficiency of the production of the service' (Plepys 2002, p. 510).

Recycling: Reprocessing of products or parts thereof for reuse or other purposes during their end of life stage.

Reuse: Recycling of products or parts by entering in a subsequent product use stage.

Second Order or 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). From this perspective, 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).

Stakeholder: Anyone with an interest or stake in the decisions made by an organization, or anyone affected by those decisions. Freeman (1984) defines stakeholder as any individual or group who can affect or be affected by the achievement of the organization's objectives.

Strategy: Refers to 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 (products and services) that comply with the principles of environmental sustainability. It is also referred to as 'eco-design' (Papanek 1995).

Design for Environment: '…Is design that seeks to eliminate potential negative environmental impacts before a product is made…This concept involves reducing the quantity and number of materials used in a product or service; the resources used in manufacture, operation and disposal; the hazardous materials that are used; and the quantity of non-recyclable materials used. It also involves modular design that allows for upgrades, easy refurbishment or parts replacement, and simpler dismantling for re-cycling or disposal…' (Greenpeace, 2005)

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).

Sustainability Principles: 'In a sustainable society, nature is not subject to systematically increasing…
(1) … concentrations of substances extracted from the Earth's crust,
(2) … concentrations of substances produced by society,
(3) … and degradation by physical means.
And, in that society,
(4) … people are not subject to conditions that systematically undermine their capacity to meet their needs' (Robèrt et al. 2006, xxv).

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).

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

Triple Bottom Line (PPP): This term refers to 'a situation where companies harmonize their efforts in order to be economically viable, environmentally sound and socially responsible.' (Elkington 1997, cited by van Marrewijk 2003, p. 103)

Upstream Solution: Generally refers to a solution focused on the source and origin of the problem, as opposed to the effects of it.

Acronyms

CFC: Chlorofluorocarbon

CO2: Carbon Dioxide

CRC: Carbon Reduction Commitment

CSR: Corporate Social Responsibility

DDT: Dichlorodiphenyltrichloroethane

DJSGI: Dow Jones Sustainability Group Index

EICC: Industry Code of Conduct

EMS: Environmental Management System

EPA: Environmental Protection Agency

GeSI: Global eSustainability Initiative

GHG: Greenhouse Gases

ICT: Information and Communication Technologies

IPCC: The Intergovernmental Panel on Climate Changes

IS: Information System

ISDT: Information Systems Design Theory

IT: Information Technology

LCM: Life Cycle Management

LCT: Life Cycle Thinking

PBB: Polybrominated Biphenyls

PBDE: Polybrominated Diphenyl Ethers

PCB: Polychlorinated Biphenyls

PCs: Personal Computers

PVC: Polyvinyl Chloride

RoHS: Reduction of Hazardous Substances

SPs: Sustainability Principles

SSD: Strategic Sustainable Development

VOCs: Volatile Organic Compounds

WEEE: Waste Electrical and Electronic Equipment

WSIS: World Summit on the Information Society

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. Following the motivation and justification for the study, the theoretical background and the research problem are discussed and then the purpose, the research questions, and the scope are provided. At the end of this chapter, the disposition of the study is outlined.

1.1. Motivation and Justification

Information and Communication Technologies (ICT) are increasingly recognized as the strongest change means humanity has to its disposal. It is well known that ICT have a profound effect on economy and environment. A large part of economic growth is attributed to and continuously fuelled by innovative ICT systems that are becoming an essential and strategic component of all economic sectors. In an environmental context, ICT have significant potential to enable new solutions to environmental challenges pertaining to resource depletion minimization, energy efficiency, emissions reduction, waste elimination, etc. 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 ongoing ICT improvements and innovations have several positive effects, such as dematerialization, digitization, e-substitution, virtualization, etc. Further, ICT can help to reduce the environmental footprint of what we do (Madden and Weißbrod 2008). Nevertheless, the performance improvements in ICT as well as their growth and increased use lead to increased consumption of ICT products and services, which has numerous environmental implications on different levels (Plepys 2002). 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, hazardous substances (Forge 2007), resource depletion, toxic waste generation, etc. ICT involve complicated assemblies that are designed to intensively consume energy, contain toxic and hazardous substances, and int end need to be disposed of. In addition, we rarely think about the large volumes of earth crust moved in manufacturing, the associated damage to biodiversity, and the huge amounts of energy required in the extraction and refinement process (Madden and Weißbrod 2008). ICT have a number of potential risks and uncertainties that we need to understand when placing high expectations on ICT (Plepys 2002). There are many dimensions to the relationship between ICT and the environment and there are complex connections among the positive benefits, negative impacts, and unintended consequences for the environment that flow from the design, use and disposal of ICT throughout the economy and society (MacLean and Arnaud 2008). Understanding the interdependence between the environmental, social, and economic systems will enable ICT firms to think strategically and act proactively through devising holistic, robust, and well informed design solutions to mitigate the negative ICT impacts.

To what extent ICT impacts progress towards an economy's environmental sustainability is still a matter for debate (Forge 2007). Global economy and society continue to allow unsustainable practices regarding the physical destruction of the ecosystem while allowing greenhouse gases (GHG) to disperse into the biosphere. GHG emissions are the main culprit for global warming that accelerates climate change. ICT impact on the climate change derives from the GHG emissions resulting from the intensive energy consumed all through ICT manufacture, use, and application. 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 paradigm. The threat of climate change exposes systematically increasing trends that escalate negative environmental effects, including the intensive use of unsustainable energy sources (i.e. fossil fuels) and the destruction of ecosystems for energy production. Additionally, the current unsustainable ICT design approaches encourage resource depletion from extraction and manufacturing; toxic waste disposal; and hazardous substances use.

Sustainable design is mostly a general reaction to global environmental crises, the rapid growth of economic activity, depletion of natural resources, damage to ecosystems and loss of biodiversity (Shu-Yang et al. 2004). The entire phenomenon of sustainable design is constantly growing and changing; practitioners are currently trying design sustainably and experiencing their ways of sustainable design (Llewellyn et al. 2005). Growing awareness of the global sustainability issues and challenges facing the planet is forcing us to devise upstream design solutions. Quick fixes to current problems have proven to be inadequate given the scale and acuteness of the looming environmental issues. Considering the huge impact of ICT upon modern society development, it is certainly of value to call to mind the timeliness of strategizing ICT design with sustainability in mind. Being an essential and strategic component of every industry sector, ICT must be treated as an environmental hazard factor, with new design criteria and measures (Forge 2007).

There is growing consensus that an understanding of the interdependence between the environmental and economic systems will enable ICT sector to mitigate the environmental impacts through sustainable design solutions. Corporate sustainability is a strategic model for adopting an overall environmental strategy encompassing design practices. ICT firms need to identify the materiality of key sustainability issues and prioritize the relative risks and opportunities. Just as in other sectors, the sustainability challenges facing ICT businesses are complex (Madden and Weißbrod 2008). However, the economic value of corporate sustainability strategies can be elusive and hard to pin down, since it only materializes in the long term (Salzmann et al. 2005). Nevertheless, neither can the green wave be ignored to be sweeping the world, nor can the environmental change to be a key factor when it comes to developing corporate strategies. Thus, ICT firms should understand and act upon the demands and concerns of stakeholders (i.e. consumers, communities, opinion leaders, investors, policymakers). The changing roles of ICT industry and the focus on sustainable development, rather than simply development, have meant that ICT design decisions need to be made with different stakeholders in mind to mitigate the harm to people through clean technology operating in safe environment. Overall, corporate sustainability is a strategic model and choice for ICT sector to respond to environmental issues, including those of current unsustainable design.

This study endeavours to investigate the negative environmental impacts of the prevailing ICT design approach and to explore some potential remedies for sustainability of ICT design looking at both environmental and corporate sustainability dimensions. The topic of this thesis is a significant research area that merits further focus as it has been a mainstream theme in the ICT and sustainability debate. There is increasing evidence that environmental threats of ICT design are involved, which deserves more research and attention, thus the motivation behind this thesis. This is an exciting area for investigation with many intriguing questions and substantial amount of multidisciplinary work awaiting future scholarly inquiry.

1.2. Theoretical Background

This section discusses key definitional issues covering the basic theoretical constructs that make up this research study, including ICT, design, and sustainability.

1.2.1. ICT

Information and Communication Technologies (ICT) is a generic term that is used to encompass all forms of technologies used to handle information (i.e. create, acquire, process, store, retrieve, transmit, exchange, disseminate) and to aid its communication in a digital format. ICT include technical devices (hardware) and related applications (software). ICT encompass computers, laptops, cellular phones, personal devices, telephone, television, broadcasting and wireless mobile telecommunications network systems, and so on. And the associated software services, such as e-commerce, e-learning, e-mail, e-communities (i.e. virtual team), videoconferencing, decision support system (DSS), enterprise resource planning (ERP) etc. ICT use spans over diverse areas, such as education, management, business, health care, scientific research, industry, communication, ecology, government, etc.

ICT is an umbrella term for information technology (IT) and communication technology (CT). Generally, CT refers to the activity of designing, constructing, and maintaining communication systems which are used to facilitate virtual communication between individuals or groups. It is commonly assumed that ICT is synonymous with IT; it is an umbrella term for the IT field. 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, including work, learning, and everyday life. 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)

In the broadest sense, the term information technology is often used to refer to all of computing which generically refers, according to the Association for Computing Machinery (ACM 2006), to 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 computer 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 with regard to the integration the infrastructure and architecture of systems and the management of their interaction with users through interfaces as well as with the external environment. 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 focus of IT use is to meet information needs of people and organizations over a wide spectrum and improve problem-solving endeavors pertaining to computing systems. This occurs through as well the design, development, use, implementation, application, and innovation of technological systems as theory about these systems and related processes. It is to note that IT can also be considered as an umbrella concept as it is quite large, covering many areas which include: installing applications; designing complex computer networks; information databases and software; data management; networking; engineering computer hardware; and the management and administration of entire systems (i.e. ERP, SOA).

1.2.2. 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. The term design in ICT is often used to indicate a broad set of activities in the product design and development processes. Generally, design refers to an inventive or creative problem solving process or activity aiming to produce artifacts to fulfill human, social, and organizational needs. It has become an intuitive concept used by many people to mean different acts (planning, conceiving, sketching, arranging, inventing etc.) depending on the context. Indeed, it 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) The genesis and purpose of design is to create and enhance utility and value of artifacts within their environment both functionally and aesthetically. From 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); and transformative.

Design is that area of experience and knowledge that is concerned with humankind's ability to shape and reshape the external environment to fulfill various needs. Design is born from the human mind and landed in the veracity of useful artifacts (i.e. laptop, mobile, computer application, hybrid car etc.). It is a process that combines creativity, pragmatism, vagueness, subjectivity and scientific knowledge to provide solutions to wicked problems spaces encountered by humans through their interaction with the external environment. Wolfgang (2001) classifies design as an attempt of seeking to categorize the fuzziness. This is manifest through bringing a learning approach to each problem space using creativity, intuitiveness, expediency and so on to achieve a solution. Conklin (2001, p. 15) states: 'any design problem is a problem of resolving tension between what is needed and what can be done'.

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). Indeed, design is not merely a noun, verb, or object; it is also a product, process, and tool for engaging people in the process of change, i.e. towards sustainable society. Bearing that in mind, one would wonder how enormous the benefits could be if the design could be informed and driven by holistic philosophies such as sustainability. It would definitely be appropriate and of great value to direct design endeavors towards creating holistic design human systems that entrench ecological sustainability considerations. Danko (2005) points out that design is unique in the arts because it is inherently proactive, synonymous with creative problem solving, and can directly impact the well-being of society. Rusts (2004) 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.' Moreover, design enables to envision and explore new scenarios, make effective use of creativity, and unfold tacit knowledge gained through years of practical experience. From a conceptually different angle, design can be conceived as a social system interacting with other social systems; its meaning is in the form of mediated communication which is necessary for its formation and continued existence (Wolfgang 2001).

1.2.3. Sustainability

Sustainability is a multifaceted, dialectical, and philosophical concept that can be over-whelming 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. There are multiple ways to define the concept of sustainability. Murcott (1997) listed 57 definitions; a current survey would construct dozens more pertaining to a variety of contexts. Sustainability generically refers to a characteristic or ability of a process that can be maintained or sustain itself indefinitely. '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 environmental sustainability in relation to ICT design. 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 deplete natural resources or harm natural cycles. Although not a focus of this paper, sustainability, in a social context, refers to maintaining 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. From an economic approach, sustainability means the amount of consumption that can be sustained indefinitely without degrading capital stocks, including natural capital stocks (Costanza and Wainger 1991).

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.

1.3. Problem Discussion

Scientific evidence shows that most ecosystem services on which we all rely for our very survival are currently being degraded or used unsustainably (Madden and Weißbrod 2008). The factors causing the biodiversity to be lost and earth's atmosphere to heat up are in continuous rise (IPCC 2007). The anthropogenic disturbance to natural systems is causing unequivocal 'warming of the planet' (ibid, p. 5) that accelerate climate change leading to many looming disasters (Mittelstaedt 2007; IPCC 2007). It is conspicuous that our current economic and societal development path is unsustainable, owing to the increase of human-induced environmental degradation and environmental thresholds being pushed in unprecedented ways. 'Human activity is putting such strain on the natural functions of the

Earth' (UNEP 2005). All these issues expose underlying flaws in the design of technological systems, especially ICT given their profound impact on economy and environment. The current unsustainable ICT design path poses a real issue regarding technological innovations, and if not taken seriously, it could worsen the world's problems. Researchers have recently observed that scientific assessments of the environmental impacts of ICT do not converge and suggested building more predictive design models to cope with these discrepancies (Lan and Hywel 2007). The current ICT design philosophy needs to entrench environmental considerations to reduce the negative impacts on the environment. The lifecycle environmental impact of ICT concerns not just GHG emissions but also the extraction and disposal of harmful materials (Plepys 2002). Key related environmental issues include: resource depletion caused by manufacturing and extraction; high energy consumption; toxic waste disposal; and hazardous chemicals use. However, climate change remains the most critical environmental ICT impact; it relates to GHG emissions – the culprit of global warming - driven by intensive consumption of unsustainable energy resources. Years of scientific study have led to consensus on the deleterious effects of GHG and the consequent need to radically reduce the carbon footprint of ICT industry and other sectors.

Toward seeking alternative solutions while recognizing that panaceas are unlikely to come to light, environmental sustainability can be a potential strategy for ICT industry to reduce negative impacts by entrenching environmental considerations into the design of technologies (ICT). Our sustainable existence on Earth increasingly means that our future ICT must be inherently sustainable in usage (Forge 2007). Further, Datschefski (2001) contends that sustainability can only be achieved through design. To this end, the focus should be given to greening ICT product design and development processes. Sustainable ICT design entails minimizing resource depletion through dematerialization; using most efficient energy required over life cycle in as well technology usage as in manufacturing processes; increasing the use of renewable energy that is cyclic and safe; ensuring recyclability, re-use, and responsible disposal; mitigating or eliminating toxic and hazardous chemicals. As an ideal approach, sustainable ICT design should be based on biological lines; strive to mimic natural design, patterns, and processes. The philosophy of this design approach is to design technological artifacts that are informed and improved by and comply with the principles of environmental sustainability. To achieve the goals of sustainable design, it is then required to adopt a holistic view and understand the accumulated scientific knowledge pairing ICT and environmental sustainability to create well-informed, robust, innovative, and upstream design solutions.

Furthermore, ICT firms need to identify the materiality of key sustainability issues and prioritize the relative risks and opportunities. Corporate sustainability trend can be a strategic path for ICT sector to respond to the environmental challenges. Through corporate sustainability, ICT sector can address environmental issues, thereby paving the way for reaching the goals of environmental sustainable ICT design. Salzmann et al. (2005) argue that corporate sustainability is a strategic corporate response to environmental issues caused through the organization's operations and activities. Aside from creating profit, sustainable (ICT) organization captures other qualitative criterion as references for their performance, such as environmental protection, social responsibility, and stakeholder relations, and human capital management (Lo and Sheu 2007). To work in accordance with sustainable practice is to automatically heighten auspiciousness in the very design of technologies. Overall, ICT design strategy should entail a solid assessment of environmental factors as well as stakeholders' needs. If ICT could be designed in a sustainable way, the rewards and benefits could be enormous both environmentally and economically.

1.4. Research Purpose

The purpose of this study is to investigate the negative environmental impacts of the prevailing ICT design approach and to explore some potential remedies for unsustainability of ICT design from environmental and corporate sustainability perspectives. In this regard, the author aims to spotlight key environmental issues pertaining to resource depletion; GHG emissions resulting from intensive energy consumption; toxic waste disposal; and hazardous chemicals' use; and also to shed light on how alternative design solutions can be devised based on environmental sustainability principles to achieve the goals of sustainable technologies. Addressing this topic is an attempt to highlight the downside of ICT given the acuteness of the environmental looming global crisis. This study moreover highlights the relationship between ICT design and sustainability and how they can symbiotically affect one another. Overall, the ultimate goal of this study is to add to the body of knowledge and contribute to the previous research endeavours in ICT and sustainability, and, more importantly, present a journeying departure for further empirical and theoretical research and development.

1.5. Research Questions

To achieve the objective of this thesis, the author attempts to answer the following questions:

1. What are the negative environmental impacts of the current mainstream ICT design approach?
2. What are the potential remedies for ICT design unsustainability?

1.6. Scope

The scope of this research work is too broad as it deals with two sweeping areas: ICT design and environmental sustainability. The author limited the research to view the above stated research questions focusing mainly on key direct and indirect environmental effects. Systemic effects were briefly looked upon though. It is moreover to note that technical specifications regarding ICT product design and development are beyond the scope of this thesis. Additionally, this study is concerned with all sectors of ICT industry (hardware, software, and services) for they are all involved in unsustainability of ICT design. Reducing the scope was an iterative process through the author gaining a better knowledge of the problem and gauging what could reasonably be achievable within the timeframe provided.

1.7. Disposition of the Study

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

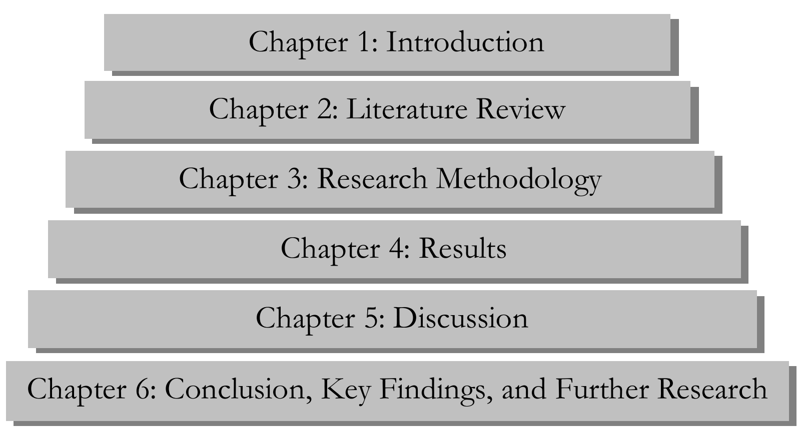

Figure 1.1 Outline of the study

The first chapter, which has already been presented, provides an introduction to the research study. More specifically, it covers: the motivation and justification; theoretical background; problem discussion; purpose; research questions; and finally the disposition of the study. The second chapter delves into the theoretical literature relating to the research study, including: design issues; design science and ICT design; design research framework for ICT; sustainability; corporate sustainability; and, as a final point, design and sustainability. This chapter thus gives background information required for the understanding of the entire research study. The third chapter discusses and motivates the chosen methodology. The fourth chapter analyzes, synthesizes, and evaluates results garnered from earlier and contemporary theoretical and empirical studies in accordance with the research questions. The fifth chapter discusses the results and findings. The sixth and 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. It 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 discuss and justify the chosen research methodology. It covers the following: research approach; literature review method and its 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 thesis, the literature review research method was used to collect information. The process entailed background research (identification and comprehension) followed by data analysis, synthesis, and evaluation. The results gathered from the literature involved a variety of sources to survey the environmental problems of current unsustainable ICT design approaches and the related potential remedies. Sources included empirical, theoretical, and critical/analytic studies. According to Cooper (1988), the types of scholarship found in literature material may be empirical, theoretical, critical/analytic, or methodological in nature. These studies drawn form the literature were projected to inform the research process by providing theoretical, statistical, descriptive (or interpretive) information. Explicitly, they provided connections and contradictions between different research results; definitional implications; 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 inform about and answer the research questions.

