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Master's Thesis

Green ICT Labels

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List of Abbreviations

EPA	**E**nvironmental **P**rotection **A**gency
PSU	**P**ower **S**upply **U**nit
UPS	**U**ninterruptible **P**ower **S**upply
CRAC	**C**omputer **R**oom **A**ir-**C**onditioning
ITT	**I**nformation **T**echnology and **T**elecommunications
PCB	**P**rinted **C**ircuit **B**oard
UN	**U**nited **N**ation
ICT	**I**nformation and **C**ommunication **T**echnology
CO2	**C**arbon **D**ioxide
CSR	**C**orporate **S**ocial **R**esponsibility
IEA	**I**nternational **E**nergy **A**gency
GHG	**G**reen**h**ouse **G**as
LAN	**L**ocal **A**rea **N**etwork
ALR	**A**daptive **L**ink **R**ate
RE	**R**enewable **E**nergy
AWS	**A**mazon **W**eb **S**ervices
NGO	**N**on-**G**overnmental **O**rganization

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1. Introduction

In September 2015, The United Nations (UN) general assembly adopted a resolution called “the 2030 agenda for sustainable development”. The purpose of this resolution was meant to promote sustainable development in multiple areas, and the assembly set 17 goals and 169 targets (UN General Assembly, 2015).

These goals and objectives are nowadays commonly known as Sustainable Development Goals or (SDGs)-2030. This was not new that the United Nations showed genuine interest in establishing and maintaining sustainable environments. Indeed, it had already focused on eco-labeling in 1992 during a conference on Environment and Development in Rio de Janeiro.

Considering United Nations Environment Programme (UNEP, 2010), Sustainable development means:

“Development that agrees the needs of the present without compromising the ability of next generations to fit their own needs. Development of sustainability includes economic, environmental and social sustainability, which are self-sufficient and mutually reinforcing pillars, it can be achieved by rationally managing physical, natural and human capital” (UNEP, 2010).

It also means: “*changing unsustainable patterns of production and consumption and protecting and managing the resource of nature base of economic and social development are overarching objectives of, and essential requirements for, sustainable development”* (UNEP, 2010).

These are not just the words of the United Nations. Over the past decades, a more cautious sentiment towards the environment has grown in organizations, companies, and governments, as well as among individuals.

On the other hand, a substantial and unprecedented need and desire to reach information and people in an instant manner has triggered more demand in the software and hardware sectors. This has translated into the production and continuous usage of significantly powerful systems and has unfortunately resulted in a much impactful daily footprint (Ozturk, et al., Green ICT (Information and Communication Technologies): A review of academic and practioner perspectives, 2011)

We do now undeniably amazing things and share valuable information, but the question is, are we ready for it? If we aren't as prepared as we thought, assuming the consequence with a blatant negative impact that affects our environment, what can we do to curb the damage and improve the advantages of having a digitally connected world? Facts are here and reports cards are out: According to Gartner, information technology is responsible for 2% of the world's total CO2 emissions. (Ozturk, et al., Green ICT (Information and Communication Technologies): A review of academic and practioner perspectives, 2011).

Several environmental changes are attributed to the increase in the amount of carbon dioxide. This increase is due to the increased computing activities of companies, organizations, and machines. In order to measure the amount of carbon dioxide released in the environment, a carbon footprint is used; therefore, the carbon footprint of Information and Communication Technology (ICT) measures the amount of carbon generated by ICT.

In Figure 1.1, a comparison made between the carbon footprint of 2002 and 2020.

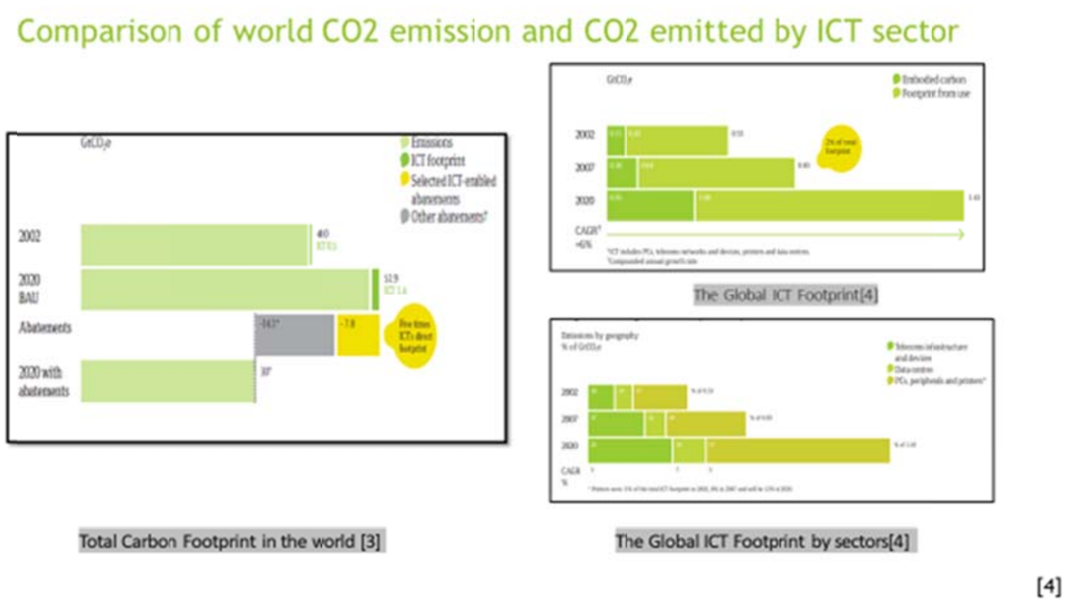

Figure 1.1 Comparison of world CO2 emission and CO2 emitted by the ICT sector

Figure 1.1 Source (A Presentation on Recent Trends in Green Computing) (Global eSustainability Initiative (GeSI))

As evidently shown in the visuals, the carbon footprint of ICT has significantly increased. It has probably become inevitable for companies, scientists, and engineers to develop a keen interest in a more sustainable approach or “green” approach to ICT hardware and software.