2.2. Literature Review Method

Literature review is a crucial endeavor for any academic research (Webster and Watson 2002). This research method 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 analysis and synthesis of quality literature enables to develop a solid foundation for a research study

(Barnes 2005; Webster and Watson 2002). Building a solid theoretical foundation based on quality resources enables researchers to 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'. The aim of the literature review is to find out and unfold what is previously known about the intended research topic. 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.' 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. 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). On the whole, the literature review remains the preferred method for data gathering as it is assumed, given the scope and the multidimensional nature of this study, to be an efficient way to frame the researcher 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 and environmental sustainability from a design perspective. This research method was carried out not only to provide a valuable insight into how others may have approached the subject area of ICT design and sustainability, but it 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 current study. Aitchson (1998) supports the view that the literature review research 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 the research'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 investigation (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 books, reports, theses, 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; books; abstracts; and personal communications (in this case, dialogue with and letters from 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 the topic of this study. They include:

- Design issues
- Design science
- Design Research Framework for ICT
- Sustainability
- Corporate sustainability
- Design and Sustainability

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

- ICT and sustainable development
- ICT and sustainability
- ICT and Climate Change
- Green ICT
- Environmental impacts of ICT
- Unsustainable ICT
- Corporate sustainability in ICT sector

2.6. Organizational Framework

Generally there are various ways of organizing or 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 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, 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 a given topic, progression of time was an important factor in the process.

2.7. Data Analysis, Synthesis, and Evaluation

Analysis, synthesis, and evaluation of information (results) are all critical phases in the literature review process. Yair and Timothy (2006) point out that the essence of analysis entails identifying why the information being presented is of importance; that 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 research questions in an attempt to demonstrate how they supported and extended the topic in the area of ICT design and environmental sustainability. In doing so, the author provided a critique of the research through voicing his perspective and position after gaining understanding and insight into the topic at hand. Leedy (1997) notes the more knowledgeable you get, the better you will be able to understand your problem. 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 an important issue for any study for it brings out 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: 'quality means appropriate breadth and depth, rigor and consistency, clarity and brevity, and effective analysis and synthesis.' 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, design quality, 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 design and related environmental sustainability issues. This was intended, apart from gaining further knowledge, to feed critical perspective into the study. As far as the information is concerned, that 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: evidence gathered is clear and comprehensible

C H A P T E R   T H R E E

L I T E R A T U R E   R E V I E W

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

2. Literature Review

The aim of this chapter is to establish a theoretical foundation for the proposed study. The author reviews earlier and contemporary theories and studies concerning the research questions. The theoretical elements covered in this chapter include: design issues; design science and ICT design; design research framework for ICT; sustainability; corporate sustainability; and design and sustainability. After discussing key definitional issues in those domains, the author examines the scholarly literature proceeding from the discussion of the related literature from a broad perspective, and then deals with more and more specific studies that focus on the topic under investigation, following the inverted pyramid organizational framework for structuring the literature review. To begin with, design issues are addressed.

3.1. Design Issues

3.1.1. Definitional Issues

The scholarly literature on design is as diverse as the wide range of approaches to conceptualizing design in different kinds of disciplines. 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 very different kinds of design activities, including disciplines, such as 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 (i.e. see Wolfgang 2001). Although much has been written about design research, practice and education, and even with a seemingly endless and ever-burgeoning discourse on 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). 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 complicating the matter depicts that looking for an ideal definition may not help to grasp or precisely describe what design is, not to mention classify it as a science. However, Rusts (2004) points out that the ability of designers to create a practical environment for us to experience them by producing experimental artifacts is a valuable aid for scientists who want to identify ideas that merit investigation.

Rather, design can be considered as a combination of many elements intertwined together to insinuate that design merely is but a concept of another kind. The fundamental nature of design cannot be rendered to a logical framework or to an ordinary definitional concept. It defines itself beyond the epistemology of a definition so t can't simply be characterized by the epistemological boundaries of any construct. Further, Glynn, (1985) 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.' Design involves creativity, intuitiveness, vagueness, subjectivity, scientific knowledge, etc. Perhaps, a definitional endeavor could be to frame it within what a designer intends to create or solve and for what purpose, and what method can be used in a given design process. These elements can help make up the constructs to the specific form of design, yet not design in its broad perspective. Thus, design can be approached from different perspectives depending on the context and related variables. It remains very intricate to have an all-embracing single interpretive or definitional outcome. From a philosophical perspective, design theorists 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. Among the key views on the classification of design is that design problems are of two kinds, structured and ill-structured.

3.1.2. Structured and Ill-structured Design Problems and ICT Design

Design is synonymous with problem solving or a creative process applied to problem-solving artifacts and interactions within an environment. In the domain of problem solving (design), there are two types of problems to be distinguished: well-structured (rational) and ill-structured.

According to King and Kitchener (1994), a well-structured problem yields a right answer or one solution through the application of a certain logic or appropriate algorithm. A well-structured problem is more often encountered in disciplines, such as mathematics, applied science, engineering, or business administration (Ibid). In contrast, an ill-structured (wicked) problem doesn't yield a certain answer or one solution; it indeed mirrors real world situations where data are conflicting or inclusive, where disputants disagree about appropriate assumptions or theories, thus it is required to claim or justify the proposed arguments (Ibid). In ill-structured or wicked problems, there is thus no one solution to a given design problem and each set of solutions contains strengths and weaknesses. According to Rittel and Webber (1973), wicked problems are extremely difficult to define or formulate correct solutions to due to the chaotic nature of multiple relationships of cause and effect. The rational problem-solving paradigm was first introduced by Simon (1981), which is based on the conceptual framework that is still a dominant paradigm in the field of design models and methods developed within that paradigm. Critics have been raised on Simon's problem-solving approach and its applicability to the field of design as many of the original statements in this problem-solving theory dealing with design have been qualified and refined (Dorst 2006). That said the design process is rather a dynamic and scientific process utilized by designers to devise solutions to wicked problems through research, conceptualization, testing, validation, application, and improvement as well as through creativity and intuitiveness. Although the rational problem-solving paradigm has become a powerful tool for the modeling of design, inspiring and permeating a large part of design methodology, there are still some fundamental weaknesses and shortcomings in the conceptual framework that are an integral part of the problem-solving inheritance that they cannot easily be solved from within the rational problem-solving paradigm (Dorst 2006). Hatchuel (2002) claims that any design model that tries to reduce design to rational problem solving is bound to miss important aspects of the design activity.

ICT are systems whose design considers a wide variety of aspects, including technical, environmental, social, cultural, 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 - it is difficult to define its related problems at a certain point of time (a variety of experiences in project design have proved this fact). ICT are to be designed to fulfill human, social, and organizational needs expressed by different users in different contexts. This complexity inherent in functionality and aesthetics specifications expressed by users may raise issues in the design processes, owing to the design approach being espoused by a designer, whether designer-centric, user-centered; participatory, multi-stakeholder, or integrated design methods. 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 resource depletion, intensive energy consumption, GHG emissions, toxic waste, hazardous chemicals, etc. ICT design should consider and take in input from environmental systems in which both the designer and the user exist through a dynamic interaction. Designing ICT should act upon the external world, continuous learning, and problem redefinition. It is a process of multiple steps; hence a one-off decision making situation is irrelevant as new interpretations evolve and new considerations (i.e. environmental) emerge to add up to the problem solving process. In this multistep problem-solving process, the designer gets the chance to pile interpretation upon interpretation, and thus end up taking this process in completely different directions (Dorst 2006).

3.2. Design Science and ICT Design

Many attempts have been undertaken to scientize design. Accordingly, some design theorists have endeavored to provide definitions as to the fields whereby scientific (systematic methodologies) are applied like in engineering and applied sciences. It is notable that ICT design draws from both 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 and laws and rules of design and its activities (Hansen 1974), which implies that the procedures and processes of designing are organized in a systematic way – systematic design (Cross 2001). However, Hubka and Eder (1987, cited by Cross 2001, p. 3) viewed this as a narrower interpretation of design science than their own: 'design science comprises a collection (a system) of logically connected knowledge in the area of design, and contains concepts of technical information and of design methodology...Design science addresses the problem of determining and categorizing all regular phenomena of the systems to be designed, and of the design process. Design science is also concerned with deriving from the applied knowledge of the natural sciences 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 scientific/technological underpinnings of design of artifacts, and thus it 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). Nevertheless, most opinion among design methodologists and designers holds that the act of designing itself is not and will not ever be a scientific activity, which means that 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, realism and applicability of the natural science theories through the usability of scientific-based designed artifacts. ICT research and development relies on and is the manifest of applied science. Thus ICT design comes from design science as it relies on the application of scientific knowledge and methodologies. Engineering (application of scientific methodologies and analytical strategy) is applied to the design of technologies (i.e. ICT). Simon (1969, p. 253) states: 'rather than producing general theoretical knowledge, design scientists produce and apply knowledge of tasks or situations in order to create effective artifacts.'

3.2.1. Distinction between Design Science and Natural Science

Design science centers on 'devising artifacts to attain goals' (Simon 1981, p. 133). The concern is how effective and useful the artifacts can be. On the other hand, natural science is more concerned with explaining how and why things are. While natural science tries to understand reality and seek the truth, design science endeavors to create artifacts and increase value and utility to serve human needs. March and Smith (1995) point out that design scientists produce and apply knowledge of tasks to create effective artifacts rather than produce general theoretical knowledge as natural science does. Scientists can investigate the activities of artificial phenomena and artifacts created by design science the same as they do for natural phenomena. Design science is technology oriented and uses the knowledge available from natural science to develop the technology. And natural scientists create knowledge which design scientists can exploit in their attempts to develop technology (Ibid). Design science activities include building and evaluating and its outputs consist of four types: constructs, models, methods, and instantiations; they are based on usefulness for the task or situation for which a related solution might be proposed (Ibid). Generally, the ultimate products of natural science research are theories in the form of specialized language of concepts and models used to describe phenomena. Hence the aim is to develop sets of concepts to characterize phenomena, and these concepts are used in higher order constructions - laws, models, and theories - that make claims about the nature of reality (Ibid). Then, natural science differs in perspective from design science since it focuses more on seeking the truth rather than utility to fulfill urgent human needs.

There is a 'prestige attached to science in modern societies and the belief that the term "science" should be reserved for research that produces theoretical knowledge.' (Ibid, p. 252) The research in natural science seeks to understand reality and nature of phenomena. Nevertheless, partiality and sample selectivity in scientific research remains a contentious issue in the process of proving or disapproving theories or hypotheses. Research methodologies prescribe appropriate ways to gather and analyze evidence to prove or disapprove a posited theory (Jenkins 1985; Lee 1989). Moreover, the resulting knowledge in natural science isn't infallible because scientists are aware that there is no definitive truth as the pursuit for it seems to never end. Besides, our human perceptual experience is too limited to fully comprehend what is larger than us. The only truth in natural science is that there is no definite truth; it does not currently and probably never will give statements of absolute eternal truth. In general terms, theories are to be conceptualized, interpreted, tested, validated, applied, and refined, and some may even completely be discarded in favor of theories that emerge in light of alternative data generated or discovered by future scientists. In the words of Karl Popper (1968), science is a history of corrected errors.

Discovery and verification of phenomena in natural science is done through respectively induction and deduction approaches. Discovery is the process of generating or proposing scientific claims (i.e. theories, laws) and justification includes activities by which such claims are tested for validity (March and Smith 1995). This hypothetic-deductive method is widely used in scientific study. According to Bechtel (1988), theories can be tested insofar as observational hypotheses can be deduced from them and compared to relevant empirical data. Thus, explaining how or why an artifact works by natural science that uses hypothetic-deductive method may lag years behind the application of the artifact (Ibid). The fact is that natural science is driven by different research objectives and tends to diversify the means for achieving a certain goal. Adding to this is its special characteristics: objectivity, rationality, consciousness, repeatability, and rigorous undertaking. They are intended to produce models of reality while design science aims at increasing value and utility. Nonetheless, philosophical pragmatists deny the correspondence notion of truth, proposing that truth essentially is what works in practice (Rorty 1982). Consistent with that, the justification of natural science claims is overcome in part by the effectiveness of theories in practical applications (Leplin 1984) and theories are intended to correspond with a true account of reality as well as receive confirmatory support from the facts (March and Smith 1995). Nevertheless, natural scientists can always create knowledge which design science can use to develop technology employed to construct artifacts for context relevant human purposes. Design science thus provides substantive tests of the claims of natural science research (Ibid). Overall, natural science is descriptive in intent as it aims at understanding and explaining phenomena while design science offers prescriptions and creates artifacts that embody those prescriptions as it aims at developing ways to achieve human goals (ibid).

3.2.2. Design Science Research: Theory

Design research is generally concerned with investigating the design process in all fields; it seeks to provide theoretical and applied methodologies to the application of design. In this section, the intent is to discuss design research from theoretical perspective. Theorizing and theory building occur before, during, throughout, at the end and as a result of design science research (Venable 2006). Design science research is, according to Havner et al. (2004), informed both by existing theory and human needs. Theories are proposed by someone, analyzed, validated or refuted, and adopted over time by many; they may indeed be modified many times during a single design science research project (Venable 2006). Still, design theorists should embrace the need for theory and develop a way to make theory work for design science (Ibid). Nevertheless, Gregor (forthcoming) argues that design theorists need a language of their own to talk about theory and should not adopt uncritically ideas about what constitutes theory from any one other disciplinary area. To this line of thought, March and Smith (1995) add that theory is not part of design science; it is 'deep, principled explanations of phenomena' (p. 253), which is developed by natural science. They contend that design artifacts are evaluated for their situated utility in design science, explaining that utility through theorizing and justification remains the province of natural science. Havner et al. (2004) argue, describing the duality of design science and natural science, that 'truth (justified theory) and utility (artifacts that are effective) are two sides of the same coin and that scientific research should be evaluated in light of its practical implications' (p. 77). March and Smith (1995) make the clearest argument that design science does not need to generate or test theories asserting that that knowledge can be in the form of constructs, models, methods, and instantiations. In an attempt to provide more clarity and contrast, design science research 'addresses important unsolved problems in unique or innovative ways or solved problems in more effective or efficient ways' (Ibid, p. 81) as opposed to routine design, which 'is the application of existing knowledge to organizational problems.'

Walls et al (1992) directly addressed the role of theory and theorizing in design science research. They suggest that an Information Systems Design Theory (ISDT) should 'be a prescriptive theory which integrates normative and descriptive theories into design paths intended to produce more effective information systems.' (p. 36). According to Walls et al. (1992, pp. 40-41) there are seven characteristics that distinguish design theories:

'1. Design theories must deal with goals as contingencies. …

2. A design theory can never involve pure explanation or prediction. …

3. Design theories are prescriptive. …

4. Design theories are composite theories which encompass kernel theories from natural science, social science and mathematics. …

5. While explanatory theories tell 'what is', predictive theories tell 'what will be', and normative theories tell 'what should be', design theories tell 'how to/because.' …

6. Design theories show how explanatory, predictive, or normative theories can be put to practical use. …

7. Design theories are theories of procedural rationality.'

3.3. Design Research Framework for ICT

Design draws upon continuous research frameworks to create new knowledge and advance understanding toward enhancing design activities and approaches to create innovative solutions aiming to improve performance and increase utility of technological artifacts.

3.3.1. The Two Dimensional Framework

In 1995, March and Smith developed a two dimensional framework for design research in IT. This framework can also be applied to ICT due to the fact that ICT is an umbrella term for the field of IT and usually assumed to be synonymous with IT as highlighted in the introduction section. Throughout this section, the term IT is referred to as ICT. This framework is driven by the distinction between research artifacts and activities. The two dimensions of this framework are respectively based on design science research outputs (representational constructs, models, methods, and instantiations) and on broad types of design science and natural science research activities (build, evaluate, theorize, and justify). Both design science and natural science activities are needed for relevance and effectiveness of ICT research (Ibid). The core idea behind merging design science and natural science in this research framework stems from the fact that ICT should include knowledge of understanding the nature of ICT artifacts and that of improving their performance within the environment where they operate. However, the credibility of any scientific conclusion of the applicability of this framework can be measured by the extent to which we make its conditioned character clear to all concerned stakeholders.

Design tasks are to be critically performed and stem from reflective practice supported by heuristics - critical system heuristics - when considering facts and values upon which designers justify their claims and assumptions. In line with that, Smith and March (1995) point out that problems must be properly conceptualized and represented; appropriate techniques for their solution must be constructed; and solutions must be implemented and critically evaluated using appropriate criteria. It is of import to develop an understanding of how and why ICT (artifacts) work or do not work. In this perspective, research frameworks need to amalgamate natural laws governing these systems with those governing the environments in which they operate. This scientific framework was developed for ICT research due to the scientific attractiveness of ICT and its potential for dramatically impacting organizational effectiveness both positively and negatively, as well as to the pervasiveness of its phenomena in information society (Ibid). There are two kinds of scientific interest in ICT, descriptive and prescriptive. Descriptive research aims at understanding the nature of ICT. According to Hempel (1966), descriptive research involves knowledge-producing activity corresponding to natural science, while prescriptive research aims at improving ICT performance; it is, as Simon (1981) claimed, a knowledge-using activity corresponding to design science. The overall intent of this framework is to combine the scientific design method and the hypothetic-deductive upon which the natural science study is based.

3.3.2. Framework Application and its Applicability Spectrum

The framework is comprised of 16 cells as illustrated in table 3.1. Different cells have different aims and different methods are accordingly appropriate in different cells (March and Smith 1995). More often, research efforts cover multiple cells depending on what aspects the researcher wants to address in the research project. Thus, the researcher would have to tailor the framework's cells to respond to the requirement and goals of the study/project or just cover all cells for inclusive applicability. The application of this method aims at providing scientific base in dealing with research area of ICT.

	Build	Evaluate	Theorize	Justify
Constructs				
Model				
Method				
Instantiation				

Figure 3.1 Research framework

Source: March and Smith 1995

It is to note that this framework was originally developed to be applied to IT research area where the artifacts of constructs, models, methods, and instantiations can be built, evaluated, and theorized about. But its applicability tends to be wider than what it was originally developed for. It is built on scientific ground from design and technology perspectives; hence it can be applied to design research in almost all fields concerned with technology (i.e. ICT), and even beyond IT domain such as hybrid cars. It is certainly a broad research framework that can be applied to different kinds of artifacts; especially where design plays a pivotal role in the construction of the artifact. Also, it can be used both as a categorization and evaluation framework. It aims at explicating and evaluating technologies and its related outputs which facilitate their categorization so that research efforts will not be wasted building and studying artifacts that have already been built and studied (March and Smith 1995).

3.3.3. Design Research Framework and Environmental Sustainability

Earlier research frameworks in IT have focused on specific research subjects, identifying sets of variables to be studied (Ives et al. 1980; Gorry and Scott-Morten 1971; Mason and Mitroff 1973). Such frameworks were associated with several weaknesses, including failure to account for the large body of design science research being done in the field; to recognize that IT research is concerned with artificial phenomena operating for a purpose within an environment; and to recognize the adaptive nature of artificial phenomena that is subject to change, even over the duration of the research study (March and Smith 1995). Weber (1987) recognizes that IT research is the study of artifacts as they are adapted to changes in their underlying components and to the changing environments where they operate. Arguably, an effective research framework for sustainable ICT involves both design and natural sciences that ought to be informed by sustainability. Sustainable ICT design research is concerned with both utility - environmental quality - and with truth - the cycles of nature, the conservation of matter, and the laws of thermodynamics. March and Smith (1995) assert that fitting framework for IT research lies in the interaction of design and natural sciences. This framework is driven by the distinction between research outputs and activities.

3.3.3.1. Research Outputs

As previously mentioned, design science involves four research outputs: constructs, models, methods, and instantiations.

3.3.3.1.1. Constructs

Constructs are concepts that form the vocabulary (specialized language and shared knowledge) of a domain and constitute a conceptualization used to describe problems within the domain and to specify their solutions (March and Smith 1995). Commonly, conceptualization is critical and valuable to both designers and researchers. However, the over complexity and formalism associated with it may prevent them from seeing the holistic system view. This counters the philosophy behind sustainability and sustainable practice in design. Thus, conceptualization can influence the course and the outcome of the design or research study and eventually the performance and usefulness of the artifact in relation to environmental sustainability factor. Conceptualizations can blind researchers and practitioners to critical issues (Ibid).