The word “Green” is nowadays seen as environmentally safe or friendly. Being Green is not just a preferable option nowadays; it has become the only viable option. Indeed, the immensely high levels of carbon dioxide (CO2) that technology has contributed are dangerous and can cause health concerns to humans as well.

On the other hand, and undeniably, computing is becoming more ubiquitous and universal. Because of this phenomenon, energy consumption is growing as well. It is then now undoubtedly paramount to “reverse the trends” (Sadikul, Ampah, & Musal, 2018).

However, how can we reverse the trends? Who would want to let go of the technology that prevails in almost every aspect of our lives? We will not have to do it if we choose an approach that compels everyone to maintain and even increase computing performance while not only minimizing the negative impact on the environment but also contributing to a positive impact, or in other words, in less carbon footprint and energy consumption.

As this perspective is increasingly adopted by people, societies, and leading organizations, sustainability has become gradually more critical, and several governmental agencies and non-profit organizations have developed and/or established regulations to promote Green Computing (Calero & Piattini, 2015). Nowadays, “a business that loses to have sustainable development as one of its top priorities could receive considerable public criticism and subsequently lose market legitimacy” (Calero & Piattini, 2015) Taking in consideration an IBM survey conducted in 2008, almost 50% of organizations have started a redesign of their business models around sustainability, innovation in sustainability, and cost-cutting, even if it’s for the sake of gaining more competitive advantage (Calero & Piattini, 2015).

Nowadays, a large number of people argue that they would pay a premium for a product that protects the environment, a green product. This general sentiment pushed towards the establishment of an ISO 26000 standard for corporate social responsibility (CSR). According to this standard, decision-makers leading companies and organizations should advocate and enable a protective approach towards the environment through responsible practices (Calero & Piattini, 2015).

As a result, the assumption of stakeholders is now much stricter than they have ever been. Investors, among others, often evaluate companies according to the now-famous ‘triple bottom line’ that includes three dimensions: a financial, environmental, and one related to corporate social responsibility (CSR), although CSR definitions include voluntariness and stakeholder management in addition to the previously mentioned triple bottom line (Calero & Piattini, 2015).

1.1. What is Green Computing

Global warming has almost become a pair word or expression of future, sustainability, and environment. Scientists warn and research; engineers, try, design and re-design, and users and consumers remain perplexed on what to do and what to avoid. One term, however, gives them relative confidence in their consumer habits and in products they purchase: Green. The term green is now almost always associated with environmentally safe. For many, buying green means directly contributing to protecting the environment even if there is increasing awareness around the small differences of green.

The “Green” vocabulary has gained quite some momentum. For instance, “Green Computing”, “Green IT”, and “Green ICT” have become the buzzwords over the past years. They define the environmentally responsible design and use of computer equipment, information and communication technologies, and they include the implementation of energy-efficient central processing units, servers, peripherals, etc. as well as minimize resource usage and proper disposal of electronic waste (e-waste) (Kharchenko, Gorbenko, Sklyar, & Phillips, 2013).

As Green Computing is relatively still a new field, terms and concepts are not yet well defined. In other words, there is still some confusion over the word “green” and the word “sustainability”, whose scope is not precisely well defined yet. In this study, for instance, a table with multiple definitions are included in various interpretations of one of the concepts: Sustainable Software Engineering.

Green Computing means using computing resources optimally without negatively affecting the environment (Sadikul, Ampah, & Musal, 2018). However, it also means designing, disposing, and manufacturing in a way to protect the environment or with the least impact: A green computer is one where the whole process from design, manufacture, use, and disposal has as little environmental impact as possible”. (Sourabh, Mutahhar, & Elahi, 2017).

Figure 1.2 plays out the different aspects mentioned in the definition relayed above.

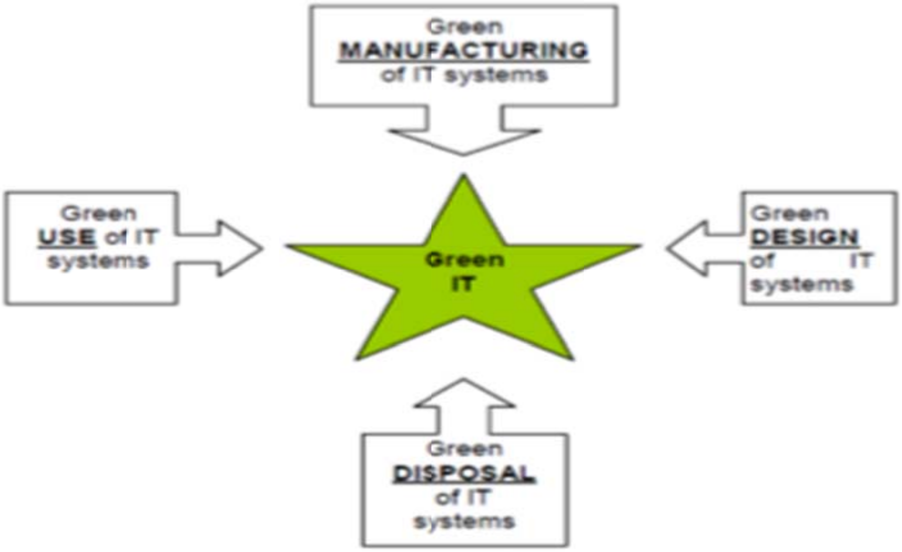

Figure 1.2 Green Computing Process. Source: (Murugesan, 2008)

To crystallize this holistic perspective, the buy-in of not only companies, researchers, and decision-makers is needed, but also that of the ordinary user. In other words, the entire society needs to be engaged and motivated to contribute into saving the environment. Otherwise, consequences might be seriously overwhelming: “Literature shows that if the trends of present emissions stay, an estimated trillion tons of CO2 will be added by the year 2050 which may have adverse consequences for human life” (Lashkarizadeh & Salatin, 2012).

Therefore, Green Computing is everyone’s business. What does Green Computing need to do? It needs to include several things according to Murugesan:

“(Green Computing) is the study & practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems with a reduced impact on the environment. Green IT also pursues to achieve economic viability and improve system performance and use, while abiding by our social and ethical responsibilities.” (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008) .