3.3.3.1.2. Models

A model generally refers to a set of statements expressing relationships among constructs (concepts) or representation of situations as problem and solution statements. It aims at describing and representing how things are (Ibid). The term model is often used in natural science as a synonym for theory, or proposes models as incipient theories, in that they propose that phenomena be understood in terms of certain concepts and relationships among them (Ibid). In this research framework, the concern of models is utility and not truth (Ibid). Models can be conceptualized in a way that they may deliberately ignore other details when tackling complex natural or artificial phenomena that might involve chaotic unpredictable patterns in their interaction with the hosting environment. This is clear, for instance, if we take a closer look at how the technological artifacts are modeled in terms of environmental considerations. Models tend to overlook ecological considerations when it comes to ICT design. This is manifest in the fact that current mainstream ICT design approach has negative impacts on the environment (including resource depletion, energy intensity, GHG emissions, toxic waste, hazardous chemicals etc.). Usually, inaccuracies and intricate abstractions are expected to emerge in conceptual modeling. A model may need to capture the real world situation in order to be useful (Ibid). It is indeed necessary to have contextual understanding of facts and values as well as awareness of different abstractions when modeling so the ICT designers can shun or reduce the consequences of potential externalities. They should continue to work on the resulting inaccuracies while attempting simultaneously to have a holistic system view.

3.3.3.1.3. Methods

A method is a set of steps used to perform a particular task and is driven by the conceptualization and models built and evaluated to create the artifact. Methods are based on a set of underlying constructs and a representation of the solution space (Nolan 1973). Like models in design, methods may blind the ICT designers of seeing contexts beyond the reference systems to which they are bounded, which eventually lead to adverse consequences for their actions. This is when these actions are not informed or aware of other contexts, such as environmental, social, cultural, cognitive, sense of value, ethical, etc. ICT designers should be aware of these contexts in order to create well informed and sustainable design solutions. Side effects associated with designed artifacts usually result from partial or incomplete understanding of the environment where the systems operate. There is an issue associated with the formalization and over complexity of methods that may obstruct the ICT designers to think holistically as they get biased by the adherence of the appropriate application of the method and the achievement of the goals of the system as defined in the reference frame. Further, the desire or partial need to utilize or select a certain type of method can influence the constructs and models developed for a design task. (March and Smith 1995)

3.3.3.1.3. Instantiations

An instantiation is concerned with the implementation of technological artifacts (ICT) in its operating environment. It involves the realization and operationalization of constructs, models, and methods. There are indicators and metrics developed in each area for monitoring and measuring the progress and effectiveness of constructs, models and methods built for a particular domain. Instantiations demonstrate the feasibility and effectiveness of the models and methods they contain and provide working artifacts, the study of which can lead to significant advancements in both design and natural science (March and Smith 1995). An instantiation may actually precede the complete articulation of its underlying constructs, models, and methods (Ibid). In some situations driven by necessity, technological artifacts are instantiated before conceptualized, modeled and methodized. A nice articulation of instantiation was done by Newell and Simon (1972) who described computer science as an empirical discipline and further stated that each new program that is built is an experiment; it poses a question to nature, and its behavior offers clues to the answer. For example, the instantiation of ICT has posed many questions to nature pertaining to environmental impacts of technologies. The behavior of technologies (through energy consumption and GHG emissions) has negatively affected the environment and created serious problems. This is because the design of ICT has overlooked the ecological dimension, which led to such behaviors during the instantiation phase of technological artifacts. Environmental sustainability is aimed to be incorporated into design processes, decisions, and solutions in an attempt to promote sustainable practices that help preserve environmental quality. It is useful to design technologies (human systems) that maintain the potential evolutionary quality of the ecosphere and don't compromise its ability to support all life forms and combinations. According to Walker and Salt (2006) and Princen

(2005), design systems should stress adaptability; efficiency; harmony; regeneration; resiliency; and sufficiency; and ultimately mimic natural patterns, processes, designs, and rhythms.

3.3.3.2. Research Activities

As previously mentioned, design science consists of two basic research activities, build and evaluate. Building is the process of creating or constructing an artifact for a specific purpose while evaluation is the process of assessing the effectiveness and performance of the artifact in its operating environment. Research activities in natural science are known as discover and justify. Generally, discover refers to the construction of theories that explain how or why things happen; and justify refers to validation of theory through using appropriate ways of gathering and analyzing evidence to prove or disprove a posited theory.

3.3.3.2.1. Build and Evaluate (Design Science)

According to March and Smith (1995), we build constructs, models, methods, and instantiations as technology that once built, must be evaluated scientifically. The building activity should be judged based on value and utility. Building sustainable technologies can have enormous environment benefits. Indeed, scientific evidence shows that this has theoretically and empirically demonstrated feasibility. The research study of building sustainable technologies is to mitigate the harm to the environment and people through minimizing resource depletion, reducing GHG emissions, eliminating waste, and limiting hazardous chemicals. Given the negative impacts of ICT, the building activity may not be well grasped by the designer, owing to the lack of holistic view in the design and construction of ICT artifacts. Evaluation tends to demonstrate how the artifacts perform in their operating environment by using metrics or assessment criteria that are usually developed for measurement purposes. Metrics define what we attempt to accomplish and are used to assess the performance of an artifact; hence lack of metrics and failure to measure artifact performance according to established criteria result in an inability to effectively judge research efforts (Ibid). Metrics are to be scrutinized and contextually understood in a way that all related claims should be questioned and based on argumentative and reflective ground. Tarjan (1987) asserts that metrics themselves must be scrutinized by experimental analysis. Evaluation can be a complicated activity and may lack holistic system view. In current mainstream ICT design approach, evaluation is concerned with the performance and effectiveness, which is mostly related to the intended use of artifacts but overlooks environmental externalities associated with resource depletion, energy consumption, toxic waste, and hazardous substances. Further, only the intended use of an artifact can cover a range of tasks (March and Smith 1995). Therefore, ICT designers may not paint a wide-ranging picture in the phase of problem analysis and definition since the designers' claims and assumptions are more often driven by a given reference system. Design claims are not usually questioned and challenged, rather framed within the relevance and validity of system of concern - the intended use of the artifact. From sustainability perspective, there are some metrics and indicators that are developed and implemented to assess environmental state in an effort to assure and support the transition into sustainable design. These indicators can be used in the evaluation activity of design science to support and build sustainable technologies. They include: indices of GHG emissions, energy efficiency metrics, Cleaner Product, Zero Emission, Zero Waste etc. Sustainable technologies minimize natural resources depletion, support de-carbonization, are recyclability oriented and eco-friendly low or non-noxious, etc.

3.3.3.2.2. Theorize and Justify (Natural Science)

After the building and evaluation of the performance of an artifact, comes the phase of explaining why and how it works or doesn't within its operating environment. Theorizing about constructs, models, methods, and instantiations and then justifying theories about those artifacts is what this research framework intends to perform in IT research. March and Smith (1995) argue that design artifacts are evaluated for their situated utility in design science, explaining that utility through theorizing and justification remains the province of natural science. Further, theories explicate the characteristics of the artifact and its interaction with the environment as reflected by the observed performance, which requires an understanding of the natural laws governing the artifact and those governing the environment where it operates (Ibid). The theorizing activity attempts to unify the known data (observations of effects) into viable theory (Ibid). If artifacts are not mathematically and logically represented, justification may be a daunting task as it might not be adequate to only follow the scientific methodologies governing data analysis. However, formal (systematic and mathematical) theories are proven only within their defined formalism, thus they must be tested in practice to validate that formalism (Ibid). Overall, the justify activity performs empirical research to test the theories posed and once justified, can provide direction for the development of additional technologies (Ibid), i.e. sustainable technologies.

Speaking of sustainable technologies, sustainability has been solidified into a defined science, which is to articulate it with methodological and scientific rigor so to be intelligible, clear and useful for analyzing and managing human activities, particularly design activity that is responsible for the design of all human systems. A significant contribution in this line was a development of a set of four guiding sustainability principles. These principles were determined through a peer-reviewed process of scientific consensus (Holmberg et al. 1996; Holmberg and Robèrt 2000). Given the scientific ground of sustainability as to how to avoid the destruction of the biosphere (Holmberg et al. 2000; Robèrt et al. 2002; Ny et al. 2006) through understanding the cycles of nature, the conservation of matter, and the laws of thermodynamics, it is highly important to incorporate them in the activity of theorizing related to this research framework for ICT. Theories relating to environmental sustainability have been scientifically justified and thoroughly tested by credible institutions and research centers. Then, embracing sustainability to restore and preserve the environment has become a must in all human activities, especially design. It can therefore be of great value if those theories are included in this research framework for ICT to inform the application of natural science activities – theorize and justify - along with those of design science - build and evaluate. This is to imbue the established sustainability knowledge in ICT design activity in order to sustainably build and evaluate technological systems - ICT.

3.4. Sustainability

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.

3.4.1. The Four Sustainability Principles (SPs)

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.

(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.

3.4.2. Implications of Sustainability Principles

The four sustainability principles are aimed to be incorporated into decision-making, strategies, processes, activities, systems, and policies etc. as an attempt 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, ingenuity, and humanity.

3.4.3. Strategic Sustainability

Sustainable development is an approach and a vision 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 ecological 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 and societal problems and mitigating the negative impact of the current path of our development. This path is inflicting serious environmental issues, including rapid resources depletion, global warming, pollution, and environment degradation. As an alternative approach, SSD seeks to guide and help individuals, organizations, governments, institutions, etc. to agree upon concrete ways to take action together to implement sustainable development on a global scale.

3.4.4. Operational Sustainability

Generally, operational sustainability involves living within the carrying capacity of the planet through creating patterns of using ecosystems and its resources within the material and systemic limits of the planet. To survive on the planet humans must live within its measurable biophysical constraints - carrying capacity (Costanza 2000). There is now clear scientific evidence that humanity is living unsustainably on planet Earth, and that an unprecedented effort is needed to return natural resources use to within sustainable limits. It is necessary to forge new patterns and create new measures to monitor and manage these limits as to using natural resources for sustaining life on Earth. As Porritt (1984) puts it in more vatic style, we must rethink the links between ourselves and the Earth, and the way the Earth exists for us through an ideal of life. 'Perhaps the root idea of environmental concern is that modern humans should find ways of consciously *living with the grain of nature.'* (Foster 2001) The premise of going with the grain rests on the fact that if the reach of human life into the future is held in line with the self-directedness of regenerative growth and change found across the biosphere, the Earth is perhaps speaking to us acceptingly in the only way it can (Ibid).

However, our lifestyle and development pattern is increasingly placing pressure on natural systems. Orr (2004) suggests that the better sense making is to reshape ourselves to fit a finite planet than to attempt to reshape the planet to fit our infinite wants. This calls for rethinking economic and societal models in a way to promote conservation of rather than dominance over nature. The ultimate goal of sustainability model is to enhance living without increasing the use of resources (i.e. material, energy) beyond globally sustainable levels. This model has proved influential, effective and useful, despite or perhaps even because of the several approaches to the key concept which have been canvassed as cogently reviewed by Jacobs (1999). However, these approaches correlate in a sense that there is the baseline criterion that some quantum representing the human demand on natural regeneration remains constant over time; and at its most general this quantum is expressed as the total carrying capacity of the planet's natural systems (Foster 2001). Considering sustainability as the conservation of any kind of quantum, its fundamental ground is the continued creative deployment by human beings of their central skills and knowledge in life-intelligent sense making (Ibid). Stables and Scott (1999) argue that our actions are congruent with environmental sustainability as we are learning to understand it. We should gauge what we can have from nature and ensure the replenishment of resources to renew the biosphere and preserve the environment through strategic actions and astute decisions. Living sustainably is about living within the means of our natural systems and ensuring that economic development doesn't harm other stakeholders. It is clear why a model with these structural dimensions and management should be so hospitable to international bodies, governments, and policy makers who have to normalize their responses within a world increasingly seen as a unity (Foster 2001).

There are strategies developed and implemented to operationalize sustainability, in addition to a wide range of indicators designed to monitor, measure, and assess environmental and social (human welfare and well-being) state in an effort to assure and support the transition into sustainable development. Examples of indicators include environmental and social measures separately or together over many scales and contexts: Zero Emission, Zero Waste (cradle to cradle), indices of GHG emissions per GDP, Environmental Management System (EMS), Cleaner Product, Life Cycle Management (LCM), Life Cycle Thinking, Happy Planet Index, and the Local Agenda 21 indicator packages: measures of the extent to which human needs are met, community contributions, and trust, etc. Although these measures and indictors are necessary to pursue and enable the kind of sustainability criteria to continue and realistically function, there are some shortcomings associated with their application in the real world. According to Foster (2001), these parameters that are intended to be measured don't get identified and created as indicators in a cultural void; the processes of constructing and interpreting them rely on collaborative judgment as regards to, for instance, the trustworthiness of the institutions involved, the acceptability of the assumed scientific framings, and validity of the various statistical measures in relation to people's lived experience; indicators do not read themselves nor do they simply register whether particular forms of development are sustainable or not. Overall, it is certainly useful to set limits and monitor thresholds at environmental level as a continuous process in order to create effective models that support a qualitative development rather than solely quantitative growth that has proven to be fallible and unsound as to sustaining living in mutual way with nature.

3.4.5. Deep Sustainability

Foster (2001) argues that the problem of internalizing limits is far more fundamental than a socio-economic challenge or even a demanding lifestyle choice; and these limits need to come to bear at the phenomenological level, on the way we comport ourselves in representing and interpreting the world. He characterizes deep sustainability 'as constructing any operational limits within which we aspire to live, within limits; that is, working as we construct them within our natural limits as representation ally-conscious intelligent agents.' (Ibid, p.160) Deep sustainability is not a measurable trend, but rather a particular way of understanding limits and carrying capacity of nature through being humanly alert to and alive through the world (Ibid). Sustainability has much more to do with environmental philosophy and ecological intelligence in the sense of informing spirit in the recognition of the limitedness of the biosphere capacity as to satisfying human needs infinitely and allowing resources use beyond globally sustainable levels. The premise of deep sustainability rests on living by and from creative intelligence of natural order; it is deep in the sense of being logically prior, standing to the operational form of the concept as deep structure to surface grammar (Ibid).

If operational sustainability is about not living in the economic and political dimension as if there were no tomorrow, deep sustainability is about not judging as if there were no tomorrow (Ibid). It is not of astuteness to think of the economic model as a process to generate growth without considering tomorrow to come or rather future generations to meet their needs. Rather, it is of good judgment and sense making to recognize the claims of the whole succession of tomorrows and drive our patterns of understanding intelligence in a more holistic view. We are known for our fallibility and imperfection no matter how hard we direct our intelligence and energy of insight into understanding our dynamic interaction with nature. That said it has been seen in many occasions that our phenomenological perception of intelligence has led to unknown and unpredictable outcomes, i.e. unsustainable living on Earth. We have pushed environmental thresholds in unprecedented way under the so called economic growth to realize at the end of the day how we have repeatedly failed to grasp the unintelligent/brainless patterns of our perceived intelligence path. Foster (2001) argues that all our judgments are not to be forgotten to be the work of humans who, despite their marvelous wits, get very easily tired and bored, and wish on most new mornings that they could undo at least part of what was done yesterday. Pressures and covetousness for development distort holistic thinking as our infinite needs can bear on subsequent actions, plans, and strategies we intend to develop.

3.4.6. Sustainability: An Organizational Paradigm

Sustainability seeks to reshape the philosophy according to which organizations operate, interact, and behave towards society. Organizations must think holistically, on a larger scale, and of future generations. A sustainable organization is one whose culture, strategies, and actions are designed to lead to a 'sustainable future state' (Funk 2003). The challenge of sustainability aims to instigate a new economic development paradigm shift. Dunphy et al., (2003) argue that sustainability is widely held to be the desirable path forward for organizations to conduct their operations and activities. This paradigm challenges organizations to rethink current models. Sustainability has grown out of a need for real change - out of concerns that economic growth-based development efforts were performing poorly in meeting human needs and improving human welfare (UNDP 1990). Sustainability paradigm seeks to address environmental concerns as well. Adopting sustainability paradigm will enable organizations not only to steer clear from escalating environmental and social threats, but also to take advantage from future opportunities.

Today, it can be seen by all indicators that the crisis of current industry and economy model is acute, and therefore to await consensus is meaningless given the criticality of the global looming threats facing the planet Earth. As Dunphy et al. (2003) claim that the crisis is currently too urgent to wait for consensus; there is a vital need to start out on the path towards sustainability by generating new organizational models that support the natural environment and social relationship. It is increasingly recognized that to truly meet present and future resource requirements, sustainability must address both social and environmental aspects of society (Robèrt et. al. 2006). Humanity faces an unprecedented challenge to reinstate, recover and sustain socio-ecological system. Empirical evidence (IPCC 2007) shows that enormous challenges are facing humanity, including growing population pressure, continuous decreasing of health of natural habitats, mounting socioeconomic disparities and inequalities, increasing human-induced environmental degradation, etc.

The whole premise of sustainability is to create a societal model where people can coexist, create productive lives, and forge new patterns to satisfy their needs in a mutual way. Sustainability is an alternative worldview in search of social structures, economic activities, accounting procedures, production and consumption patterns, and technologies that empower and improve the lives of all present people and guarantee quality lives for future generations (Peskin 1991; Nordhaus and Kokkelenberg 1999; Princen 2005). Quick fixes to current complex environmental and social problems have proven inadequate and useless; hence the sound approach is to devise upstream and innovative solutions to tackle the global issues (i.e. climate change, social injustice). Many organizations have responded to the sustainability call. Such initiatives have begun to take shape as some organizations have embarked on the path towards sustainability commencing to change the way they operate and deploying efforts to support sustainable development. Dunphy et al. (2003) point out that the transformation of corporations is emerging, driven by the changing demands of modern society and also by the leadership of far sighted and responsible people who see the need for change. Besides, organizations need to rely on behaviors that have a future by establishing a vision of finding pathways towards all-embracing value for sustainable economy, if they are willing to forfeit their rights to unsustainably exist. Organizations are the fundamental gears of modern society. They can influence the change needed and contribute to the auspiciousness of sustainable society. Sustainable human institutions (i.e. corporations, organizations, governments, and NGOs) should provide security and opportunity for social and spiritual growth (David 1996). Organizational strategies need to encompass the needs of all key stakeholders that might influence or be influenced by the organization 'primary or secondary activities' (Salzmann et al. 2005). Reaching sustainable societal model requires concerted corporate action. Corporate sustainability is a strategic model that seeks to address societal needs. This is the subject of next section.

3.5. Corporate Sustainability

3.5.1. What is Corporate Sustainability?

Toward more efforts of rethinking current industrial and economic models and seeking alternative solutions while recognizing that panaceas are unlikely to come into sight no matter how paradigms can qualitatively improve or change, corporate sustainability has emerged as an alternative solution that discourages narrowly-focused profit approach that unfairly impacts other stakeholders. Corporate sustainability is a new management paradigm that considers not only economical needs of the organization, but also environmental and social needs. It is a positive multi-faceted concept covering areas of environmental protection, social equity, and sustainable development (Lo and Sheu 2007). More recently, the concept of corporate sustainability has gained a significant ground in academic, corporate, and economic arenas. It has been used by the corporate sector (i.e. ICT, chemicals, materials, pharmaceuticals) and consultancies to seek justification for sustainability strategies within organizations (Signitzer and Prexl 2008). Corporate sustainability is a concept that describes the planned and strategic management processes of working towards a balance of economic, social, and environmental goals (Ibid). It can be considered as a business philosophy that advocates the long-term profitability without harming other stakeholders that may be affected by an organization's operations and activities. Thus, it seeks to support business practices that balance and increase social, environmental, and financial capital.

Based on the literature reviewed, corporate sustainability is an umbrella term that encompasses various concepts and approaches needed in the process to achieve environmental, social, and economic goals of an organization. These concepts include: sustainable development, stakeholder approach, corporate social responsibility (CSR), corporate accountability, Triple Bottom Line (PPP) (Elkington 1997), corporate citizenship, corporate communications, corporate social performance, and corporate governance, etc. (see glossary for further clarification). Such concepts as CSR, corporate accountability, sustainable development as well as business ethics and their sister concepts are still ambiguous in academic debate or in corporate implementation (Votaw and Sethi 1973; De George 1990; Henderson 2001). More often, these concepts are used in organizations to fit various management purposes (Lo and Sheu 2007).

3.5.2. Key Related Concepts

For the scope of this study, the relevant concepts related to corporate sustainability include the first four of the abovementioned concepts. In the following, these concepts are defined and discussed.

3.5.2.1. 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.

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. 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. Sustainable development seeks to bring out changes in the path of the current development insuring that environmental sustainable protection does not preclude economic development which, in turn, must be ecologically and socially viable now and in the long run. Nevertheless, the idea of sustainable development is viewed as an oxymoron because development inevitably depletes and degrades the environment (Redclift 2005).

3.5.2.2. Stakeholder

The stakeholder theory is associated with various philosophical underpinnings and diverse implications and can be approached from different perspectives (i.e. e-society, corporate sustainability, leadership, governance, strategizing, policymaking, ethics, etc). Stakeholder is a complex, philosophical, and multifarious concept (Friedman and Miles 2006). Freeman (1984) was the first credited with its popularization; with his 1984 book *Strategic Management: a Stakeholder Approach*. A stakeholder is defined as 'any group or individual who can affect or is affected by the achievement of the organization's objectives.' (Ibid, p.46) There is a variety of practices and theories informed by stakeholder concept such as design and strategy. Indeed, it has attracted attention, gained popularity, and recently burgeoned among academicians, practitioners, strategists, technologists, and policymakers. The wide and multi-context use of stakeholder concept has led to criticism. Donaldson and Preston (1995, p.73) states that stakeholder concept is 'mudding of theoretical bases and objectives'. The term stakeholder is becoming 'content free' meaning 'almost anything the author desires' (Stoney and Winstanley 2001, p.650). (Weyer 1996, p.35) refers to it as 'a slippery creature…used by different people to mean widely different things which happen to suit their arguments'. It is 'a rather vague and cryptic concept that is open to a wide variety of rather divergent political interpretations' (referring to a vision of a stakeholder society, Hay 1996, p.47). In addition to this is the criticism in corporate communication by (Duncan and Moriarty 1997), in corporate governance by (Alkhafaji 1989), in financial reporting by (Stittle 2004), in corporate sustainability and business ethics by (Weiss 2005) etc. However, the stakeholder approach denotes that organizations are not only accountable to their shareholders, but also to stakeholders that may affect or may be affected by the operations or objectives of a business (Freeman, 1984 and O'Rourke, 2003). From this perspective, stakeholder concept is useful when it comes to ethical analysis because the idea provides a framework for weighing obligations and gauging the impact of decisions on all relevant groups, not just the organization (Murphy and Laczniak 2006). Overall, the stakeholder concept enables organizations to develop more effective strategies to effectively interact with those who have a stake in the organization.

3.5.2.3. Corporate Social Responsibility (CSR)

According to Enderle and Tavis (1998), CSR is the practice of a corporation's social initiative and involvement over and beyond its legal obligations for the benefit of the society at large. Angelidi and Ibrahim, (1993) defines CSR as corporate social actions and practices that aim to satisfy social needs. Another definition provided by MMI Report (1997) states that CSR is all expectations that people have from a company's ability and willingness to follow the rules and regulations to perform justly and responsibly towards all stakeholders. Lerner and Fryxell (1988) suggest that CSR describes the extent to which organizational outcomes are consistent with societal values and expectations. CSR involves economic, social, and environmental criteria that a company should consider when conducting its operations and activities in relation to other stakeholders. CSR concept has been around for quite long as its history can be traced back to ancient Greece according to an article published by Nicholas Eberstadt in 1973. Friedman and Miles (2006) point out that the roots of modern CSR date back to the 1930s. The modern era of CSR began with the publication of the first definitive book *Social Responsibilities of the Businessman* by Howard Bowen in 1953 (Carroll 1979, 1999). Carroll (1979, p. 500), who has majorly contributed to the field, states: 'social responsibility of business encompasses the economic, legal, ethical, and discretionary expectations that society has of organizations at a given point in time'. This order is according to his model in term of the role in the evolution of importance; early focus was on economics, then legal and then ethical, while most recently emphasis has been on discretionary responsibilities. Based on the literature, CSR definitions were expanded and proliferated during the 1970s. In the early 1970s, many companies published so-called social reports to demonstrate socially responsible behavior (Signitzer and Prexl 2008). In the 1980s, more empirical research began to emerge, and alternative themes were established. Although CSR concept has been criticized by different academicians and practitioners, it has spotlighted moral and ethical issues in business and has raised consciousness (Friedman and Miles 2006). The debate has been on the extent to which organizations must consider their level of CSR. As Wilson (2003) argues in this regard, what is to question is not whether corporate leaders have an obligation to consider the needs of society, but the extent to which they should consider these needs.

Corporations have responsibilities that go beyond their legal obligations (shareholders' value); they have also ethical obligations towards society. According to Freeman's stakeholder theory, corporations have responsibilities to their shareholders and other interest groups (Freeman 1984). Many of the issues developed under the label of CSR or corporate social performance (CSP) have consequently influenced stakeholder theorizing (Friedman and Miles, 2006). CSR seeks to increase and promote the prosperity of an organization while improving living standards and protecting the environment. Commonly, CSR involves organizations voluntarily adopting management practices to improve their social and environmental standards by mitigating their negative impacts on the environment and society. For Johnson (1971) social responsibility concerns, in reference to companies, the balancing of a multiplicity of stakeholder interests. CSR contributes to corporate sustainability by providing ethical arguments as to why corporations should support and work toward sustainable development: If society in general believes that sustainable development is a worthwhile goal, corporations have an ethical obligation to help society move in that direction (Wilson 2003).

3.5.2.4. Corporate Accountability

Broadly, corporate accountability refers to the moral and ethical obligation for organizations to be held accountable to all stakeholders affected by their activities and operations. Wilson (2003) defines corporate accountability as the legal or ethical responsibility to provide a reckoning of the actions for which one is held responsible. However, this concept is fundamentally different from CSR in the sense that CSR can be perceived to be voluntary activity while corporate accountability is more of a justification of actions. This is supported by Wislon (2003) who argues that corporate accountability differs from CSR in that CSR refers to the corporation's duty to act in a certain way, whereas corporate accountability refers to one's duty to justify or report on one's actions.

Within a legal context there is an increasing awareness that the pursuit of short sighted profit maximization as the only purpose of a company's activity might harm other stakeholders and create more harm than good to society generally (Brønn and Vrioni, 2001). Corporate accountability should hold organizations accountable for their actions, operations and activities to stakeholders, instead of urging them to voluntarily give an account of their activities and impacts through voluntary CSR reporting. Strong measures should be developed and strictly applied in an attempt to hold corporations accountable and liable for their actions towards stakeholders. Put differently, stakeholders should be able to control the organization's operations in the sense that they make sure it doesn't cause harm to living organisms in the biosphere. There is general consensus that corporate accountability should be forced as a regulation to hold organizations accountable for their actions and impacts with respect to social and environmental wrongdoing, slackness and malpractice. Otherwise, freewill won't solely bring concrete and desired outcomes. According to an interview in Yes Magazine (1998), Karl-Henrik Robert believes that free will of organizations will not be sufficient to make sustainable practices widespread - legislation is crucial if we want to make the transition in time. Wilson (2003) contends that corporate accountability helps define the nature of the relationship between corporations and the constituencies of society, and sets out the arguments as to why companies should report on their environmental and social performance, not just economic performance. Thus, companies should not only be accountable for economic capital, but also for natural and social capital to be successful in the long run (Dyllick and Hockerts 2002).

3.6. Design and Sustainability

3.6.1. Design and Environment

Papanek (1995, p. 32) states: 'the relationship between design and ecology is a close one.' For instance, the relationship between ICT design and environment is multidimensional as there are complex connections among the positive benefits, negative impacts, and unintended consequences for the environment that flow from the way ICT is designed, manufactured, used, and disposed of. 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, scientific evidence shows that current environmental trends indicate a decrease in ecosystem and planetary health (Broman et al. 2002) along with an increase in the complexity of these same issues (Holmberg and Robèrt 2000). This implies that design of human systems has for long overlooked and disregarded environmental considerations which led to flaws and complex problems. 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 current paradigm, 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 nor sustain the renewal of the biosphere.

3.6.2. Eco-/Sustainable Design

Sustainable design has emerged as a general reaction to global environmental crises, the rapid economic growth, depletion of natural resources, 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 needs 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 is recognized as a strategy that can be applied to reduce the negative impacts associated with the production, use, and disposal of ICT products. Eco-design is a promising path and strategic approach for sustaining societal development. The practice of eco-design could potentially yield great social and environmental benefits (Shu-Yang et al. 2004). The need to think ecologically, moving from an environmentalism driven by sectoral issues involving resources, climate change, and biodiversity, to a more integrated ecologicalism that recognizes the inherent interdependence of all life systems (Esty and Chertow 1997). Further, eco-design is to realize the potential of designers and benefit from their creative abilities and strengths to instigate changes that mitigate the negative environmental impacts and ultimately achieve sustainability. Datschefski (2001) contends that sustainability can only be achieved through design.

Then, the challenge for ICT designers is to embrace environmental sustainability principles for the pursuit of auspiciousness in economic development. 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 and activity. Designers of technologies should be aware of their role in designing systems with sustainability in mind. This will contribute to a high quality of life for future generations. Therefore, it is necessary for designers to know and understand how the world operates in order to take actions that support environmentally responsible design. Sustainable/eco-design is an approach that seeks to extend and replicate opportunities; generate new opportunities for sustainable livelihoods; and protect ecosystems and environments; and conserve and replenish scarce resources. Designing with sustainability in mind is an emerging paradigm shift that should prevail.

3.7. Sustainable Technologies (ICT)

The philosophy of sustainable design is to design technologies (products and services) that comply with the principles of environmental sustainability. In other words, designing technologies sustainably is about designing for the environment. 'Design for Environment is design that seeks to eliminate potential negative environmental impacts before a product is made…This concept involves reducing the quantity and the number of materials used in a product or service; the resources used in manufacture, operation and disposal; the hazardous materials that are used; and the quantity of non-recyclable materials used. It also involves modular design that allows for upgrades, easy refurbishment or parts replacement, and simpler dismantling for re-cycling or disposal' (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: energy efficiency in both manufacturing processes and producing products that require less energy; natural resources replenishment through dematerialization; replacement of hazardous and toxic chemicals with safe substances; recyclability and reuse of materials and products that require less energy to process; reduction of carbon footprint and other GHG emission; and use of sustainable design measures and standards. In addition, it should mimic natural designs, patterns, and processes. Redesigning systems on biological lines enables the constant reuse of materials in continuous closed cycles (Hawken et al. 1999). Also, it should be based on service provision rather than ownership of physical products. This idea entails shifting the mode of consumption from product ownership to services. This usually provides similar functions, i.e. instead of buying physical products we replace them with digital alternatives. Such an approach promotes minimal resource use per unit of consumption (Ryan 2006). '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 these characteristics of environmental sustainable design of technologies is the renewability aspect associated with optimizing materials and products transport as well as using sustainably-managed renewable sources that can be composted at the end of their useful life. Table 3.1 presents examples of sustainable design principles from two engineering disciplines, namely product design and green design. Although some slight variations exist, similarities draw from the focus on minimizing depletion of natural sources; use of renewable energy for product design; and preventing the release of toxic by-products and waste.

Sustainable Product Design (Datschefski 2001)	Green Design (Abraham and Nguyen 2003)
1. Cyclic: Made from compostable organic materials or from minerals that are continuously cycled. 2. Solar: Their manufacture and use consumes only renewable energy that is cyclic and safe. 3. Safe: All releases to air, water, land or space are non-toxic. 4. Efficient: Most efficient use of energy required over life cycle. 5. Social: The products manufacture and use supports basic human rights and natural justice	1. Engineer processes and products holistically using systems thinking, and environmental impact assessment tools. 2. Conserve and improve ecosystems and human health and well-being. 3. Use life cycle thinking in all engineering activities. 4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible. 5. Minimize depletion of natural resources. 6. Strive to prevent waste. 7. Develop and apply engineering solutions, being cognizant of local geography, aspirations and cultures.

	8. Do not be limited by current or dominant technologies; seek fundamental and incremental change. 9. Create awareness in and engage communities and stakeholders.

Table 2.1 Sustainable product design and green design

Source: Llewellyn et al. 2005

CHAPTER FOUR

RESULTS

4. Results

4.1. Overview

This section analyzes and synthesizes the results and illustrates the findings followed the literature review research methodology. The author obtained pertinent data covering theoretical, empirical, and analytic scholarship found in earlier and contemporary studies in relation to the study under investigation. This is to answer the two research questions outlined in chapter introduction, section 1.4.2. Extensive literature review helped to gain better knowledge and understanding of the relationship between ICT design and environmental sustainability. To provide a logical and coherent structure of literature material and bring clarity to the reader, the author used the thematic approach - the results are divided into sections representing the categories for the topic of the thesis. The results are presented in two sections that are, in turn, divided into subsections based on the issues explored to answer the research questions:

1. Negative environmental impacts of the current mainstream ICT design approach.
2. Potential remedies for unsustainability of ICT design.

4.2. Negative Environmental Impacts of the Current Mainstream ICT Design Approach

According to the first three sustainability principles that deal with environmental issues, nature should not be subject to systematically increasing…:

(1)…concentrations of substances extracted from the earth's crust (i.e. fossil fuels, metals, oil);

(2)…concentration produced by society (hazardous and persistent substances, i.e. PCB, PBB, PVC)

(3)…degradation of natural systems by physical means (i.e. landfill, deforestation) (Holmberg et al. 1996; Ny et al. 2006).

Based on the reasoning above, the current mainstream ICT design approach is unsustainable as it has led to negative impacts on the environment; hence it doesn't comply with the environmental sustainability principles. Next, the results are presented in relation to key environmental issues associated with resource depletion, intensive energy use, toxic waste disposal, and hazardous chemicals use.

4.2.1. Resources Depletion: Extraction and Manufacturing

It is clear by many indicators that the current mainstream ICT design approach has generated negative impacts on the environment. Design affects the whole product lifecycle and has a central role in ICT manufacture. ICT industry is a major contributor to resource depletion. We rarely think about the large volumes of earth crust moved in ICT manufacturing, the associated damage to biodiversity, and the huge amounts of energy required in the extraction and refinement process (Madden and Weißbrod 2008). Mining metals and scarce material for manufacturing ICT products leads to resource depletion due to the tremendous and rapid growth of ICT that exhausts resources. The manufacture of ICT products starts with resource extraction, which is highly material and energy intensive (Plepys 2002). In 2004 United Nations University (UNU) study shows that around 1.83 tons of raw materials are required to manufacture the average desktop PC and monitor, about equal to the weight of a mid-size car (Williams 2007). To manufacture only one desktop computer and 17-inch cathode ray tube monitor requires at least 240 kilos of fossil fuels (Madden and Weißbrod 2008). Only 0.1% is the computer's mass of 16–19 metric that is considered to be the total material intensity along the life cycle of a PC (Grote 1996; Mallay 1998; Hilty et al. 2000). One computer is made of more than 1000 different materials, of which a lot are toxic (i.e. heavy metals) (WSIS 2003, 2005). Moreover, a study using the ecological footprint methodology indicates that total footprint of the analyzed PC was about 1800 m2 (Frey and Harrison 2000).

Furthermore, the advancements in semiconductor technologies are marked by continuous need for using new compounds based on scarce elements, which are responsible for large material displacement and generation of huge quantities of mining waste (Plepys 2002). A research study shows that around 220 pounds of mine waste is generated to source the gold in a single circuit board (Earthworks 2006). Wuppertal Institute confirms, using the MIPS method, that a golden ring has an ecological backpack of material intensity equal to 10 tons (Grote 1997). The backpacks of numerous scarce elements commonly used in electronic circuits are large (i.e. tantalum, arsenic, germanium, gallium, and indium) (Plepys 2002). In addition, to manufacture only one desktop computer and 17-inch cathode ray tube monitor requires at least 1,500 kilos of water (Madden and Weißbrod 2008). How critical the issue can be as to the amount of water used in ICT manufacturing processes depends on the location where the industry operates (Ibid). Primarily for washing, the average computer chip requires 45.46 liters of water (Fuchs 2006). A study carried out by Silicon Valley

Toxics Coalition (SVTC, 2000) shows that the production of a 6-inch silicon wafer requires 8.6 m3 deionised water, 9 kg hazardous chemicals, and 285 kWh of electricity. Consistent with that, the production of an 8-inch chip used for Pentium CPUs requires 11.44 m3 of deionised water, 120.8 m3 of bulk gases and 12 kg chemicals (Anzovin 2000).

4.2.2. Energy Consumption and GHG Emissions

4.2.2.1. ICT Product Lifecycle and Climate Change

Due to the impacts of ICT on climate change, it is apparent that ICT design has flaws and overlooks the externalities relating to direct and indirect effects of the total technological product lifecycle associated with energy consumption that drives CO_2 and other GHG emissions, which accelerates climate change. ICT have become a significant global environmental issue from manufacture, through use to disposal, especially when it comes to uncontrollable use of energy that results in the increase of GHG emission - the main culprit to global warming. According to Forum for the Future (FF 2006), the effects of ICT on climate change are of three types: direct, indirect, and systemic (see glossary for clarification). Considering the scope of this paper, the author focuses only on some of direct and indirect impacts of ICT. Direct effects arise from the design, production, distribution, maintenance and disposal of ICT products and services by the ICT industry, and that 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. ((MacLean and Arnaud 2008). Indirect effects arise from the use and application of ICT throughout the economy and society, and that 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 (Ibid).

Technology analysts estimate that the manufacture, use and disposal of ICT products contribute around 2% of global emissions of CO_2 (Griffiths 2008). As a similar result, the ICT sector currently accounts for GHG emissions, generally estimated to be in the range of 2-3% (MacLean and Arnaud 2008). Further, in developed countries, the total electricity demand consumed by ICT is between 5% and 10% which contributes with 1%-3% to worldwide CO_2 emissions (WSIS 2003, 2005). 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). One recent report estimated that direct effects of ICT provision account for 20% of ICT-generated GHG emissions (Ibid). 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).

Regarding 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). 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 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, GHG emissions, and waste generation. 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).

4.2.2.2. Data Centers: Energy User and GHG Emissions Generator

Data centers are considered to be the hungriest energy users and generators of GHG emissions. This is a flaw owing to the faults associated with the design of ICT equipment regarding energy usage. A data center (or server farm) is a dedicated facility used to house ICT equipment, such as data storage systems, servers, and telecom devices, in addition to backup power supplies, redundant data communications connections, security devices, environmental controls (i.e. air conditioning, fire suppression), etc. 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). According to the world summit for an Information Society, the estimate of electricity demand for the ICT sector for developed countries is between 5 and 10 % of total electricity demand (Madden and Weißbrod 2008). 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).

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).

At micro level, the actual power consumed by each processor (dual -processor PC-type server as an example) 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. Overall, the data center is a GHG generator due to the huge energy it devours, which increases global warming effect.

4.2.2.3. Software Technology: The Adverse Environmental Effect

Like all ICTs, 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). Increasingly ICTs are becoming like other consumer durables and finding new sales in the software technology comes from design which makes us want to update to the latest, greatest, and most powerful. Planned obsolescence generally concerns all ICT equipment, including laptops (3 years) or desktops (3-5years) along evidently with their software applications. In 2007 the chairman of Microsoft when speaking of the Vista operating system 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 (Ibid). 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. 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. Figure 4.1 illustrates a comparison of the upgrade configurations for an industry standard PC across eight years. The upgrade of operating system may also make the applications and utilities obsolete as incompatibility may reign (Ibid). From a systemic ICT effect perspective, transformational impacts of ICT (i.e. software technology) on the environment (climate change) are difficult to be controlled and measured as they arise from changes in organizational and social structures and behaviors enabled by the accessibility, availability, application and use of ICT products and services. The social and attitudinal dimensions of consumerism compromise the environmental dimension of ICT. The ICT-enabled changes affect organizational and social parameters such as: the attitudes, expectations and behaviors of consumers; organizational structures; production, distribution and service processes; and governance in the private and public sectors (MacLean and Arnaud 2008).