For clarity sake and to place Green Computing in context, the author added: “Design for environment sustainability, energy-efficient computing, power management, data center design, layout and location, server virtualization, responsible disposal and recycling, regulatory compliance, use of renewable energy sources, and eco-labeling of Information Technology products.” (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008).

Below is a comparative table of some definitions of Green Computing, definitions made at different times by different authors (Table 1.1)

Green and environmental friendly domain and discipline: Emerging trends and future possibilities	Paul, P. K.	2014	"Green Computing is one of the main study and practice fields and also a significant schedule for designing as well as the development of computing devices and computing systems, as it is based upon the theory of power management principle. Eco-friendly computing platform, as well as architecture creation, is the main responsibility of Green Computing which reduces less harmful chemical CO2 and other injurious and harmful gas with such as CFC. It is minimizing the use of lead and also concerned the area for Green Computing. As computer manufactured with several kinds of chemical and therefore IT manufacturers are working on designing of faster computers and systems with minimum energy and minimum harmful chemical output"
A Study about Green Computing	Pushtikant Malviya, Shailendra Singh	2013	"Green Computing is the form of designing manufacturing, using and disposing of computer server and associated subsystems such as monitors, printer's storage devices networking and communication system efficiently and effectively with no impact on the environment"
Green Computing and Communications in Critical Application Domains: Challenges and Solutions	Vyacheslav Kharchenko, Anatoliy Gorbenko, Vladimir Sklyar, Chris Phillips	2013	"Terms "Green Computing", "Green IT", "Green ICT" have become the buzzwords over past years. They define the environmentally responsible design and use of computer equipment, information and communication technologies, and include the implementation of energy-efficient CPU, servers, peripherals, etc. even reduced resource consumption and proper disposal of electronic waste (e-waste)"
Green Computing	Biswajit Saha	2014	"Green Computing points to the practice and procedures of using computing resources in an environmentally friendly way while maintaining overall computing performance."

Table 1.1 Definitions of Green Computing

Table 1.1 : Definitions of Green Computing Source: (Kharchenko, Gorbenko, Sklyar, & Phillips, 2013) (Malviya & Singh, 2013) (Paul, Kumar, Chatterjee, Ghosh, Ganguly, & Dangwal, 2014) (Saha, 2014)

It is also worth mentioning that, for many, Green Computing and Green Information Technology hold the same meaning. To others, Green IT is more significant and broader and enables a sustainable environment through better organizational practices. It also includes "the implementation of the whole computing, hardware, software, networking, and multimedia systems in the organizations and institutions for (better) power management as well as releasing less destructive harmful chemical and gas”. (Paul, Kumar, Chatterjee, Ghosh, Ganguly, & Dangwal, 2014)

The actions for the environment using ICT, IT, software, etc., are called Green or Greening ICT/IT/Software and sometimes sustainability in Information Technology. The issue that is showing is that, as in every new discipline, there is a blurry map of concepts and definitions. In all cases, Green Computing is not only a trend; it is getting important as organizations are implementing some form of sustainable solutions. Green Computing solutions have become a well lucrative and coveted sector in the past years (Calero & Piattini, 2015).

1.2. Energy Consumption

There is not one aspect of our lives that has not seen an exponential technological advance. Whether it is medicine or transport, building, or aerospace, technology has influenced everything. This technological progress has been partly made possible by the fast and vast supply of electrical energy.

The introduction of electricity marked the beginning of an age of growth based on electric power technologies. The electricity-dependent systems generally consume a massive amount of energy for technologies that are based on these systems. Nowadays a handy have more computing power than the computing power of the machines that sent men to the moon. And while it is rising day by day, the size of the device is declining and becoming cheaper driven by Moore's law. The effect is an exponential growth in all fields of technology (Ahmed, Naeem, & Iqbal, 2017).

Consequently, energy demand is exponentially increasing as technology is being introduced into every aspect of our lives. Because most of the technology depends on electricity, the main concern/requirement for technology sectors to sustain growth is its generation. Electrical energy is produced from fossil fuels, hydro, nuclear, and renewable sources, according to the world energy statistics provided by the International Energy Agency (IEA). Renewable energy accounts for just 5% of electricity generation, while coal is the most common fuel for power plants in the world, accounting for more than 40% of the world's electricity generation (Ahmed, Naeem, & Iqbal, 2017). Besides, all types of technologies and sectors consume the energy generated, and this is why worldwide energy consumption is then being consumed at an alarming rate.

For instance, industrial consumers use about 37 percent of the total 15 TW of energy consumed, according to the “Global Energy Outlook 2007” of the U.S. Department of Energy. Personal and commercial transport consumes 20%; domestic heating, lighting as well as; appliances are responsible for 11%, and business use is 5% of the total. Furthermore, 27 percent of the world’s energy is wasted on storage and production. Therefore, in terms of adverse climate change and rising financial burden, humankind is paying a heavy price for modern technologies. These supplies are not permanent, and one day are bound to end (Ahmed, Naeem, & Iqbal, 2017).

As a result of this technological development and consequent increase in energy usage, greenhouse gas (GHG) emissions have a detrimental effect on the climate and global warming. Most stakeholders in the world are in general agreement that we need to cut Greenhouse gas emissions and go towards a green and sustainable future. Energy management and energy efficiency are, therefore, the primary goals for which work is being carried out in a wide range of science fields (Ahmed, Naeem, & Iqbal, 2017). It is undeniable that small changes to everyday behaviors can have a significant impact on energy consumption, especially if one keeps in mind some facts such as 85% of the 250 billion dollars spent on powering computers is wasted idling (Chakraborty, Bhattacharyya, & Nargiza, 2009). Besides, the amount of energy we consume is directly related to Greenhouse Gas (GHG) emissions. On the other hand, The energy usage of Information and Communication Technology (ICT) products is estimated to be almost 4% of the world energy consumption in 2008, and this rate is pointed to double by 2020 (Van Heddeghem, Vereecken, Pickavet, & Demeester, 2009).

However, and in spite of an increased awareness over an obvious endangerment to the environment, it is often difficult for people to associate their personal and individual behavior with worldwide concerns such as climate change or global warming. In other words, even if we think about it, talk and write about it, we still do not act accordingly in a consistent manner (Kollmuss & Agyeman, 2002).

Other phenomena seems to influence our consumption behavior, such as anchoring, or the tendency to rely on only one piece of information. In consumption, this can translate to choosing brands over environmentally-safe products out of habit. Also, loss aversion can impact our behaviors: For instance, even if we do not need to have the lights on all over the house all the time, we might find it challenging to change this habit. A more significant phenomenon that can directly play out in computing is the status quo bias or the “by default” syndrome. This is why we should have by default options with energy consumption better practices such as double-sided printing (European Commission, 2012).

1.3. Thesis Objective

The target of this thesis is to evaluate the current approaches and efforts, highlight current and upcoming trends, and suggest how a new ecolabel could be developed and look like in light of the existing ones. Indeed, there certainly has been progress in establishing labels and related certifications. Things are better, but they are not good enough yet. Hence, throughout the description of the labels, the reader will be able to see the labels‘ present advantages and disadvantages.

In this research, approaches and labels will be described as well as their respective impact and their expected future. In a world full of ambiguity, it is, of course, quite challenging to describe in detail what a “good” Green Computing label would look like. However, for the sake of this research, suggestions over the development of the new label will be based on evaluations of the current Blue Angel, Energy Star, EU ECO-LABEL, EPEAT, and Nordic Swan green labels. The purpose here is not to criticize the labels but to define lessons learned for the sake of continuous improvement in the world of sustainability.

The objective is also to relay a good understanding of current practices in a variety of approaches in Green Computing, certifications linked to them, impact on community, environment, and possible trends to further investigate. Areas of improvement, criteria, and yardsticks will be talked about in the evaluation part before a conclusion made at the end of this research.

1.4. Related Work

1.4.1. Green Software Engineering

Software is an essential part of IT. This is why, as far as "greening" is concerned, the software is both the solution and the problem. Indeed, software contributes immensely to whether the platform used in computing has energy-saving functions. A fact that is even more rarely appreciated is that the key to increasing energy efficiency and protecting natural resources lies not with the hardware but rather above all with the software. In contrast, the efficiency gains in hardware have been overcompensated for by higher software requirements and the need for larger volumes of data.

Hence sustainability should generally be taken into account from the very first stages of software development. That is not always currently feasible since it is hard to change how developers operate. Moreover, there is little information on how software engineering can contribute to improving the sustainability of the systems under development (Kern E. H., 2018).

Various districts of software sustainability need to be checked: software systems, products, web applications, data centers, etc. Many steps are in process, but many of these concerns data centers because they consume largely more energy than commercial office space (Khandelwal, Khan, & Parveen, 2017). Also, "since software products are immaterial goods, it is a challenge to capture the indirect material and thus environmental impacts of these products in conceptual and methodological terms" (Kern E. H., 2018).

For instance, while there has been a continuous focus placed on improving the energy efficiency of hardware, the software has not kept up with the same type of progress. Energy efficiency has hardly ever been considered as a criterion of good design in the software development life cycle or related development tools and methods. While this is regrettable, it means that there is immense potential in improving software development if only by introducing energy efficiency as a requirement (Kern E. H., 2018).

Table 1.2 below highlights a variety of definitions for software engineering.

Reference	Term	Definition
Toward sustainable software engineering: NIER track (Amsel, Ibrahim, Malik, & Tomlinson, 2011)	Sustainable software engineering	"Sustainable software engineering targets to make reliable, long-lasting software that meets the needs of users while reducing environmental affects; its goal is to create better software so we will not have to compromise future generations' opportunities" (Amsel, Ibrahim, Malik, & Tomlinson, 2011).
A systematic mapping study on sustainable software engineering: a research preview (Manteuffel & Ioakeimidis, 2012)	Sustainable software engineering	"Sustainable software target to create reliable, long-lasting software that meets the use of users while reducing the negative affect on the economy, society and the environment" (Manteuffel & Ioakeimidis, 2012).
Guidance on social responsibility (Calero & Piattini, 2015)	Sustainable software engineering	"Sustainable software engineering is the art of enhancing software products so that the bad and good impacts on sustainability that show and/or are expected to result from the software product over its whole life cycle are continuously assessed, documented and optimized" (Calero & Piattini, 2015).
Sustainable software development: an agile perspective (Tate, 2005)	Sustainable software engineering	"Sustainable software engineering is the development that balances rapid releases and long-term sustainability, whereas sustainability is meant as the ability to react rapidly to any change in the business or technical environment" (Tate, 2005).
Enhancing software engineering processes towards sustainable software product design. (Dick & Naumann, 2010)	Green and sustainable software engineering	"Green and sustainable software engineering is the art of developing green and sustainable software with a green and sustainable software engineering process. Therefore, it is the art of defining and developing software products in a way, so that the negative and positive impacts on sustainable development that result and/or are expected to result from the software product over its whole life cycle are continuously assessed, documented and used for further optimization of the software product" (Dick & Naumann, 2010).
Green software and green software engineering – definitions, measurements, and quality aspects (Kern, Dick, Naumann, Guldner, & Johann, 2013)	Green and sustainable software engineering	"The target of green and sustainable software engineering is the enhancement of software engineering, which targets 1. The direct and non-direct consumption of natural resources and energy 2. As well as the aftermath that is caused by software systems during their entire life cycle, the goal is to monitor, continuously measure, evaluate and optimize these facts" (Kern, Dick, Naumann, Guldner, & Johann, 2013).
Aid to recovery: the economic impact of IT, software, and the Microsoft ecosystem on the global economy (Calero & Piattini, 2015)	Software engineering for sustainability	"The target of software engineering for sustainability (SE4S) is to make use of methods and tools to achieve this notion of sustainable software" (Calero & Piattini, 2015).