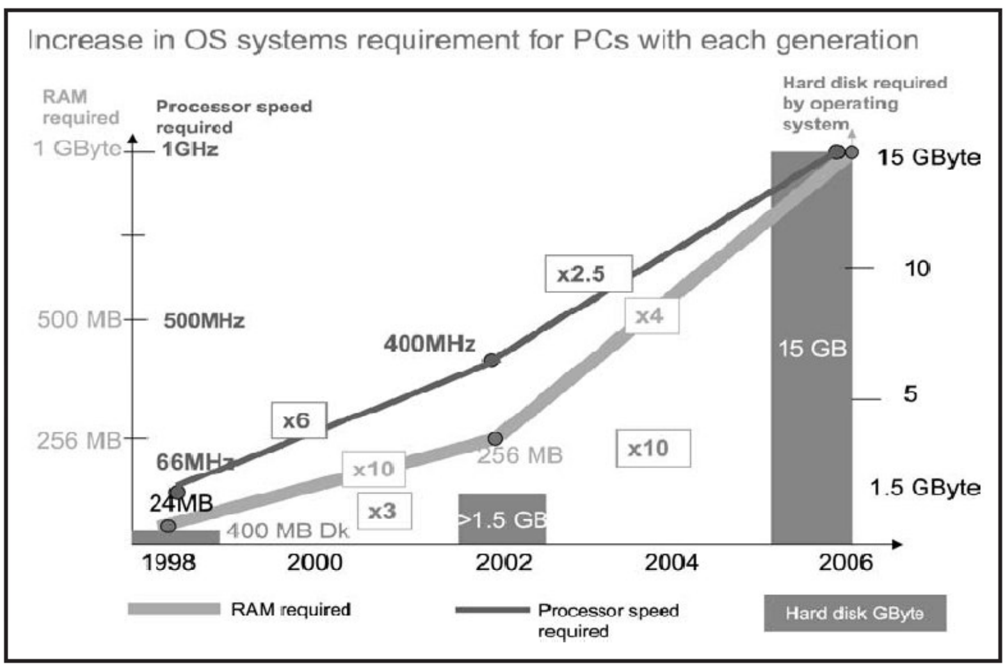

Figure 4.1 Each increase in OS requirement is beyond the range of extension of the previous system
Source: Forge 2007

4.2.3. Toxic Waste Disposal

Adding to the negative environmental impacts of current unsustainable ICT design is the quantity and the number of materials used in manufacture, operation and disposal of ICT products. This results in generating a huge amount of waste at the end of ICT products useful life. PCs, laptops, printers, screens and now mobile phones are major contributors to an immense and rapidly growing global e-waste issue as they have a considerable negative impact on the environment. ICT products are becoming ubiquitous in consumer and business environments and bring with them environmental problems at all stages of their lifecycle (Forge 2007). Over 2 billion mobile phones are in use worldwide; more than 1 billion units were sold in 2006 (being made up of 300 million subscriber expansion, plus 700 million at least replacement units - and thus up to 700 million discarded in some way) indicating a disposal in 2006 of up to 700 million units globally (Ibid). The negative environmental effects of mounting consumption of electronic products are most visible in the end-of-life stage (Plepys 2002). Huge amount of waste is produced from industries and businesses due to the quantity of materials used each year. At general level, the average human uses 45-85 tons of materials each year (Bournay et al. 2006).

ICT equipment (i.e. computers, laptops, mobiles, servers, routers, switchers, hubs, filters) are usually not designed to be refurbished, re-used, or recycled, rather designed to be disposed of, which is the worst option environmentally. This is occurring because of the planned obsolescence phenomenon that prevails in the current mainstream ICT design paradigm. Planned obsolescence generally concerns all ICT equipment, including mobile phones (average life 12 months), laptops (3 years), and desktops (3-5years). It started with mainframes, spread to PCs and the new challenge will be in mobile handsets, especially smart phones that will soon have gigabytes instead of current hundreds of megabytes as standard RAM sizes for more applications (Forge 2007). Further, the problem will move from the hundreds of millions of units to the billions with mobile phone users likely to reach five billion by 2020 (Forge et al. 2005; Blackman et al. 2007). It is well known that most ICT products fall into the category of use for a relatively short time and then are discarded, especially mobile phones, PCs, and laptops, etc. There is a questionable strategy in environmental terms that model cycles in ICTs are getting shorter, not longer (Forge 2007). Moreover, design for disposal encourages throwing away more sophisticated and energy-expensive items, for instance, Hewlett Packard incorporate the print head technology within the cartridge – so it must be discarded when empty with the ink container (Ibid). Separation of a simple ink container from a permanent print head means that the real print technology - the energy expensive part of the printer - can be reused (Ibid). Consistent with that, it is sometimes impossible to repair an ICT device (i.e. mobile, printer, laptop etc.) because vendors deliberately carry no parts for it because they intend to encourage consumers to buy new devices and dispose of the old ones in spite of their usefulness.

Waste management is a growing concern in ICT industry, owing to the non-responsible disposal that has toxicity complications with regard to electronic components containing hazardous chemicals, such as lead, cadmium, mercury, selenium, etc. A number of studies have looked into end-of-life management of electronic waste particularly computers, laptops, and mobiles. A study of the product group PCs in the EU shows that the life cycle of PC generate 22% of waste at its production, 65% during its use, and 13% at its disposal (IPU/AC 1998). Some 20 to 50 million tons (UNEP 2006) of toxic waste are generated worldwide every year as a result of the growing demand for consumer electronics (Madden and Weißbrod 2008). The European Commission (EC 2004) estimates that the EU produces over eight million tons of Waste Electrical and Electronic Equipment (WEEE) per year. Gartner estimate 170 million computers were thrown away in 2006 alone (Madden and Weißbrod 2008). At global level, some 130 million PCs are produced annually and in the USA alone around 130,000 PCs are thrown out a day. The billionth PC was produced in 2002 and the USA alone had over 600 million PCs at the end of 2005 (Forge 2007). Of this total, 72 million were recycled, and 150 million went into landfills (Greenpeace 2005). Of all PCs, 27 percent are laptops, growing at 22 % CAGR (IDC 2007). According to the US Environmental Protection Agency (EPA), more than 4.6 million tons of e-waste ended up in US landfills in 2000. Based on a model developed at Carnegie Mellon University, in the United States alone, nearly 150 million computers were recycled and 55 million land-filled in 2005 (Matthews et al. 1997). It was estimated that in 2006 the US would be producing almost 3,513 tons of obsolete computers, televisions and cell phones per day (Silicon Valley Toxics Coalition 2004). At global level, there are around 14 - 20 million computers scrapped yearly, about 10–15% of them reused or recycled, 15% end up in landfills and the rest are stockpiled by users (Goldberg 1998). They are destined primarily for waste dumps; this e-waste represents a growing global environmental crisis (Samuel and Lesley 2007). In addition to the volume of waste, these electronics contain significant amounts of heavy metals and other toxic and hazardous substances, which are gradually released into the groundwater (Ibid) and land. Electronic waste largely consists of incineration residues or waste placed in landfill sites which may contain toxic or hazardous materials, and which the new EU legislation is designed to deal with (Forge 2007). ICT waste deserves special attention because of its toxicity (Ibid). Hazardous chemicals issue is addressed next.

4.2.3.1. Hazardous Chemicals

It is apparent that the current mainstream ICT design doesn't comply with avoiding systematic increase of concentrations of chemical and persistent substances as an environmental sustainability principle. ICT design then overlooks the toxicity of hazardous materials used in the manufacturing of products, which has a considerable negative impact on the environment. Many studies have been conducted on this regard to show how toxic and hazardous chemicals are immensely used in the manufacture of ICT products. A recent report shows that the harmful materials used in ICT components include toxic metals - lithium and cadmium in batteries; lead in cathode ray tubes; and flame retardants on appliance shells (FF 2006). In addition to those toxic substances are polychlorinated biphenyls (PCBs), chromium, polyvinyl chloride (PVC), mercury, selenium, antimony trioxide, etc. They are largely found in PCs and laptops (i.e. circuit boards, peripherals), mobile phones, handsets, CDs, cables, toner cartridges, etc. A recent study shows that one computer is made of more than 1000 different materials, of which a lot are toxic (i.e. heavy metals) (WSIS 2003, 2005). It requires large amounts of toxic materials to manufacture semiconductors, printed wiring boards, and cathode ray tubes (Plepys 2002). The production of electronic equipment (i.e. semiconductor) uses various types of solvents and hazardous chemicals (WSIS 2003, 2005). To manufacture only one desktop computer and 17-inch cathode ray tube monitor requires at least 22 kilos of chemicals (Madden and Weißbrod 2008). The production of an 8-inch chip used for Pentium CPUs requires 120.8 m3 of bulk gases, 12 kg chemicals, and produces 0.82 m3 hazardous gases, and 4 kg hazardous waste (Anzovin 2000).

Waste treatment facilities can lead to leaks of such chemicals and subsequent environmental damage (Madden and Weißbrod 2008). If waste is not disposed of properly, the leaking of toxic chemicals can lead to water and air pollution and the contamination of land. US Environmental Protection Agency (EPA) research indicates that IT equipment, especially copiers and printers, may introduce unhealthy solids and gases into buildings, including brominated flame retardants, phthalates, dust, ozone, Volatile Organic Compounds (VOCs), and ammonia (Forge 2007). According to Greenpeace (2005), when e-waste is burned, brominated flame retardants generate brominated dioxins and furans. In many EU states, plastics from e-waste are not recycled to avoid brominated furans and dioxins being released into the atmosphere (Forge 2007). Also, the US EPA estimates that 3/4 of the PCs sold in the US are stockpiled in garages and homes and when thrown away, they end up in incinerators or landfills. The incineration process releases heavy metals such as lead, cadmium and mercury into the atmosphere as ashes, as well as hazardous chemicals and GHG emissions that attack the ozone layer (Ibid). When mercury is released into the atmosphere, it bio-accumulates in the food chain, particularly in fish (i.e. tuna), which is the major route of exposure for the general public (Ibid). If ICT products contain PVC plastic, highly toxic dioxins and furans are also released, which is extremely detrimental to the environment.

4.3. Potential Remedies for Unsustainability of ICT Design

In this section, the author presents the results of potential remedies for unsustainable ICT design. These results are framed into environmental and corporate sustainability perspectives. They center on the reduction of the quantity and the number of materials as well as the resources used in manufacture, use, and disposal of ICT products; GHG emissions through design of low power consumption-type ICT products; and hazardous chemicals use; and the elimination of toxic waste. These solutions to design flaws and problem of ICT products are aimed at mitigating the impacts of ICT on the environments, and ultimately achieve the goals of ICT sustainable design.

Design affects the whole lifecycle of ICT products - manufacture, use and disposal. Currently, one of the issues drawing the most interest environmentally is global warming. There are global efforts to reduce GHG emissions that are accepted as the main culprit of global warming. 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). Currently, a great deal of the research focuses on the impacts created by the ICT design processes (Madden and Weißbrod 2008). Also, EU, UK, and USA are currently undertaking initiatives and actions as to the regulation of e-waste and the use of hazardous chemicals in the production of ICT equipment in attempts to mitigate their negative impacts on the environment. The Electronics Industry Code of Conduct (EICC) outlines standards to ensure manufacturing processes are environmentally responsible (Arbogast 2006).

4.3.1. Dematerialization: Material Reduction and Digitization

Design for environment or sustainable design seeks to eliminate potential negative environmental impacts when a product is designed – before it is made. Among other things sustainable design involves reducing the quantity and the number of materials as well as the resources used in manufacture, use and disposal of products. Green design minimizes depletion of natural resources (Abraham and Nguyen 2003). To minimize depletion of natural resources - caused by extraction and manufacturing - the improvement of design should be driven by the dematerialization approach/strategy in early stages of ICT product design and development processes. Indeed, much of the sustainability efforts with materials in all types of design are directed at dematerialization. Plepys (2002) points out that dematerialization is one of the most effective strategies, and its potential can be particularly well utilized in ICT design where new approaches relying on less material product are relatively easy to develop. Generally, this approach entails converting the linear path of materials to a circular material flow that reuses materials and increase use of material flow analysis in the design process of products. In the context of ICT design, dematerialization commonly refers to the relative or absolute reduction in the quantity of materials used to make ICT products. To achieve this goal, increasing the amount of recycled materials is one obvious step. Sustainable product design should be cyclic: made from compostable organic materials that are continuously cycled (Datschefski 2001). There are many opportunities to radically improve the substances used in the manufacture of ICT products. For instance, copper is considered as a major source material for ICT products. In 2003 the Wuppertal Institute calculated that 500 kilos of raw materials are needed to produce only one kilo of primary super refined copper (Madden and Weißbrod 2008). This figure includes the materials used in manufacture, the energy consumed, the transport requirements, and the packaging of the components (Ibid). Producing a kilo of secondary (i.e. less refined) copper requires only 9.7 kilos of materials – under 2% of what is used to make primary copper (Aldrich et al. 2003). Consistent with that, fiberglass technology has higher eco-efficiency than copper: 1 ton of copper can be replaced by 25 kg of fiber-optic cable, which can be produced with only 5% of the energy needed to produce the copper wire (Plepys 2002). Also, dematerialization can be achieved by the reduction of demand for ICT (hardware and software). Further, extending the life of a PC would in effect reduce the impact from making a PC by the percentage of the extension, say 50% if the life cycle of a PC is doubled. Extending ICTs operational life through re-use holds a great potential for energy saving (Madden and Weißbrod 2008).

In addition to material reduction as a part of dematerialization strategy is digitized alternatives. 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. This provides similar functions, i.e. buying physical products can be replaced with their digital alternatives. Such a system promotes minimal resource use per unit of consumption (Ryan 2006). 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). Apart from saving energy, there are also other improvements concerning better air quality and less noise pollution (Ibid). Besides, the positive ecological dimension rests on ICT's potential to deliver greener products and increase consumption efficiency through dematerialization, e-substitution, ecological product life optimization, etc. (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 virtual alternative - 'virtualization' (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'. In addition, such dematerialization of society may allow total municipal solid waste to grow more slowly than GDP (Forge 2007).

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). Sustainable product design is solar: use consumes only renewable energy that is cyclic (Datschefski 2001). 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 and waste (Dowling 2005). However, it is important that claims of potential environmental benefits are assessed for the entire lifecycle of a material or product (Ibid).

4.3.2. Energy Efficiency and GHG Emission Reduction

4.3.2.1. De-carbonization

Sustainable ICT design involves producing low energy consumption-type ICT products and improving ICT manufacturing processes. Examples are often from Asia, 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). According to Datschefski (2001), 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. 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. Green ICT design is intended to substantially reduce GHG emissions to alleviate global warming by cutting energy consumption. This is to mitigate the impact of ICT on climate change. This can be achieved through de-carbonization strategy - the exploration of renewable energies and developing less carbon-hungry or low power ICT equipment. These criteria are to be considered in the design process of sustainable ICT products that require less energy or ideally use renewable energy. In addition, extending ICT equipment's operational life through re-use holds a great potential for energy saving (Madden and Weißbrod 2008). Upgrading PC storage space so that it may continue to be used can produce potential energy savings of between 5 and 20 times those gained by recycling (Williams 2004).

The Confederation of British Industry estimates that by 2030, nearly 60% of the required carbon emissions savings must come from more efficient energy use at home and in business (Madden and Weißbrod 2008), considering ICT equipment tends to have a large share of energy consumption. 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.

4.3.2.2. Data Centers: Solving the Dilemma

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 (Forge 2007). 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). Regarding data center design, 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 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; pro-active 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. 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 presencedetecting 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 (Madden and Weißbrod 2008). 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).

4.3.2.3. Legislation and Policy: Data Centers

Regarding legislation and policy, many sustainability efforts and initiatives have been implemented and more are emerging to deal with the issue of energy consumption in data centers. The Energy-using Products Directive adopted by the European Parliament in 2005 aimed to encourage manufacturers to design products, including ICT equipment, with whole life environmental impacts in mind (Griffiths 2008). For each product group covered, minimum standards for energy efficiency will be set and meeting them will determine the eligibility for sale in the EU (Ibid). The Carbon Trust is releasing a simulation tool that will allow data center owners to model the effects of changes before their implementation (Ibid). In 2008 The European Commission launched a voluntary code of conduct for data centers, which aims to raise awareness of their energy use (Griffiths 2008). In 2008, the British Standards Institute launched a methodology known as PAS 2050 for measuring whole life emissions from goods and services (Ibid). Overall, global policy efforts are needed to influence manufacturers to reduce the standby power consumption of their products (WSIS 2003, 2005). Some leading ICT manufacturers are already responding to global calls to reduce standby power consumption by developing new technologies (Ibid).

4.3.3. Recyclability and Limiting Hazardous Substances

4.3.3.1. Recycling Materials

Adding to the practices of sustainable design, using recyclability of materials is also key principle of design for environment. Design for environment entails designing out waste in the first place, rather than to deal with it afterwards (Greenpeace 2005). Also, it involves modular design that allows for upgrades, easy refurbishment or parts replacement, and simpler dismantling for re-cycling or disposal (Ibid). Sustainable product design is cyclic: made from compostable organic materials that are continuously cycled (Datschefski 2001). Green design should strive to prevent waste and engineer processes and products holistically using systems thinking, and environmental impact assessment tools (Abraham and Nguyen 2003). Indeed, the idea of 'Green ICT' was based on the fact that ICT is deeply related to production of harmful materials and non-recyclable waste that do not decompose, and aimed at eco-friendly and recyclable ICT goods (Lee 2009). In addition, sustainable design includes the principle of bio-mimicry, i.e. mimicking natural design, patterns, and processes. Redesigning systems on biological lines enables the constant reuse of materials in continuous closed cycles (Hawken et al. 1999). In ICT, designing out waste in the first place is effective because it shun externalities at the end of the useful life of ICT equipment. This can be considered as an upstream solution to the problem of waste.

Research studies about sustainable use of materials in design have focused on dematerialization strategy that seek to convert the linear path of materials (i.e. disposal in landfill) to a circular material flow that reuses materials like the cycling of waste in nature. Dematerialization is encouraged through the idea of eco-design and industrial ecology (Fuad-Luke 2006). Some industries have embarked on this path by turning the waste produced by industrial metabolism into resources (Shu-Yang et al. 2004). Additionally, extending ICT equipment's operational life through re-use holds a much greater potential for recycling (Madden and Weißbrod 2008). Indeed, increasing ICT product's lifespan is becoming a key factor in ICT design to cope with the phenomenon of planned obsolescence. Further, a new ecosystem for recycling with a secondary market is gradually appearing to confront planned obsolescence, offering specific service support for: extending the physical life of equipment and the service warranty of equipment with support services (Forge 2007). The ICT recycling industry is taking root, for instance, printer cartridges have spawned a whole new business sector in the UK, France and Germany (Ibid). This new industry segment has in reality been around for some 30 years but is now blooming as never before with industrial and individual consumer level recycling (Ibid). Many industrial players are growing in this ecosystem. Three examples of the business level ICT recycling ecosystem include: server recycling, recycling network equipment, and an eco system for recycling (see Appendix E).

Regarding legislation on recycling, being now in force, EU legislation on the Waste Electrical and Electronic Equipment (WEEE) has had a great impact on recycling processes. WEEE is the European Commission directive on waste electrical and electronic equipment. The EU directive sets collection, recycling and recovery targets for all types of electrical goods (Madden and Weißbrod 2008). It requires the recycling and take-back of consumer electronics (Forge 2007). The directive assigns responsibility for the disposal of electrical and electronic waste to the manufacturers of such equipment (Madden and Weißbrod 2008). WEEE Directive was implemented in the UK in 2007 and requires producers of ICT equipment to pay for the cost of treatment, recycling and disposal of waste equipment (Griffiths 2008). Looking beyond the EU, major programs are beginning in the USA, Japan and now China (Forge 2007). Some ICT directions and practices are now coming to the fore in the USA, such as take-back campaigns and regulations; IT equipment recycling programs; 'Universal' hazardous waste regulations; green procurement programs for electronics, and Data cabling (Ibid) (see Appendix F). Overall, those policy initiatives are emerging on international level that aim to make ICT producers responsible for collecting and safely disposing their products in their useful life. The EU Directive on WEEE and the Swedish Ordinance on Waste Electronic Equipment are relevant examples. Policy intervention is often needed where the market fails to address environmental problems (Plepys 2002). If properly designed and implemented, these policies can eventually affect product design and induce innovative business approaches that could be less material intensive (Forge 2007).

4.3.3.2. Reducing Hazardous Chemicals

Reducing or ideally eliminating the hazardous substances (chemicals) is one of the principles of sustainable design. Sustainable product design is safe: all releases to air, water, land or space are non-toxic (Datschefski 2001). Green design conserves and improves ecosystems and human health (Abraham and Nguyen 2003). In the ICT context, design process should replace or, at least, mitigate hazardous chemicals due to the risk of their toxicity - detrimental to the ecosystem and human health. Thus, design solutions should strive to replace hazardous chemicals to produce safe ICT products. Some sustainability efforts for producing eco-friendly low or non-noxious goods - less hazardous to human health – are emerging under the so called green ICT design initiatives. An example of the eco-friendly ICT production is manufacturing of parts of mobile phone bodies using eco-friendly plastic made from fermented corn, the production of low-hazard chargers, headsets and peripheral devices, and the development of ink using vegetable oil (Lee 2009). Other recyclable ICT products including 100 % recyclable VOC-free LCD TV products are being manufactured as a part of design for environment - product-oriented Green ICT (Ibid). Furthermore, there are some promising applications (i.e. nanoparticles) in nanotechnology to manipulate and control chemicals in ICT (electronics) at nanometer scale. However, there is evidence that at least some manufactured nanoparticles will be more toxic per unit of mass than larger particles of the same chemical (Dowling 2005). Therefore, it is important that claims of potential environmental benefits are assessed for the entire lifecycle of a material or product (Ibid). Also, in the design process and innovation of products and materials containing nanoparticles, ICT industry should assess the risk of release of these components throughout the lifecycle of its products.