Table 1.2 Definitions for Software Engineering

Table 1.2 Definitions for Software Engineering Source: (Calero & Piattini, 2015)

1.4.2. Nuances of Green (Green IT, Green By, and Green For)

Some authors have differentiated between Green IT, Green by, and Green for IT. As this research covers several dimensions of green, it would be interesting also to investigate concepts such as Green by IT. The difference between Green IT and Green by IT lies in seeing it as, a maker to handle the emissions made by the IT gadgets themselves or taking IT as an setup to permit reduction of emissions across all areas of an enterprise (Calero & Piattini, 2015).

This concept can be leveraged both in software and hardware. We can then have "green in software, green in hardware, green by software and green by hardware. See Figure 1.3.

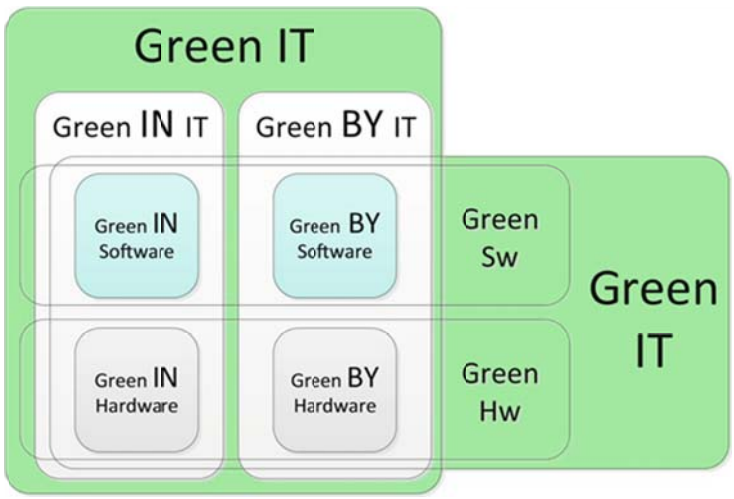

Figure 1.3 Nuances of Green

Figure 1.3 Nuances of Green Source: (Calero & Piattini, 2015)

2. Green Computing

2.1. Approach of San Murugesan

It would be very dismissive to talk about Green Computing without highlighting the approach of Dr. San Murugesan, the author of several articles and papers on Green Computing since as early as 2008 at least.

In his paper “Harnessing Green IT: Principles and Practices,” IEEE IT Professional, January–February 2008, pp 24-33, San Murugesan defines Green Computing as "the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems — such as monitors, printers, storage devices, and networking and communications systems — efficiently and effectively with minimal or no impact on the environment" (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008).

In his work, the researcher highlights several dimensions, encompassing "Design for environment sustainability, energy-efficient computing, power management, data center design, layout and location, server virtualization, responsible disposal and recycling, regulatory compliance, use of renewable energy sources, and eco-labeling of IT products.” (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008). Most of these areas will be investigated in this part of the study.

Murugesan also talks about four paths that should genuinely be worked on: Green use, green disposal, green design, and green manufacturing. According to him, Green Computing should also include the development of solutions where not only IT practices but also processes should be aligned with the following the three Rs: Reusing, reducing, and recycling to ensure alignment with principles of sustainability. For "Green use," the product should also be able to consume a reduced amount of electricity. Any product made should meet quality requirements but also be used for an adequate lifetime. Once retired, it should be possible to disassemble it and use some of its parts while recycling others (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008).

2.2. Design Of Sustainable Environment

The Brundtland announce from the United Nations (UN) defines sustainable development “as the ability to match the needs of the present without compromising the ability of later generations to satisfy their own necessarily” (World Commission on Environment and Development, 1987). Undeniably there are several definitions for sustainability, as seen above. However, they all encompass to two elements: the capacity to be durable and the limitation of resources.

Green Computing’s purpose is to improve how computing devices are used, and green IT encompasses developing sustainable production practices, computers made to save energy, and an improved approach to handle waste and recycling. This is why we should have complementary approaches to provide a completely sustainable environment. The following six approaches would be used to embed Green Computing at all levels.

1- Green use. “Reduce the energy consumption of computers and other information systems and use them in an environmentally sound manner” (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008, S. 27).

2- Green disposal. “Refurbish and reuse old computers and adequately recycle unwanted computers and other electronic equipment” (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008, S. 27).

3- Green design. “Design energy-efficient and environmentally sound components, computers, servers, and cooling equipment” (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008, S. 27).

4- Green manufacturing. “Manufacture electronic components, computers, and other associated subsystems with minimal or no impact on the environment” (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008, S. 27).

5- Green standards and metrics. “These are required for promoting, comparing, and benchmarking sustainability initiatives, products, services, and practices” (Murugesan & Gangadharan, 2012, S. 7).

6- Green IT strategies and policies. “These effective and actionable strategies and policies add value and focus on both short- and long-term benefits. These are aligned with business strategies and practices and are key components of greening IT” (Murugesan & Gangadharan, 2012, S. 7).

Figure 2.1 below shows the entire Green IT cycle, as seen by Murugesan.

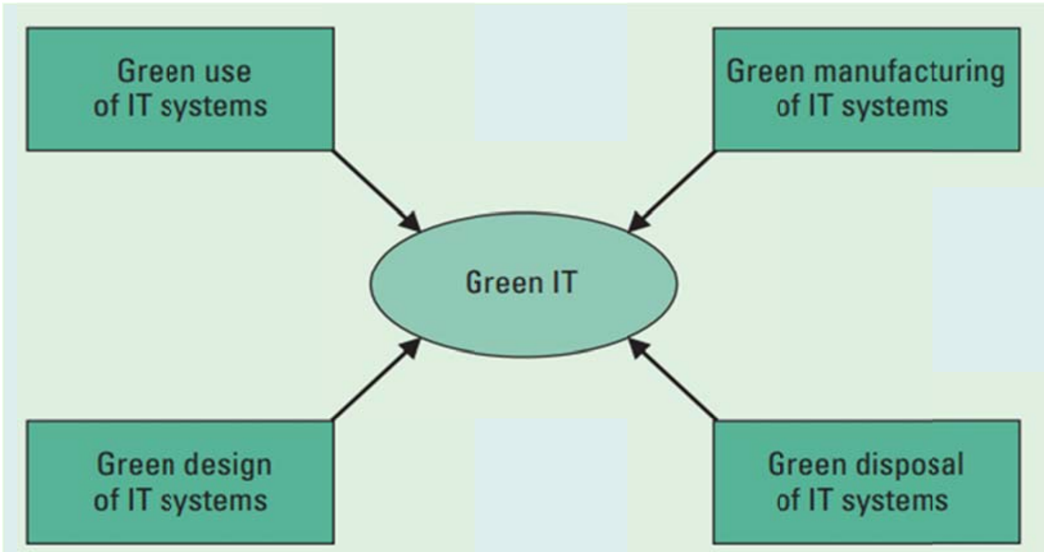

Figure 2.1 Green IT Cycle. Source: (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008)

On the other hand, the engagement of all stakeholders is also quite important. To help build a more sustainable environment, people need to be informed about Green IT. Unfortunately, there is quite a difference in understanding between users, students, and IT professionals. It is crucial that IT professionals have a perfect understanding of Green IT, but it is also essential that everyone in the "lifecycle" is informed about it as well (Murugesan & Gangadharan, 2012).

Luckily, some companies have already aligned their operational practices with some of the concepts as mentioned earlier. For instance, as far as green use is concerned, SAP, the well-renowned company, located in Waldorf, Germany, has established a system where any product is requested through a portal. Once the product is received, the user is bound to use it for a minimum amount of time (for instance, 4 to 5 years). It is only once the minimum period is "served", that they are allowed to request a replacement. This type of system is made to promote maximum use and efficiently serves sustainability.

2.2.1. Energy Efficiency

As mentioned above, several things can help contribute to a safe environment. However, while trying to keep the same product as long as we can is recommended and helps maintain a sustainable environment, other dimensions are not only essential by also driving to Green Computing, such as energy efficiency (Harmon & Auseklis, 2009).

Indeed, energy efficiency is ever more critical for future ICT (Information and Communication Technologies). This is because, as far as energy is concerned, both cost and availability are to be addressed. On the one hand, ICT is using more power and consequently suffering from higher expenses, and on the other hand, it cannot dismiss the need to decrease greenhouse gas emissions. This is why there is mounting anticipation for technologies that are more energy-efficient in computation, storage, and communications (Soomro & Sarwar, 2012).

Energy efficiency is defined in a very reader-friendly manner by Ansuageto et al. as follows: "Energy efficiency is to use fewer energy to provide the same service or providing more services with the same energy. For example, if a consumer replaces a refrigerator or a washing machine with a more energy-efficient model, the new equipment provides the same services, but uses less energy" (Ansuategi, Delgado, & Galarraga, 2014) .

The bottom line, here, is then to keep the same computing services while using less energy. So the target is to have the same product but with less energy consumption. However, while IT companies are increasingly focused on using products for the longest time possible, this might be distracting them from focusing on what happens before having received the product itself. How about improving the practice itself and act before even proceeding to the purchase? (Ansuategi, Delgado, & Galarraga, 2014). Indeed, it would be paramount to think of those five years, for example, when the product would be used and take into consideration how much energy would that product be using. Energy costs could differ considerably (Ansuategi, Delgado, & Galarraga, 2014).

For instance, and very often, choosing laptops over desktop PCs would make sense since laptops use six times less energy than desktop PCs. Indeed, laptops are designed to use at least 80% less energy than desktop PCs (Sheikh & Lanjewar, 2010).

This is what the holistic approach means: Targeting the entire value chain and the whole of the corporate ecosystem. IT departments can become essential to stakeholders in doing this as they are at the core of business competitiveness. With an increasing IT world, it is undeniable that looking at the entire value chain where IT is or should be involved in the essential thing to do.

“We define sustainable IT services from a total societal value perspective as the aggregate value available to society from the systematic integration and alignment of the individual IT service components for the purpose of creating superior societal value. Therefore, all aspects of IT services must meet societal goals for sustainability while meeting customer and business value goals in terms of economic, environmental, and social responsibility requirements [38]” (Harmon & Auseklis, 2009).

The aim is then to create a future in which technology becomes as energy-efficient as possible and where energy needs are sustained with minimal adverse effects on climate change. This can be achieved through the implementation of three strategies in the management of energy efficiency and sustainability, which can be classified as follows from (Ahmed, Naeem, & Iqbal, ICT and renewable energy: a way forward to the next generation telecom base stations, 2017):

- Innovative SMART technologies and procedures in all industries to make energy-efficient systems as much as possible.
- Virtualized servers
- Promoting the use of renewable energy (RE), as much as possible, to make energy demands affordable and green.

Embracing SMART steps that conserve energy and reduce its carbon footprint should mean that ICT will significantly reduce its carbon footprint. The sector's SMART strategy was summarized as follows:

- **“S**tandardization of energy measurement techniques. The first energy conservation prerequisite is to know how much energy is consumed. To do this, not only do we need efficient but also standard energy measurement techniques. To ensure correct data on usage, all devices and systems should have a common yardstick for energy calculation” (Ahmed, Naeem, & Iqbal, ICT and renewable energy: a way forward to the next generation telecom base stations, 2017).
- **“M**onitoring of energy consumption across the board. To obtain a full and detailed image, monitoring through sensors and meters should be ensured on each and every segment of technology” (Ahmed, Naeem, & Iqbal, ICT and renewable energy: a way forward to the next generation telecom base stations, 2017).

- **“A**ccounting for energy at every step. Not only is the energy expended on the server or the end equipment, but it should be accounted for at any node where it is dissipated (Ahmed, Naeem, & Iqbal, ICT and renewable energy: a way forward to the next generation telecom base stations, 2017), regardless of how small it may be” (Ahmed, Naeem, & Iqbal, ICT and renewable energy: a way forward to the next generation telecom base stations, 2017).
- **“R**ethinking and researching innovation to reduce ICT emissions across devices and services. Constant progress has resulted in the reduction of energy consumption by smaller and lighter parts. The cycle must be pursued through research, investigation of all possible ways and means of achieving energy efficiency” (Ahmed, Naeem, & Iqbal, ICT and renewable energy: a way forward to the next generation telecom base stations, 2017).
- **“T**ransformation of the ICT sector into a model of low carbon technology. The ICT industry is capable of demonstrating highly efficient structures” (Ahmed, Naeem, & Iqbal, 2017).