Being now in force, EU legislation on the Waste Electrical and Electronic Equipment (WEEE) and the Reduction of Hazardous Substances (RoHS) has greatly impacted on recycling processes and hazardous chemicals limitation and elimination. The RoHS directive is closely linked to the WEEE directive. The EU directives restrict the use of six hazardous materials in quantities exceeding maximum concentration values in the manufacture of various types of electronic and electrical equipment (Madden and Weißbrod 2008; Forge 2007). The six materials covered are lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE). For ICT casings as well as components, the arrival of RoHS in 2006 has required plastic resin suppliers to eliminate the brominated chemicals used to achieve flame retardancy; they contain myriad of highly volatile chemical substances (i.e. cycoloy) to achieve flame retardancy. The Restriction of Hazardous Substances (RoHS) Directive that came to force in the UK in 2006 regulates the use of harmful chemicals in products (Griffiths 2008). Overall, policy intervention is often needed where the market fails to address environmental problems (Plepys 2002).

4.3.4. Corporate Sustainability Actions

4.3.4.1. Corporate Sustainability: ICT Users and Producers

Mitigating the negative environmental impacts of ICT is the responsibility of both ICT users - organizations - and producers. Corporate sustainability strategies have a pivotal role in supporting sustainable development. Corporate sustainability is the road to achieve the goals of promoting sustainable technologies in terms of design, production, operation, application, distribution, provision, and disposal. Looking at the whole life cycle of ICT products and services, it is conspicuous that both the ICT users and producers are involved. It is up to all involved in production, use and disposal of ICT to understand and implement 'Green ICT' policies (Forge 2007). However, the whole ICT community should take a stand to ensure emissions and pollutions savings across all operations, software, hardware and infrastructure including the manufacturing processes with design for recycling and energy efficiency (Ibid). This can be an opportunity to reach consensus on how to address environmental issues of ICT design at a large scale. To this end, both ICT-enabled organizations and ICT sector need to come together and realize the risky impacts of ICT on the environment so to collaboratively tackle the problem. ICT businesses, chief information officers (CIOs) and IT managers as well as the business users must be active participants (Forge 2007). The route is first to debate with the ICT-enabled organizations on streamlining the applications portfolio, followed by data center reconfiguration to cut energy and cooling. ICT procurement is the next crucial phase to get the message through to suppliers who won't move without user pressure (Ibid). Overall, both ICT users and producers need to identify the materiality of key sustainability issues and prioritize the relative risks and opportunities. Besides, the goal of creating a sustainable world requires concerted action of all sectors in society.

4.3.4.2. ICT-enabled Organizations

ICT seem to be a genuinely socially responsible sector (Raths 2006). ICT-enabled organizations should rethink the whole corporate IT strategy, especially energy usage and GHG emissions. This relates to direct effects of ICT on climate change that arise from the application and use of ICT. The key tool for ICT users is to rationalize the usage of ICT equipment at all levels through virtualization; 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 (Forge 2007). The so called green IT strategy can be effective in this regard, and also sustainability should be a part of organizational culture. This will enable ICT-enabled organizations to achieve the goal of reducing the negative effects (global warming) on climate change resulting from the application and use of ICT. That said the efficiency of data center's energy should be a top priority as well for ICT users as for producers' corporate policies to help achieve effective results in terms of cutting energy consumption and alleviating global warming. While corporate image may also have a role, environmental considerations tend to come second to cost considerations in managing ICT emissions (Griffiths 2008). Also, the poor office management is responsible for approximately 19,000 tons of CO2 (Madden and Weißbrod 2008). It is then necessary for ICT-enabled organizations to change behaviors relating to energy consumption and rethink organizational structures to achieve desired outcomes in this regard. Systemic effects of ICT arise from changes in organizational structures and behavior enabled by the availability, accessibility, application and use of ICT goods and services (MacLean and Arnaud 2008). From this perspective, the large-scale economic choices made by organizations about how to use ICT to change their structures and behaviors will play a potentially significant role in determining whether there is a successful global response to the challenge of climate change (Ibid). The cost of nondomestic electricity is increasing tremendously so controlling electricity use has become more important to ICT-enabled organizations (Griffiths 2008).

From legislation perspective, general measures restricting the total carbon emissions of organizations may have more impact than ICT-specific legislation (Ibid). For instance, in 2007 Energy White Paper introduced the Carbon Reduction Commitment (CRC), a mandatory emissions trading scheme for large organizations. However, the CRC excludes outsourced data centers from an organization's requirement to report emissions that it is responsible for, which creates an incentive for companies to outsource data centers, doing nothing to reduce emissions (Ibid). In terms of corporate attitudes as to putting ICT emissions reductions into practice, there is much scope for improvement in certain areas, albeit the energy use of ICT is moving up the corporate agenda (Griffiths 2008):

- Measurement: 42% of executives responding to an Economist Intelligence Unit survey (EUI) said their organization does not monitor its ICT-related energy spending.
- Accountability: often the ICT department of a company is not responsible for the company's energy bills.
- Procurement: 63% said reliability was a critical factor in ICT procurement and 32% said price while only 12% said that energy efficiency was critical.

4.3.4.3. Giant Technology Companies

ICT sector – giant technology companies - has the capacity as well as the opportunity to drastically improve, through design, how technological artifacts can be produced, used and disposed of. This can be done by producing products that use less material; require less energy; are recyclable, and contain fewer potentially hazardous materials while devising sophisticated industrial processes to prevent their leakage or release to the atmosphere. Some initiatives in this regards have been evident for quite long in CT sector. The adoption of lifecycle thinking by large companies, and its integration into the design and production of their products is being fostered by various influences, including environmental concerns associated with land-filling and incineration of waste material, as well as an increasing realization that resources stocks must be conserved (Shu-Yang et al. 2004). This is also being driven by stakeholders (i.e. consumer) choice that is becoming increasingly reflective of environmental concerns (Ibid). All giant technology companies should integrate ecological sustainability into their business processes, procedures, and planning to help mitigate the negative effects of unsustainable ICT on a variety of stakeholders. Espousing corporate sustainability trend is the way to strategic sustainable development (SSD) that seeks to guide and help all economic sectors to agree upon concrete ways to take action together to implement sustainable development on a global scale. Corporate sustainability can also be a strategic model and choice to promote environmental sustainable design ICT. Its premise is to understand and act upon the demands and concerns of stakeholders (i.e. consumers, communities, opinion leaders, investors, policymakers). The changing roles of ICT sector and the focus on sustainable development, rather than simply development, have meant that ICT design decisions need to be made with different stakeholders in mind. Corporate strategies in ICT sector tend to have a potentially significant role in radically improving product design processes - sustainable practices - as ICT producers are directly responsible for ICT impacts on the environment - at least the main contributor in information/digital society. Besides, it is in ICT sector's interest to be aware of the longer-term environmental benefits of sustainable business practice (Madden and Weißbrod 2008). This will enable ICT sector to sustain profitability while thinking strategically and acting proactively to mitigate the negative impacts on the environment and society. In line with that, Dunphy et al. (2003) argue that the sustainable organization can pursue the traditional core business objective of maximizing profit, but should go beyond the financial performance by actively promoting socio-ecological sustainability values and practices.

Corporate awareness of sustainability concerns has been evident for more than two decades (Samuel and Lesley 2007). Within this trend, ICT companies are increasingly launching eco-friendly ICT products, including electric-efficient products (i.e. computers, peripheral devices, TVs), non- or less hazardous products, and recyclable products (Lee 2009). This basically comes from the motivation to increase business profits by satisfying consumer demands as to lowering consumption of electricity and spending, and, more importantly, it carries profound intention to contribute to the reduction of GHG to alleviate global warming (Ibid). Moreover, the problem of e-waste has long been acknowledged by manufacturers in the computing industry (Samuel and Lesley 2007). For example, Xerox has set 'zero waste' as a corporate goal as it recycles 95% of their electronics equipment, which keeps millions of tons of waste from the landfill (Cramer and Ab 2001). Sony is another example of an organization that is attempting to pursue the high road to corporate sustainability. Sony's attempts at ecological efficiency focuses on the reduction of hazardous waste in the production process (Sissel et al. 2003). It has even launched and extended its efficiency approaches to ecological sustainability. For instance, in its second-generation television, Sony has reduced plastics by 52 %, increased recyclability to 99 %. Sony is now moving beyond the production and cost efficiency basis of earlier initiatives to fully adopt corporate sustainability trend (Ibid). In the same vein, Dell promotes a strong message of sustainability through recycling programs, reduction of hazardous materials and energy management (Dell 2007). Business Ethics Magazine annually publishes a list of best technology giant companies, assessed across a range of metrics including environmental responsibility (Raths 2006). Examples of ICT giant companies that consistently feature in the top ten companies, primarily on the basis of their environmental efforts include: Dell, Apple, IBM, Sony, and HP. However, Microsoft is notable for its absence. Microsoft reactively does what it legally has to do and does it well with few meaningful sustainability initiatives in place (Samuel and Lesley 2007). The company adopted a set of environmental principles in 2006 and supports waste recycling and carpooling (Ibid). Their e-waste initiative was launched on 7 March, 2007(Microsoft 2007). Dell re-branded itself as a company committed to sustainability and integrates sustainability with key business strategies. Sustainable Business Manager (Arbogast 2006) sees his position as protecting the company's future and sees a wider commitment to sustainability as crucial: stakeholders, socially responsible investor groups. Rosenberg (2004) described a similar position at HP: Corporate, Social and Environmental Responsibility - a long legacy of 'core objectives, which included good citizenship and responsible business practices.' According to

Willard (2005), companies 'do the right things' so that they are successful businesses and companies are successful businesses so that they can continue to 'do the right things'. Such companies are described by Willard (2005, cited by Samuel and Lesley 2007, p. 158) as 'driven by a passionate, values-based commitment to improving the well-being of the company, society, and the environment, the company helps build a better world because it is the right thing to do.' The drivers for such initiatives remain unknown, but have been legitimized through financial sector activities such as the Dow Jones Sustainability Group Index (DJSGI) and the FTSE4Good. Noticeably, this argument correlates with the premise of corporate sustainability which is considered, according to (DJSGI), as a business model that creates long-term shareholder value by embracing opportunities and managing risk from economic, environmental and social dimensions. Corporate sustainability has a positive impact on shareholder value as demonstrated by indices such as the Dow Jones Sustainability Group Index (Signitzer and Prexl, 2008). DJSGI and FTSE4Godd indices are used to measure the performance of companies that demonstrate socially responsible investment standards and provide ethical investment options.

CHAPTER FIVE

DISCUSSION

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 negative environmental impacts of the current mainstream ICT design approach. Then, the discussion carries on about potential remedies for unsustainable ICT design, which is framed into environmental and corporate sustainability perspectives. This is to draw a full picture of how the goals of sustainable design can be achieved. In addition, the author discusses some weaknesses and strengths of the current study. In this section, the thematic approach is used whereby the discussion is structured into categories in accordance with the topics addressed in the results section. That said the discussion is divided into two sections that are, in turn, divided into subsections according to the previous section.

1. Negative environmental impacts of the current mainstream ICT design approach.
2. Potential remedies for unsustainability of ICT design.

5.2. Negative Environmental Impacts of the Current Mainstream ICT Design Approach

As detailed in the results section above, the current mainstream ICT design approach is regarded as unsustainable due to the negative effects of ICT products associated with resources depletion, energy-intensive consumption, toxic waste generation, and hazardous chemicals use. It was found that ICT products don't comply with the first three sustainability principles (SP1, SP2, SP3) concerned with environmental issues. According to Holmberg et al. (1996) and Ny et al. (2006), nature is not subject to systematically increasing (SP1) concentrations of substances extracted from the earth's crust (i.e. fossil fuels, metals); (SP2) concentration produced by society (including hazardous chemicals and persistent substances, i.e. PVC, PBB, PCB); and (SP3) degradation of natural systems by physical means (i.e. land-filling). Thus, the prevailing ICT design approach overlooks the ecological sustainability factors pertaining to resources replenishment; renewable energy use; recyclability and reuse; and safe and efficient material.

5.2.1. Resources Depletion: Extraction and Manufacturing

There are issues to consider when manufacturing ICT products, including the non-renewable nature of some materials and their relatively short supply (scarce elements). Material selection has an impact on the environment so when specifying materials, the ICT design should consider alternatives that reduce the variety and the amount of materials that affect the weight of the product; use materials that are considered to have less adverse environmental impact; and use materials that can be recycled and reused. Environmental impacts of ICT products derive directly from the life cycle, which concerns not just energy-intensive consumption, but also the extraction and disposal of materials. It is evident that longer useful lives would lead to mitigate environmental impact as fewer products would be manufactured and fewer products would have to be recycled (WSIS 2003, 2005). However, the current mainstream ICT design approach encourages resources depletion, owing to the huge amount of metals and scarce materials extracted to manufacture ICT products. The manufacturing of electronics starts with resource extraction, which is highly material and energy intensive (Plepys 2002). This violates the first environmental sustainability principle (SP1).

Different studies found that manufacture of ICT, especially PCs, laptops, and mobiles, requires huge amount of raw materials - material intensity- such as heavy and toxic metals, (deionised) water, scarce elements (i.e. gold), fossil fuels, and so on. Additionally, it was found that electronic components increasingly use new compounds based on scarce elements, which are responsible for large material displacement and generation of huge quantities of mining. The ICT design should consider the environmental externalities of sourcing and using these scarce material and find alternatives that support natural resources replenishment and save energy - reduce GHG emissions - required to extract these rare materials. The studies on the scarce elements used in ICT industry provide interesting detailed statistical data, but no further initiatives are looked upon as to potential solutions to resource depletion or ongoing research studies on what can be done to avoid the problem or propose alternative materials to manufacture ICT products. Thus, the findings from the current studies address only ecological issues such as ecological backpack of scarce material intensity used in terms of tons in electronic components.

5.2.2. Energy Consumption and GHG Emissions

5.2.2.1. ICT Product Life Cycle

Energy efficiency is a key challenge when it comes to the design of ICT products as well as manufacturing processes. The results detailed above signifies that the current mainstream ICT design approach overlooks energy efficiency factor (or the improvements in this regard tend to be very sluggish), which subsequently impacts on the climate change through GHG emissions resulting from continuous energy-intensive consumption throughout the whole lifecycle of ICT products. Findings of studies converge regarding the fact that the large part of the environmental impact (high energy consumption and GHG emissions release) of ICT products comes during its use and then manufacture. It was found based on the life cycle assessment (LCA) methodology that the use phase of ICT has the largest environmental impacts as they are strongly related to fossil fuels (IPU/AC 1998). This shows how critical the impacts of user phase of ICT on the environment are. Analysts estimate that the manufacture, use and disposal of ICT equipment contribute around 2% of global emissions of CO2 (Griffiths 2008). 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 equipment will conserve energy in the future. This is due to the fact that ICT infrastructure is very complex, and it also is hard to measure the impacts because of other complicated factors such as organizational structures and behavioral choices relating to systemic effects of ICT. There is a high risk that efficiency gains will be compensated for by rebound effects, and that the energy demand as well as GHG emissions caused by ICT production, use and disposal will grow to serious problems (WSIS 2003, 2005). The electricity demand of new ICT services and the more intensive use and the diffusion of existing services exceed by far the energy conserved by efficiency improvements (Ibid).

5.2.2.2. Data Centers

Certainly, data centers are energy-intensive users and generators of GHG emissions due to many factors, including their complex structure, poor office management, and unsound corporate ICT strategy, as well as human and organizational behavior. This may pose some uncertainty issues as to whether the ICT design approach should focus on reducing total emissions from manufacture and disposal or producing new equipment that is more efficient in use. At global level, the total electricity generating capacity for data centers is always considerable, yet it depends on the number of data centers a country has. 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. The use of ICT is growing faster than before compared to other sectors such as airline industry. Results indicate that the key issue of energy-intensive consumption in data centers occurs mostly because of the ineffective utilization manifested in the several commodity servers idle which needlessly use electricity and drive up CO2 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. Most findings confirmed that the data centers are GHG generator and energy-intensive consumer. It poses a real challenge for ICT design to consider such ecological factors when improving technologies to cut energy consumption to reduce the GHG effect and eventually decelerate climate change.

5.2.2.3. Software Technology

While software technology is assumed to play a pivotal role in reducing GHG emissions and subsequently alleviating global warming, it was found that it produces less energy efficient software in terms of energy requirement. The phenomenon of planned obsolescence remains the culprit in this regard as it drives the whole design philosophy of ICT products and service towards more flaws and externalities. The current software utilities (i.e. operating system) upgrades are a planet killer because they devour energy. Software producers and vendors are primarily responsible for the problem. Difficulties encountered usually concern repairing equipment and the low price of new components because of the lower quality, which makes it difficult for consumers to resort to repair or replacements. There is also the problem of incompatibility associated with software technology as many computer applications and utilities become obsolete once new version or upgrade come out. Further, the problem of lacking compatibility among different software packages requires a new version of the system and then new, powerful computers or laptops, ending in the obligation to acquire new device even if the previous one is still functionally useful. All this shows that the software industry has ignored the externalities of its poor software engineering (design) and, as

(Forge 2007) argues, the continuing descent in its performance achievements regarding the parameters that really matter.

5.2.3. Toxic Waste and Hazardous Substances

5.2.3.1. Waste Disposal

Another negative impact of ICT on the environment is toxic waste disposal. This obviously results from the unsustainable practice of ICT design. ICT equipment is usually not designed to be recycled or re-used, rather for disposal, which is the worst option environmentally. The prevailing planned obsolescence phenomenon in the ICT design plays a central role in fueling the problem. Results show that this phenomenon is deliberately embedded in the product design and service development; it is even a strategy espoused by most technology giant companies in order to reap economic gains, manipulate consumerism, and drive up throw-away mentality. This finding is based on the exploration of the websites of giant technology companies as well as on studies carried out in this regard. Increasingly ICT products are becoming like consumer durables and finding new sales in the ICT industry comes from design which makes us want to update to the latest and greatest – whether be it mobile phones, laptops, desktops, or server, etc. (Forge 2007). The planned obsolescence is affecting ICT users through shaping their behaviors and attitudes towards unsound pattern of consumerism as to ICT products and services. This is causing serious environmental problems. The consumerist's throw-away mentality has a strongly negative effect on the planet, in terms of pollution levels, natural habitats, and ecosystems (Ibid). Most vendors fuel this mentality as they deliberately charge higher prices for repair services or avoid carrying parts for ICT products. For instance, in the case of a failed screen of a mobile phone or laptop, a printer DC power supply or ventilation system of a server the only course is to dispose of it since it is sometimes demanding to find replacements parts. Consequently, this discourages consumers to resort to such options. What makes it even worse is that the model cycles in ICT products and services are increasingly getting shorter, which remains a questionable strategy in environmental terms.

The design model of ICT remains the conundrum of the huge amount of waste generated from the disposal of ICT equipment, which is becoming a serious issue, due to its environmental consequences. The toxic waste disposal pollutes land, water and air that are the most important elements for human life. Indeed, electronic waste management is a growing global concern in ICT industry because of toxicity complications resulting from the non-responsible disposal of electronic components that contain hazardous substances, such as lead, cadmium, mercury, selenium, PCB, PBB, PBDE, PVC, etc. The infrastructure to manage electronic waste properly is still poorly developed (Plepys 2002). The recycling of electronics is technically problematic or simply lacks an appropriate physical infrastructure (Ibid).

The negative environmental effects of mounting consumption of electronic products are most visible in the end-of-life stage (Ibid). Findings from different studies carried out at international level (WEEE, Gartner, GeSI) correlate with regard to the growing waste generation from ICT equipment. Other studies have looked into end-of-life management of electronic and how this directly fuels the waste problem. Some similar studies show that there is a movement towards taking initiatives of recycling and complying with recycling policies among giant companies in ICT sector (i.e. Xerox, IBM, Sony), especially in where regulations have been introduced and implemented to prevent electronic waste being dumped in landfills. Nevertheless, a closer look at the whole problem of waste depicts that although encouraging or mandating recycling, tons of obsolete ICTs (i.e. computers, televisions, and cell phones) are still being produced per day. This shows the failure to develop concrete strategies that focus on designing out waste to avoid externalities in the first place and throughout the whole lifecycle of ICT products. The recycling of electronics is not feasible economically, or simply lacks an appropriate physical infrastructure, which will require huge investments to build (Ibid).