The encouraging intervention of information and communication technology to make us smart is mainly due to its omnipresent nature, such as the application of ICT protocols and technologies to other industries. ICT has become a part of most of the different technologies because it provides them with computational power and knowledge to perform better and functions more intelligently. Not only can it give items to enable processing and analysis, but it can also help develop new techniques to substitute high carbon activity with low carbon activity. ICT also can help optimize energy efficiency systems and processes. It can aid as well in the company's innovation processes by simulating various changes in structures and business strategies. Last but not least, it can help foster sector-wide collaboration in adopting smart approaches to energy management.

While looking at some specific examples, such as smart homes, smart buildings, intelligent transportation, electric motors, and smart grids. It is possible to make a categorization of three key areas: software, management systems, and computers (Ahmed, Naeem, & Iqbal, 2017).

ICT has a good role to play in making current systems/infrastructures smarter and more energy-efficient as well as producing renewable energy viable for macro and micro-level use. In order to optimize energy-efficient for information and communication systems is to make them SMART. To illustrate how companies played it out, we can see how Google, Inc. has established a data center on Columbia River in Oregon to harness hydroelectric power, while, in Washington, Microsoft did the same for the same purpose. As the trend gains more momentum, the state of Wyoming in the United States is also trying to attract data centers with the prospect of cheap power from coal-fired plants (Ahmed, Naeem, & Iqbal, ICT and renewable energy: a way forward to the next generation telecom base stations, 2017).

2.2.2. Power Management

With power management, the objective is mostly to minimize the power usage with data centers and IT equipment through simple, daily practices. Nowadays, suppliers provide devices specifying the energy consumption per hour, which has turned in quite a privilege since consumers are now more able to select the equipment that they think is appropriate for their organizations according to more precise product specifications related to power consumption.

Daily practices do matter. IT team members are usually required to keep their computer on while they leave the office to enable backups, especially before and after office hours. However, this practice inevitably leads to a higher electricity bill and a decrease in the lifetime of the IT equipment.

Backup servers like Data Protection Manager (DPM) raise the red flag once it is not able to find online machines to take backups. An alternative could be to prompt backup servers to proceed only during office hours. This process would allow users to turn off their computers once they leave the office.

Other measures could be taken by configuring the monitors to go to sleep mode once the user is away after a certain amount of time (10 minutes, for example). Besides, a hard drive could independently go to a sleep mode after a predefined amount of time where the computer is not being used (Kochhar & Garg, 2011). The operating system should also go to sleep or to hibernate mode in case the user is far for a long amount of time, and the processor is idle. Such methods would help save energy, environment and reduces the costs of an IT department. (Harris, 2008). In short, “Two key ideas govern to save energy through power management: (a) exploiting idle periods of activity to temporarily put the device(s) in a low-power sleep state, and (b) slowing down to consume less energy when maximum performance is not required” (Van Heddeghem, Vereecken, Pickavet, & Demeester, 2009).

In all cases, having the IT department purchase equipment with eco-labels such as "Energy Star" and "Blue Angel" would contribute to using those devices that effectively save energy, in addition to being manufactured with recyclable material and be of good quality. (Malviya & Singh, 2013)

However, it is not just about PCs or network equipment. A more inclusive approach is needed to include anything from more power-efficient chip design for CPUs to optimized technologies for TV and computer monitors. Other examples to highlight would be energy-efficient set-up boxes and the use of nano-technology for the same purpose as well as the realization of Adaptive Link Rate (ALR). An ALR allows temporary reduction of power consumption by a decrease of the bandwidth at times and rapid return to full bandwidth when needed. Alternatively, "backward compatible variation on ALR is proposed by the same study group is PAUSE Power Cycle. A local area network switch regularly pauses all active links connected and powers off during the times links are paused, effectively reducing the link rate" (Van Heddeghem, Vereecken, Pickavet, & Demeester, 2009).

2.2.3. Data Centers

As data centers are considered the "central brain" of IT services, IT management should plan while favoring conditions enabling improvement of data center energy. The plan should include the objective, costs to be covered, and the strategy of implementation. Besides, the number of IT devices fabricated and used is continuously increasing. One of the main consequences is the demand for higher consumption and cooling (Spafford G. , 2009).
To provide services to organizations and individuals, data centers have servers. The servers include applications. To save energy and consequently protect the environment, applications could be designed or re-designed in a way that they would require less power, less storage, and, therefore, less cooling (Spafford G. , 2009).

Storage is also an important dimension. It can be costly, although it is now much cheaper than it used to be. This is why cloud computing would be a much viable alternative, especially since nowadays, round-the-clock access and safety are offered by various suppliers (Spafford G. , 2009).

Other dimensions could be taken into consideration, such as an increase in data duplication, which leads to more demand for storage. To cover this aspect, data compression could be considered, although decompression would also consume time (Spafford G. , 2009).

Another concern should be data redundancy. As the existence of data duplication rises, higher demand for storage remains a reality. As a solution, the data that is not needed so often should not exist in duplicates, while data that is barely used could be stored on an optical drive or even archived. Another approach that could be taken would be using data compression. Here, however, decompression should also be taken into consideration as decompression might be a time-consuming activity (Spafford G. , 2009).

In addition, managing hardware in a consistent manner is important. For instance, some servers become “ghosts”. This means that although they are up and running, they are not required any longer. Frequent cleaning could help detect them and save power and cooling needs.

Furthermore, having the hardware device on the premises requires continuous, much energy-consuming cooling. This could raise power consumption costs by 25 percent and probably even more. Organizations should be aware that since finances and environment are being impacted, they should consider virtualization, cloud computing, or even using renewable energy for their infrastructure.