5.2.3.2. Hazardous Chemicals

The continuous use of toxic hazardous chemicals in the manufacturing of ICT adds to unsustainable practices of the mainstream ICT design model. Apart from ICT manufacture, toxic hazardous chemicals are also used to extract the metals from the ores. The act of dumping a major chunk of computers into landfills or even recycling poses a risk as it may cause some diseases, especially for scrap worker or those who live nearby landfills. Hazardous and synthetic chemicals remain a thorny and contentious issue within all industries because phasing them out the industrial equation or finding alternatives may demand heavy investments in R&D in this regard. Changes on this line will require heavy investment in innovation and research and development (R&D) to enable a radical improvement in the design processes of ICT. A great deal of research studies has focused on the impacts created by the ICT industry's processes as to the disposal of ICT and related environmental adverse effects. Despite of awareness of the environmental risks, the replacement of toxic substances in ICT industry remains uncertain, owing to the complexity of the industrial processes associated with the production of technologies. Failing to promote and sponsor sound innovations in this domain, especially from governments, will continue to produce synthetic chemicals and more compounds substances for economic purposes. Synthetic chemical production has escalated including domestic chemicals and hazardous substances, in addition to the introduction of new products embedding new chemicals with long-term toxic effects on both humans and other organisms (Emden and Peakall 1996). When electronics are landfilled or not disposed of properly, toxic chemicals are likely to leak leading to environmental damage- water and air pollution and the contamination of land. And when incinerated, the process releases heavy metals into the atmosphere as ashes, as well as hazardous chemicals and GHG that attack the ozone layer.

Studies show that using chemicals is predicted to be only reduced in a very slow rate in the manufacturing of ICT but their elimination remains highly uncertain. It was found that a considerable amount of chemicals are needed to manufacture ICT products. Such chemicals and persistent substances include: lithium, cadmium, mercury, lead, polychlorinated biphenyls (PCBs), hexavalent chromium, polyvinyl chloride (PVC), polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), selenium, antimony trioxide, etc. For instance, one computer is made of more than 1000 different materials, of which a lot are toxic (i.e. heavy metals) (WSIS 2003, 2005). The significant amounts of the heavy metals and toxic substances contained in electronics are gradually released into the air, land and groundwater - the biosphere - which are the source of life for humans. Although there is an awareness of the importance of protecting the biosphere, humans continue to systemically degrade it through irresponsible and unsustainable design of human systems.

5.3. Potential Remedies for Unsustainability of ICT Design

This section looks at some potential remedies for mitigating unsustainable ICT design framing the discussion into environmental and corporate sustainability perspectives. These remedies are particularly proposed for resource depletion; energy-intensive consumption, toxic waste, and hazardous materials use associated with ICT products. This is to shed light on how alternative design solutions can be devised based on the principles of sustainable design whose philosophy is to design technologies that comply with environmental sustainability.

5.3.2. 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. Thus, it is certainly of import to call to mind the significance and timeliness of strategizing ICT design with sustainability in mind. Further, 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 innovation.

As in all areas of design, it is necessary to rethink product design strategy in ICT in a way to embrace green movement 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 we have been doing for a long time. Thus, adding environmental sustainability principles to ICT design is an effective strategy to minimizing risks and unplanned long effect externalities. However, 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 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 and resource depletion caused by current ICT industrial paradigm. The expansion of ICT markets is based on the expansion and intensive consumption patterns of resources (material and energy). 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 ever more frenetic consumerism fueled by the phenomenon of planned obsolescence incorporated in ICT design strategy. Rather, ICT design strategy needs to revisit the current tactics and rethink ongoing practices. Explicitly, any alternative should be directed towards environmental performance and responsibility. ICT design, operation, and disposal constraints form a significant corporate concern for both ICT-enabled organizations and ICT producers. Some organizations are accepting environmental responsibilities and responding to corporate sustainability. 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, adoption of sustainability measures and indicators for reducing GHG emissions, compliance with take-back, recycling, and toxic disposal bans policies. 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 toxic material, land and water pollution, and GHG emissions, energy consumption, transport.
2. Product design – redesign for recycling parts and materials, eliminating toxics, lower energy consumption in use and production, less packaging and reusable packaging.
3. Manufacturing facilities – reduced energy consumption, powered by renewable energy sources with zero emissions, reduction in toxics and waste in construction and operation, elimination of land and water pollution, reduced GHG emissions.

Adding to the criteria of sustainable design, bio-mimicry and renewability are also important elements to consider in ICT design strategy. Redesigning systems on biological lines through mimicking natural patterns, processes, and rhythms enables the reuse of materials in continuous closed cycles. For the renewability, transporting materials used in ICT manufacturing should come from bioregional and sustainably-managed renewable sources. Next, the author discusses the results regarding potential remedies for current unsustainable ICT design framed into environmental and corporate sustainability perspectives.

5.3.3. Dematerialization: Material Reduction and Digitization

Dematerialization is an effective strategy to address the issue of resource depletion when designing products; its potential can be well utilized in ICT design. Dematerialization aims at both reducing the quantity and the number of materials and the resources used in manufacture, use and disposal of ICT products. The ICT product design activity has to undergo a radical improvement by planning dematerialization and increasing use of material flow analysis in early stages of ICT product development. However, there is still limited knowledge about how far some types of ICT equipment will dematerialize and on the future average useful life of ICT (Casal et al. 2005). Progress in the direction of dematerialization is only a necessary, but not a sufficient, condition for approaching the goal of sustainability (WSIS 2003, 2005). Nevertheless, material selection has an impact on the environment so when specifying materials, ICT design should consider alternatives that reduce the variety and the amount of materials that consequently affect the weight of the product; use materials that are considered to have less adverse environmental impact and can be recycled and reused. Green design is to engineer processes and products holistically using systems, and environmental impact assessment tools (Abraham and Nguyen 2003). ICT design should consider life cycle thinking (LCT), integration of the environmental impact caused by products throughout all life cycle stages early on in the product design and development processes to make decisions to improve the environmental performance of ICT products. The life cycle thinking reduces adverse environmental impacts associated with the extraction and processing of raw materials, manufacturing, use, and disposal.

In addition to material reduction, digitization initiatives have been undertaken by ICT companies in different sectors, including Sun Microsystems, IBM, HP, Nokia, Ericsson, Microsoft, etc. through offering access to the dematerialized world of computing with new product and service range. Dematerialization potential is the most important opportunity created by the fact that ICT can help to optimize processes and products as regards their material and energy efficiency and organize innovative services that can replace material products in many cases (WSIS 2003, 2005). This also holds a much greater potential for energy saving and recycling. Moreover, reducing the demand for ICT remains a critical factor for dematerialization strategy to bring fruitful outcomes because demand for ICT is projected to grow exponentially in the future. Planned obsolescence that encourages throw away mentality and frenetic consumerism is also crucial factor that ICT sector should capitalize on when developing dematerialization strategies. Much has to be done as to ICT design innovation to combat planned obsolescence and encourage more rational consumption patterns. A sound approach could be to double the life of ICT equipment (i.e. mobiles, PCs, laptops, servers etc.), extend operational life through re-use and encourage the shift to service mode instead of physical products ownership.

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 some 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).

5.3.4. Energy efficiency and GHG Emission Reduction

5.3.4.2. De-carbonization

Energy efficiency and use of renewable energy sources are potential solutions to alleviate global warming for which the GHG emissions are the main culprit. Again, the ICT design has to explore new opportunities to make efficient products, or rather embed sustainably-managed renewable energy sources in their operation. However, the whole life impact of ICT equipment is much more difficult to measure than the in-use energy consumption as it is spread through a long supply chain (Griffiths 2008). ICT indirect impacts are significantly higher than direct impacts but much more difficult to measure at the macro level (MacLean and Arnaud 2008). This is because 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. Also, designing ICT equipment with extended operational life through re-use holds a much greater potential for energy saving.

De-carbonization initiatives - exploration and use of renewable energies and developing less carbon-hungry ICT equipment remains potential solution to the impact of ICT on climate change. Concrete applications of these solutions depend on sustainable practices and principles in the ICT design. Besides, energy efficiency brings economic benefits to both ICT users and producers; hence there has to be a convincing reason why ICT sector should embrace this opportunity and strive to turn it into reality. This basically comes from the motivation to maximize business profits by satisfying consumer demands as to lowering consumption of energy and spending. Findings suggest that the estimation of carbon emissions savings must come from more efficient energy use of ICT considering ICT equipment tends to have a large share of energy consumption and will even grow to make up around 45 % of all appliance-related electricity use in Europe. However, the fraction of total electricity consumed by ICT is steadily increasing, despite tremendous efficiency improvements on the level of electronic components (WSIS 2003, 2005). Consistent with that, MacLean and Arnaud (2008) point out that increased efficiencies will not necessarily translate into reduced GHG emissions because of a phenomenon known as the Khazzoom-Brookes Postulate - the Jevons Paradox. In a recent report, economist Jeff Rubin (2007, cited by MacLean and Arnaud 2008, p.6) describes this phenomenon as an 'efficiency paradox' in which technology improvements allow for energy savings that are lost to greater consumption.... 'Improvements in efficiency have done little to reduce actual energy consumption, as consumers take advantage of those gains to drive bigger cars farther, or heat larger homes.' Consequently, improving the efficiency of ICT equipment directly, paradoxically, may result in greater GHG emissions and not less (MacLean and Arnaud 2008). This is also referred to as rebound effects where the increased energy efficiency may result in overall reduced costs which, in turn, result in increased demand and consequently an overall increase in energy consumption and concomitant GHG emissions.

5.3.4.3. 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, many design solutions are suggested to deal with the issue of CO2 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, in addition to technological adjustments and improvements. Such solutions are practically implementable and can contribute significantly to energy saving in data centers instead of simply assembling a collection of improved components that will not necessarily result in effective outcomes as to energy saving. Initiatives to implement new solutions depend on the priority of the data center's energy efficiency in terms of corporate ICT strategy. At implementation level, change is taking place in ICT-enabled organizations across the globe and subsequently saving a great deal of energy. New ICT devices allow organization to use less energy in addition to other improvements including better air quality and less noise pollution. But powering the data center with renewable energy is still at its early stages with a few recent implementations. For instance, Google and Fujitsu are turning to emissions-free power sources for data centers by installing solar roof power supply on data center buildings.

More research in ICT design innovation and technological change is underway in EU, USA, Japan, UK to develop upstream solutions to the data centers dilemma, especially to the problem of ICT devices' 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 ecological considerations in the design processes instead of just taking voluntary actions (CSR) - 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 users due to their greater impact than ICT-specific legislation. As far as metrics are concerned, there are diverse solutions in this regard but the power usage effectiveness (PUE), which is defined as the total power going into a data center divided by the power used by the ICT equipment is considered one of the most effective solutions as metric to quantify improvements in the data center. The US Environmental Protection Agency 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).

5.3.4.4. Software Technology

Based on different studies, ICT have a significant potential to enable new solutions to environmental challenges relating to energy efficiency, GHG emission reduction, and waste elimination, etc. The use of ICT can contribute more positively to the environment, potentially saving far more than its own direct negative impact. The positive ecological dimension rests on ICT's potential to deliver greener products and increase consumption efficiency through dematerialization, e-substitution, virtualization, ecological product life optimization, etc. (Reisch 2001). The software technology is deemed to be the biggest contributor to such initiatives through providing the tools that allow the measurement, monitoring, and modeling of environmental systems. Examples are countless in this regard, among them include: GIS (Pearson and Ross 1994; Mann and Benwell 1996); system models – nutrients (Smaling and Fresco 1993); climate change modeling (Shackley and Wynne 1995); remote sensing (Duvernoy et al. 1994); modeling complex systems eg rangelands (Redetzke and Van Dyne 1990); human system modeling (Luckman 1994); participatory modeling (Marr, Pascoe et al. 1998) and so on. The global conservation organization (WWF 2008) suggest ten uses (see appendix G) of ICT in other sectors that could each reduce global CO_2 emissions by at least 100 million tons by 2020. 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. This complexity requires the involvement of ICT systems in enabling and promoting sustainable development and green ICT as well.

In some ways, it however seems that ICT technology development is going backward due to environmental adverse effects that compromise the ecological dimension of ICT, particularly energy intensive consumption because of upgrade and replacement cycle fueled by the phenomenon of planned obsolescence ingrained in software technology design. This is manifest through the new and upcoming releases of large software utilities whose producers deliberately tend to entice the acquisition of new devices and render obsolete previously serviceable devices. But the growing use of free software is a trend that tries to combat this problem on the software side (WSIS 2003, 2005). As to the software incompatibility issues, new directions in software technology are called for in terms of ways to make applications constantly and consistently compatible with older versions (Forge 2007). However, transformational and systemic impacts of ICT on the environment are difficult to be controlled and measured as they arise from dynamic changes in organizational and social structures and behavior enabled by the availability, accessibility, application and use of ICT services, which compromise the ecological dimension of ICT. Therefore large-scale organizational and social choices made by individuals and organizations about how to use ICTs to change their structures and behaviors will play a potentially significant role in responding to the challenge of climate change (MacLean and Arnaud 2008).

5.3.5. Recyclability and Mitigating Hazardous Chemicals

5.3.5.1. Recycling Materials

The solution to toxic e-waste as a negative environmental impact of ICT is to design out waste from ICT products - to be recycled and reused in the end of their useful life. Reuse is usually an effective approach to increase a product's lifespan and a key factor to consider in ICT design. Extending ICT equipment's operational life through re-use holds a much greater potential for recycling (Madden and Weißbrod 2008). Yet an ideal solution would preferably be a combination of different techniques including recycling, re-use, upgrade, use of unobjectionable materials, and repair (WSIS 2003, 2005). ICT products should be designed to have a prolonged useful life and be easy to upgrade and repair through using common parts or components that are used for multiple models in the product family allowing for reuse; standardized parts that are easy to replace or repair; and modules. Design for environment involves modular design that allows for upgrades, easy refurbishment or parts replacement, and simpler dismantling for re-cycling or disposal (Greenpeace, 2005). From a conceptually different angle, ICT design should consider life cycle thinking (LCT), integration of the environmental impact caused by products throughout all life cycle stages early on in the product design and development processes in order to make decisions to improve the environmental performance of ICT products. It is better to design out waste in the first place, rather than to deal with it afterwards (Greenpeace, 2005). This can be considered as an upstream solution to the problem of waste since it focuses on the origins of the problem, as opposed to the effects of it – downstream solution.

Research studies about sustainable use of materials in design have focused dematerialization strategy in terms of both material reduction and digitization yet mimicking natural designs, patterns, and processes as remains an ideal path to sustainable design. Hawken et al. (1999) argue that redesigning systems on biological lines enables the constant reuse of materials in continuous closed cycles. Also, recycling is a major move now starting in earnest across the globe. Recycling industry is booming, especially in the major European counties, such as France, Germany, and UK (Forge, 2007). This blooming ecosystem market for recycling seeks to confront planned obsolescence by extending the physical life and the service warranty of equipment (Ibid). This with decreasing prices on maintenance services and essential spare parts can entice consumers to use ICT equipment for longer before they migrate to the new generation. It is noteworthy to mention that this industry can coordinate and cooperate with ICT producers so they can work collaboratively to green ICT product design.

5.3.5.2. Mitigating Hazardous Chemicals

The issue of hazardous chemicals is highly relevant for discussing potential remedies for unsustainable ICT design. Ideally, ICT design should eliminate persistent substances (synthetic chemicals). Except for a few successful technical solutions yet unfeasible economically, studies on this matter show that most of the current efforts tend to focus on limiting rather than on eliminating hazardous chemicals as it seems almost impossible to do without them in ICT production. Realistically, the sustainability efforts (Green ICT initiatives) for finding potential remedies to toxic substances should focus on designing eco-friendly low rather than on non-noxious ICT products. Whether reducing or eliminating hazardous substances, this should be considered as one of the priorities in ICT product design. ICT design should reduce the use of substances that require special handling or disposal during the product recycling process. That said when hazardous substances other than those that are restricted cannot be avoided; they should be identified during the design process indicating why they cannot be avoided.

Some policy initiatives, as detailed in the results section, have been recently implemented in Europe, which ban the use of hazardous materials in ICT manufacture (including lead, mercury, cadmium, hexavalent chromium, PBB, and PBDE). Appropriate information on the prohibitions and on the use of hazardous substances parts requiring special handling should be made available to ICT designers to ensure legal compliance at international level. Those initiatives may encourage ICT sector to adopt up-to-date measures in the product design process in a way to, at least, avoid using the most dangerous chemicals as a first step to produce clean and safe technology. If properly designed and implemented, these policies can eventually affect product design and induce innovative business approaches that could be less toxic material intensive (Plepys 2002). An example of the eco-friendly ICT production is the manufacture of parts of mobile phone bodies using eco-friendly plastic made from fermented corn, the production of low-hazard chargers and peripheral devices, and the development of ink using vegetable oil (Woo-kyun Lee 2009). These are concrete application of new innovative solutions to the problem in question. However, similar efforts need to be encouraged and expanded to include more of ICT products most demanded by consumers, such as laptops, PCs, servers, mobile phones, etc.

From a different perspective, there are ongoing research studies in the field of nanotechnology, particularly in materials and chemicals and their manipulation and control at an extremely small scale – at sizes of millionths of a millimeter – in the process of design, production and application of devices and systems (i.e. ICT). Based on results, this is promising and projected to revolutionize the ICT manufacturing processes, yet there are risks and uncertainties, owing to lack of evidence as to some applications regarding production of nanoparticles that may be associated with toxicological effects on the environment if accidently released from products in which they are fixed or embedded. However, as general agreement in nanotechnology, there is no justification for imposing a ban on them. There is no information available about the effect of nanoparticles on species other than humans or about how they behave in the air, water or soil, or about their ability to accumulate in food chains (Dowling 2005) like mercury for instance. Nevertheless, as a precautionary measure, manufacturing facilities and research laboratories should treat manufactured nanoparticles as if they were hazardous and reduce them from waste streams (Ibid).

5.3.6. Corporate Sustainability and ICT Design

5.3.6.1. ICT Sector and Unsustainable Design

Based on the previously discussed issues, it is apparent that ICT sector carry a big responsibility for the negative impacts of unsustainable ICT design, and that it should come up with remedies for its products' adverse environmental consequences relating to resource depletion, energy-intensive consumption, GHG emissions, toxic waste generation, hazardous chemicals use, etc. ICT sector must rethink and develop new corporate strategies that embrace and promote sustainable development including green design to achieve sustainability. ICT have become a significant global environmental issue due to the prevailing unsound ICT design strategy. The top priority should be given to sustainable design practices through applying the guiding principles of environmental sustainability. The problem of ICT design should rather be recast based on environmental performance and responsibility. This emanates from corporate sustainability strategic model developed to respond to all environmental issues faced by ICT sector, including those related to unsustainable design. Salzmann et al. (2005) argue that corporate sustainability is a strategic corporate response to environmental issues caused through the organization's activities and operations. Further, it is beneficial to focus on both upstream and holistic solutions when designing technologies in order to shun worsening the looming environmental global issues. According to Abraham and Nguyen (2003), green design is to engineer processes and products holistically using systems thinking. It is then required to understand the accumulated scientific knowledge pertaining to ICT design and ecological sustainability so to create innovative, robust, and well informed approaches to the design of technologies. Calls for embedding sustainability in ICT design have grown from environmental concerns. Overall, designing and building ICT should be based upon both a demand pull and technology push philosophy driven by sustainable development vision. This hybrid form advocates that ICT design should consider both the speed of technological change/innovation while keeping an eye on the demand, concerns and need of different stakeholders relating to sustainability. Sustainability needs to gain more attention as a new philosophy that will drive ICT design strategy in the future.

5.3.6.2. Corporate Sustainability and ICT Sector

In the reminder of the scope of this thesis, the author focuses on the environmental dimension of corporate sustainability while social and economic dimensions are mentioned only to provide a better picture of corporate sustainability strategic model. However, Just as in other sectors, the sustainability challenges facing ICT businesses are complex (Madden and Weißbrod 2008). But this should not prevent the ICT industry from dealing with this issue. In response to the environmental challenges, ICT companies need to take externalities into account regarding corporate strategies. Besides, the challenge for increasing value creation requires a deeper understanding of environmental values than the typical economic approach of short term profit maximization (Brickley et al. 2002). Corporate sustainability strategies have a pivotal role in promoting strategic sustainable development. Corporate sustainability has been used by the corporate sector to seek justification for sustainability strategies within organizations (Signitzer and Prexl 2008). Since this trend is a strategic response to the environmental issues faced, it can e extended in ICT sector to include those concerned with unsustainable ICT design. Salzmann et al. (2005) argue that corporate sustainability is a strategic corporate response to environmental issues caused through the organization's operations and activities. Corporate sustainability encompasses strategies, actions and practices that aim to meet not only the economical needs (i.e. shareholders' value) but also seek to protect, support and enhance the human and natural resources.

The global crisis the planet is facing can only be resolved by the use of concerted corporate action (Dunphy et al. 2003). This entails developing corporate strategies that support sustainable development. Sustainable development is described in *Our Common Future*, a book published by the World Commission for Environment and Development (WCED) in 1987, as a process of change in which the exploitation of resources, the orientation of technological development, and the direction of investments are all in harmony and enhance both current and future potential to meet human needs and aspirations. Through corporate sustainability, ICT firms can thus capture other qualitative criterion as references for their performance, such as environmental protection, social responsibility, and stakeholder relations (Lo and Sheu 2007). This trend enables ICT firms to sustain profitability while thinking strategically to mitigate their negative impacts on the environment. In line with that, Dunphy et al. (2003) contend that the sustainable organization can pursue the traditional core business objective of maximizing profit, but should go beyond the financial performance by actively promoting socio-ecological sustainability values and practices.

5.3.6.2.1. Sustainable Development

There exists a symbiotic relationship between ICT and sustainable development. Designing and using ICT sustainably, could reduce the world's problems. ICT have a significant potential to enable new solutions to environmental challenges relating to energy efficiency, GHG emission reduction, and waste elimination, etc. More to the relationship between ICT and sustainable development, the positive ecological dimension rests on ICT's potential to provide a variety of benefits. Being on the frontier of innovation, ICT industry has the potential to significantly reduce environmental impacts of their own products through greener products; ecological product life optimization; dematerialization and digitization; virtualizations; and e-substitution (i.e. e-commerce, e-meetings), etc. Further, ICT can secure the environment through monitoring and managing energy use; creating more efficient transport systems to reduce GHG emissions; reducing commuting and congestion; producing fewer physical products that consume finite resources; etc. ICT firms need to introduce more technological innovations that support sustainable development by encouraging a better and more rational use of available resources. ICT has been a driver for the global economic development so companies are more and more capitalizing on ICT improvements in a variety of areas trying to find the best path for a sustainable future that becomes increasingly complex. The rewards could even be enormous environmentally, socially, and economically if sustainability drives ICT development. Understanding the interdependence and relationship between the environmental, social, and economic systems will enable ICT firms to think strategically and act proactively through design in order to mitigate negative environment ICT impacts through devising holistic, robust, and innovative design solutions. Undeniably, organizations can be significantly influential in achieving different societal objectives as they are the fundamental gears of modern society. Dunphy et al. (2003) stated that they are instruments of social purpose, formed within society to accomplish different objectives. WCED (1987) remarked that corporations are the engines for economic development; they are required to be more proactive in balancing the drive with social equity and environmental protection as they have been the cause of the unsustainable conditions.

Adherence to the principles of environmental sustainability has become a critical part of the mission of ICT, particularly design and development. In such case, compliance with these principles occurs through implementing the established guidelines and indicators developed to support sustainable design practices. Examples of indicators include: Zero Waste (cradle to cradle), Zero Emission, Cycle Design Wheel (UNEP 1997), indices of GHG emissions, Cleaner Product, Life Cycle Management (LCM), eco-labeling, Life Cycle Thinking (LCT), and prohibitions of hazardous chemicals, etc. Addressing environmental issues are material to all ICT sector. And it is no longer valid that merely providing ICT will translate into sustainable development. It is through sustainable design of technologies that ICT firms can accelerate sustainability movement. Datschefski (2001) contend that sustainability can only be achieved through design. The changing roles of ICT designers and the focus on sustainable development, rather than simply development, have meant that design strategies need to be made with a number of different stakeholders in mind.

5.3.6.2.2. CSR and Corporate Accountability

While realizing the higher strategic value of technologies and their economic benefits, it is necessary for ICT firms to identify the materiality of key sustainability issues and prioritize the relative risks and opportunities. Corporate sustainability is the strategic alternative model to address environmental issues. Dunphy et al. (2003) argue that many corporations need to change the way they do business; new circumstances require new responses.That said ICT firms should embrace both CSR through making a commitment to improve their environmental performance beyond legal stipulations and corporate accountability through committing to accountability for and transparent disclosure of their activities to all involved stakeholders. Friedman & Miles, (2006) contend that a firm can demonstrate its approach to CSR to its key stakeholders by disclosing strategies and actions relating to environmental issues. It is well known that a number of ICT firms (see examples in results) have recognized the value of displaying transparency, responsibility, and accountability beyond financial performance. They have adopted corporate sustainability as a new model to address environmental issues, integrating sustainability with key business strategies to show corporate responsible behavior to their stakeholders. This practice has evolved as a reflection of the challenges created from increased stakeholders' demands and expectations. Consumers have expressed concerns about sustainability issues and are now looking at the behaviour of companies as to whether they are truly concerned about environmental issues (Brønn and Vrioni 2001). Consistent with that, the adoption of lifecycle thinking by large companies, and its integration into the design and production of their products is being fostered by stakeholders (i.e. consumer) choice that is becoming increasingly reflective of environmental concerns (Shu-Yang et al. 2004). Corporate sustainability trend will be even reinforced when stakeholders support ICT firms that conduct their operations with sustainability in mind. However, more efforts are needed from ICT sector to come forward to show their responsibility and accountability for their actions relating to sustainability issues as contributors to the current environmental problems.

In sum, considering the premise of CSR which is to treat the stakeholders in a manner deemed ethically acceptable in society, it is no longer adequate for ICT firms to show solely responsibility for increasing shareholders' value; rather they should keep an eye on a plethora of environmental issues and show responsibility for their actions. Corporate accountability (the moral and ethical obligation for organizations to be held accountable) is also required as a way to justify or report on actions to all stakeholders that can be affected by ICT industry activities and operations. Corporate accountability, if taken seriously and positively, will help bind ICT firms to improve their environmental standards through different relationships. However, as reiterated throughout this paper, strong measures should also be developed and strictly applied to hold ICT firms accountable and liable for their actions towards stakeholders. Otherwise, solely freewill won't bring concrete outcomes.

5.3.6.2.3. Stakeholders Analysis

By means of corporate sustainability, ICT firms can address and respond to stakeholders' demands and concerns relating to sustainability. It is important to encompass stakeholder analysis in the ICT strategy development in an attempt to maintain the challenge of responding invariably to the rapid change and stakeholders' expectations relating to environmental concerns. The essential purpose of shareholder analysis is to identify who the stakeholders are, understand their positions, and recognize their roles as well as how they can affect and be affected by ICT. This constitutes a critical factor in shaping the overall ICT strategy. According to Friedman & Miles (2006), the stakeholder concept involves redefining all organizations in the sense of how they should be conceptualized and what they should be. ICT industry needs to realize the importance and potential leverage of the endeavour to create meaningful, and lasting value for their multiple stakeholders in today's dynamically changing environment. Like all sectors, ICT industry needs to understand and act upon stakeholders' demands concerning sustainability. Much more is demanded from the corporation by a wider range of stakeholders, including many who come together under the wide umbrella of sustainability (Dunphy et al. 2003)

Stakeholder analysis can serve for gauging the impact of the unsustainable ICT design on all relevant groups affecting and affected by ICT lifecycle to create more holistic solutions. It is of paramount importance for making astute ICT design decisions and developing well informed solutions. Stakeholder approach enables ICT corporations to develop more effective corporate ICT strategies. The stakeholder approach denotes that business is not only accountable to its shareholders, but should also consider stakeholder interests, which may affect or may be affected by the business operations (Freeman, 1984; O'Rourke, 2003). Moreover, stakeholder approach can contribute to ICT business ethics by developing relevant strategies and setting objectives to address socio-ecological issues. Wilson, (2003) points out that stakeholder approach contributes to corporate sustainability as an additional argument to why organizations should work toward sustainable development. The inherent relationship between ICT firms and stakeholders could, if built on trust and transparency, create an environment where cooperation can continuously be stimulated to fuel changes towards global sustainability.

5.3.6.3. Multi-stakeholder Design Approach

A multi-stakeholder approach in ICT design is emerging as a philosophy that considers the needs of different stakeholders regarding the design of ICT. The value of stakeholders' involvement is increasingly being appreciated in ICT design innovation. Stakeholders are no longer stochastically at the outer borders of the technological systems, but rather facilitators, co-producers, and co-designers of ICT value creation. They are the enhancers of the future technological change/innovation. Multi-stakeholder approach in ICT design seeks to involve different actors, including consumers, communities, risk assessors, business partners, competitors, rule makers and watchdogs (i.e. regulators, and NGOs), idea generators, and opinion leaders (i.e. academia, think tanks and research centers), etc. as active actors to mobilize hidden skills, competences, and capabilities to generate robust and well informed ICT design solutions. This approach has philosophically considerable appeal; it is fraught with challenges notwithstanding.

ICT design should embrace the multidisciplinary approach by exploring the accumulated knowledge from multiple stakeholders to bring richness and effectiveness to ICT design solutions. Different stakeholders can feed continuously into the design and innovation of ICT design, which allows continuous improvement and incremental growth. Thus, more of focus should be given to stakeholders given the pivotal role they can play in the development of innovative ICT design solutions. For ICT design innovation to be sustainable, it is useful to be built upon interactive, systemic, and networked models. To support this shift, it is necessary to explore the possible convergences between technological logics and environmental instances. To this end, ICT entrepreneurs need to start creating new networks of meaningful and sustainably innovative design ideas through promoting creativity of various stakeholders that can actively participate in the development of technologies and their use in a rational and better way.

5.3.7. Weaknesses and Strengths of the Study

The author garnered the results from literature scholarship. 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.

5.3.7.1. Weaknesses

- The nature of ICT design and environmental sustainability area is extremely complex since it is contingent on a number of environmental, economic and social factors and embodies complex dynamic connections between direct, indirect, and systemic effects.
- Time constraint didn't allow for subsequent research to bring detail to the study.
- 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.

5.3.7.2. Strengths

- Results were garnered from a combination of three types of scholarship: empirical, theoretical, and analytic/critical.
- Validity of the study and reliability of the results were ensured through making use of quality literature to serve as the foundation for research.
- 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 negative environmental impacts of the prevailing ICT design approach and to explore some potential remedies for unsustainability of ICT design looking at both environmental and corporate sustainability dimensions. To collect the relevant data and foster understanding of the subject area, the author performed an extensive and pertinent literature review covering theoretical, empirical, and analytic scholarship using mainly scientific journal articles and international project outcomes. Different constructs, relationships, implications, and synergies were identified, which broadened the current study and highlighted the richness of the research area. 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 analyzed, synthesized, evaluated and discussed to draw a more consistent picture of unsustainability of the prevailing ICT design. The emphasis was on illustrating the symbiotic relationship between ICT design and environmental sustainability as to how they can inform and affect the development of one another. The findings suggest that more theoretical and empirical studies are essential to advancing sustainable ICT design that is, in turn, vital to sustainability movement. The study concluded that there are many dimensions to the relationship between ICT and the environment and strong and complex connections among the positive benefits, negative impacts, and unintended consequences for the environment that flow from the design, production, use and disposal of ICT throughout the economy and society. That said understanding the interdependence between the environmental, social, and economic systems will enable ICT firms to think strategically and act proactively through devising holistic, robust, and well informed design solutions to mitigate the negative ICT impacts.

The unsustainability of the current mainstream ICT design approach was established through key environmental issues pertaining to resource depletion from extraction and manufacturing; GHG emissions resulting from intensive energy consumption; toxic waste disposal; and hazardous chemicals' use. It was useful to frame the potential remedies into environmental and corporate sustainability perspectives in order to highlight how alternative design solutions can be devised based on environmental sustainability principles to achieve the goals of sustainable ICT design whose philosophy is minimize natural resources depletion; use most efficient energy required over life cycle and renewable energy that is cyclic and safe; use cycled and reused materials; and mitigate or eliminate hazardous substances. The emerging synergy between ICT design and sustainability might consolidate ICT design into a flourishing area of study in corporate ICT strategies.

Although other researchers have acknowledged the relationship between ICT and sustainability, it is of undeniable value that approaching the topic from design perspective and providing relevant knowledge and comprehensive review outlines avenues for future research and contributes as a stepping stone to a journeying departure for further empirical and theoretical development. This is a potentially exciting area for investigation with many intriguing questions and substantial amount of multidisciplinary work awaiting future scholarly inquiry. Since the research was exploratory in nature and considering the multidimensional nature of the research area, it may be obvious that results and conclusions are preliminary and open for discussion and qualification. Indeed, this research area and related topics are inherently complex, which may make it difficult to achieve more conclusive results. The next step is presenting the key findings of the study.

6.2. Key Findings

Having answered the research questions based on the literature review, the author formulated a number of key findings. Below they are framed into the two research questions for clarity:

6.2.1. Negative Environmental Impacts of the Current Mainstream ICT Design Approach

The unsustainability of ICT design was established through the following facts:

- ICT manufacture depletes resources through extracting huge amounts of material and scarce elements.
- Of the whole lifecycle, the use phase of ICT is the most critical in terms of the impacts on climate change due to intensive energy consumption and concomitant GHG emissions.

- ICT equipment in data centers is designed to intensively consume energy, which produces GHG emissions – the culprit of global warming.
- Design of software technology encourages frequent upgrades making software utilities a planet killer in terms of energy consumption.
- The planned obsolescence phenomenon prevailing in ICT design strategy fuels throw away mentality which worsens the waste problem.
- ICT equipment is designed for disposal, which yields a huge amount of toxic waste.
- ICT product design overlooks hazardous substances factor in ICT manufacture.

6.2.2. Potential Remedies for Unsustainability of ICT design

- Dematerialization is one of the most effective strategies to minimize resources depletion, and can be well utilized in ICT design.
- De-carbonization is an effective strategy to cut energy consumption.
- Energy efficiency in data centers involves different design solutions including hardware and software as well as technological improvements and adjustments.
- Extending ICT equipment's operational life through reuse and design with life cycle thinking (LCT) hold a great potential for recyclability.
- Mitigating hazardous chemicals occurs through green ICT design - producing eco-friendly low or non-noxious products.
- Corporate sustainability is a strategic model for ICT sector to respond to environmental issues including those of current unsustainable ICT design.
- Through adopting corporate sustainability strategy, ICT-enabled organizations can rationalize the usage of ICT equipment, and thereby cutting energy consumption.

6.3. Suggestions for Further Research

It is acknowledged that the proposed study remains preliminary so there is still a considerable amount of work to be done. Thus, further research in this area could be valuable, especially in multidisciplinary oriented studies. Based on prior discussion and conclusions, the author suggests the following future research investigations:

- Building further linkages and sequences between technological logics and environmental instances and dynamics.
- Exploring new combined theoretical approaches and conceptual frameworks merging design science, natural science, and sustainability science in ICT research.
- Initiating an area in corporate ICT strategy that looks exclusively at sustainable ICT design solutions and securing this field of action at corporate level within ICT sector.
- Exploring the implications of sustainable ICT design to sustainable development process and vision to create new relationships and interfaces.
- Exploring research areas combining behaviourism, cognitive psychology, ICT in use, and ICT design for devising solutions that positively shape social and attitudinal aspects of consumerism.

Conclusively, the field of ICT design and environmental sustainability is deemed to be an exciting area for scholarly voyaging. Sustainable design in ICT sector is burgeoning as ICT sector across the globe are increasingly responding to corporate sustainability trend; how they view and must play their roles to create socio-ecological value, learn to think more long term, and ultimately design ICT systems that stress regeneration, efficiency, adaptability, resiliency, and sufficiency, and above all strive to mimic natural designs, patterns, and processes. For all these reasons, the time is ripe for calling to mind the importance of designing ICT with sustainability in mind and pairing ICT design and environmental sustainability research for achieving the goals of sustainable technologies. It is hoped that the current study provides a step toward that goal.

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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: The Business Level ICT Recycling Ecosystem (Forge 2007)

Server recycling

A company called World Data Products (WDPI) offers refurbished servers across the whole range, from twin Opteron PC servers to the largest Unix Superdome servers, and from Dell to IBM. WDPI will buy any excess hardware, and that which is deemed to be at the end of its life, often after three years in the USA and EU. After some 19 years in this business, WDPI sees the world demand for refurbished equipment as now growing quickly and running at the multi-billion dollar level. Their key deliverable is extending the lifecycle for the low, mid- and high-end server range by at least two years, from three to five years, bringing amortization savings of some 40 percent minimum, for 40-60 percent capex savings. Quality guarantees and service contracts are as good as those of the equipment's OEM. The only brake on WDPI development rates is the availability of suitable server equipment to refurbish. WDPI has built up a base of over 4000 customers for its offerings in refurbished equipment and maintenance contracts, with sales of over $70 million, largely US based.

Recycling network equipment

Today's big IT growth area is communications, especially data networking with the Internet explosion for IP packet switching and transport. Essentially in equipment terms this is the IP router market, dominated by Cisco. In Europe and the USA, Network Hardware Resale (NHR) offer used data networking equipment, and can extend the warranty from perhaps three years to up to ten years with full service and parts, using the same OEM suppliers for key components such as memory. This gives the customer major discounts over new equipment (at least 50 percent for used equipment, even 90 percent in some cases). NHR claims that 66 percent of business is to repeat customers. Refurbished data networking equipment is now becoming essential for an increasing number of enterprises and organizations. These include "non-stop" organizations such as hospitals and telco operators, major buyers of NHR products, who demand optimum reliability. Refurbished units also provide a cheaper form of backup for business continuity and for test and development platforms. NHR claims high operational excellence, with equipment failure rates of less than one percent, comparing favorably with its OEMs – and can deliver next day.

An eco system for recycling

Several major systems suppliers are now in the "legacy business" – taking back ICT assets and either reselling or disposing of them cleanly, for instance for IBM refurbished and recycled equipment of all types is a $2 billion per annum business. Pursue whole business from this point of view as a new and valid business model, exploiting a still useful part of the life cycle that other business models do not reach. It is especially relevant for the leasing business. Here IBM is taking a "green ICT" and an economic viewpoint of assets management. This is being taken further in new products, which are now designed for recycling, e.g. no screws so the total disassembly "touch time" is reduced. In the USA and the EU, the recycling business is increasingly being driven by new legislation (e.g. in the USA, HIPPA – Health, Industrial, Privacy and Protection Act). One example is to take over the whole of the disposal compliance problem for recycling for a insurance company with many systems of all sizes, at their "end of life" for refurbishment or safe disposal and recycling.

Appendix F: Lessons from the USA (Forge 2007)

Take-back campaigns and regulations

In 2003 The State of California enacted its Electronic Waste Recycling Act that collects fees at the time of purchase to fund recovery and recycling (a state-by-state review of legislative activity is available at: www.newark.com/jsp/support/support.jsp?formpage ¼newark/en_US/services/rohs/ index.jsp). The Computer Take-back Campaign has been active in advocating producer responsibility programs. US Congress has taken initiatives on e-waste and electronics recycling issues in the Congress.

IT equipment recycling programs

Programs for reuse and recycling of computers in the US are growing, with support from major systems, PC and telecommunications equipment manufacturers (see: www.techsoup.org/ products/recycle). "Universal" hazardous waste regulations The US EPA provides definitions and Federal guidelines as well as listings for regulations in each state. In California, Universal Waste rules were full in effect from February 2006 prohibiting disposal of any kind of batteries as regular solid waste. IT-related equipment that is considered "universal" hazardous waste can include cathode ray tubes (CRTs), computers, mobile phones, waste data cabling, and batteries.

Green procurement programs for electronics

The Federal Government has taken the lead with the Federal Electronics Challenge, launched in 2004. Many US states and municipalities have enacted or are considering Green Procurement programs that include electronics and IT equipment. The USA EPA is funding an Electronic Product Environmental Assessment Tool (EPEAT) to provide a methodology and guidance for purchasing. For purchasing computers and associated equipment and software, the Center for the New American Dream offers guidelines, advice, and institutional procurement resources.

Data cabling

Cabling is a major part of ICT and a specific component of their environmental problems. A comprehensive source of information on environmental effects of data cable is the Toxics Use Reduction Institute (TURI) study: "Environmental, Health and Safety Issues in the Coated Wire and Cable Industry", 2002. TURI has undertaken a joint project with the EPA, manufacturers, and suppliers to develop more environmentally benign data cables. Firms such as DuPont are developing programs for recycling of old cable, highlighting the problem of abandoned cable, and publicizing fire and electrical code requirements for data cables.

Appendix G: Use of ICT in other Sectors for Emission Reduction (Griffiths 2008).

The global conservation organization suggests ten uses of ICT in other sectors that could each reduce global carbon dioxide emissions by at least 100 million tons by 2020 WWF (2008).

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

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

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

• 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 controls in buildings to improve efficiency.

• Dematerialization services: use of ICT to substitute for physical products and interactions e.g. online shopping.

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

• 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.