The growth of the data centers undoubtedly requires an increase in electrical demand. Typical organizations, businesses, and individuals install uninterrupted power supply (UPS) as a backup in case of electrical failure or through an electrical power cut. UPS requires space, electrical power, and produces heat, which means that it should be located outside the data center. Moreover, UPS has batteries that need to be replaced after serving for a certain amount of years. As an alternative, organizations could arrange to have two electrical lines, each from a different service provider (Spafford G. , 2009). Other practices could be adopted, such as dividing the infrastructure into two zones. The first would be a zone for devices with a high demand for power; another zone would be for the devices that have a diverse or undetermined need for power (Spafford G. , 2009).

In any event, there is a significant correlation between the power consumption of cooling, lighting, and UPS and the usage of ICT equipment. This is why there is an efficiency metric for data centers defined by the Green Grid. The power usage effectiveness (PUE) or total facility power is divided by the power consumption of ICP equipment. (Vereecken, Van Heddeghem, Colle, Pickavet, & Demeester, 2010)

In any event, cooling is essential for data centers, and until today, the traditional cooling method Computer Room Air Conditioning (CRAC) is still being used. Cooling Data centers should follow a certain standard. “ASHRAE” is an association that provides system design education and advice. According to ASHRAE, the thermostat settings should be on the inlet of air and not the outlet of the server. Since the existence of thermostat on outlet would cause overflowing cooling leading to an increase in power consumption as the data center is divided into zones according to energy consumption. Zones with high performance should be provided with a fault tolerance plan in case of a failure in the cooling system (Spafford G. , 2009).

Nevertheless, the design of the data center should contain hot and cold aisle as shown in Figure 2.2.3.1

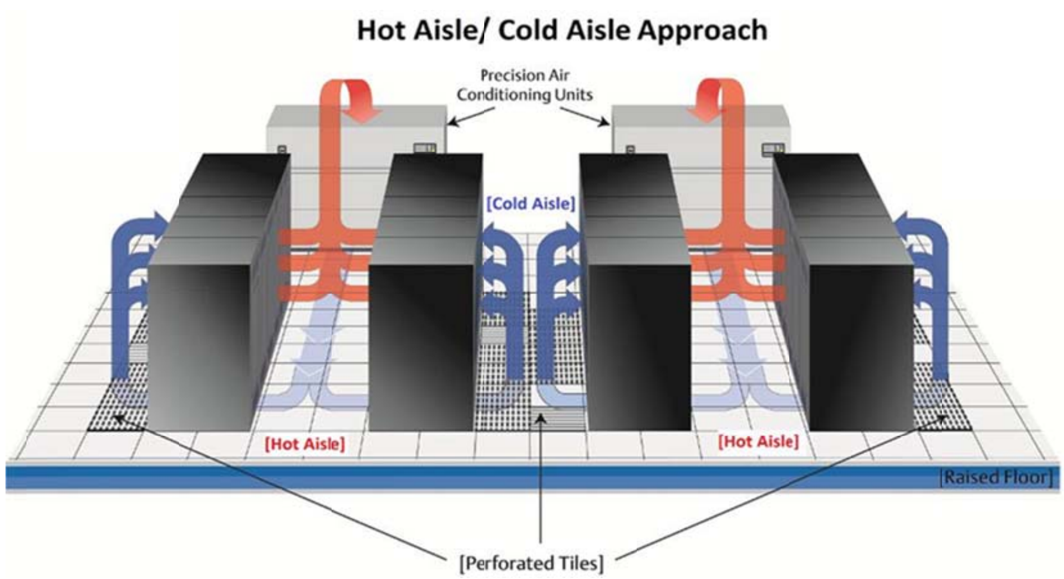

Figure 2.2.3.1 Hot and Cold Aisle Source (Dworzanczyk, 2018)

Here, cold air should rise from the ground, feeding the inlets of the server cabinets with cold air. While the hot aisle would be the back of the cabinets, a device should be installed in the hot aisle to suck up the warm air, preventing it from mixing with the cold air. A barrier should exist, preventing cold aisle from mixing with the hot aisle.

For the last few years, some companies decided to step up to the plate and produce servers with racks that could be cooled down using liquid. One of these companies is "Asetek," specialized in liquid cooling. The method targets the main parts of the server, which are the processors, and directly cools them down by installing nodes instead of fans on the top of each processor. Each node is connected to two pipes, one for cold liquid arrival and another pipe allowing the hot liquid to flow out of the node.

Figure 2.2.3.2 shows the traditional standard server using fans to cool down the processor.

Figure 2.2.3.2 Traditional HP Proliant DL380 Source: (Servershop24 GmbH, 2020)

Figure 2.2.3.3 below shows a server that uses a liquid cooling system. (Asetek Cooling Solution Company, 2020)

Figure 2.2.3.3 Liquid cooling system server Source: (Asetek Cooling Solution Company, 2020)

All of this is of paramount importance, especially that according to a Gartner study, “data centers, with their associated servers, air conditioning, fans, pumps, uninterruptible power supply (UPS), and so on, use more than 99 times the power per square foot of an office building” (Ruth, 2009).

Besides, nowadays, servers have power options with high-performance mode, balanced mode, and power save mode. Since most employees work between eight in the morning and six in the afternoon, servers could have a balanced mode during working hours, and a power-saving mode after six o'clock (Spafford G. , 2009).

2.2.4. Virtualization

Another fundamental ICT approach in handling energy efficiency and sustainability is virtualization. Virtualization had caused quite a buzz when it was first talked about years ago. Companies became interested, and so were other organizations and individuals. The technology of virtualization was first developed by IBM as early as in the 1960s. The concept was later applied to data x86 servers in data centers. With it, server load can be increased to 50-85 percent, where they can function more energy efficiently. Fewer servers are needed, which means smaller server footprints, lower cooling costs, less headcount, and improved manageability (Harmon & Auseklis, 2009).

Virtualization is a stable trend of Green Computing as it offers virtualization software as well as management software for virtualized environments. “One of the best ways to go towards green and save enough space, enough resources, and the environment is by streamlining efficiency with virtualization” (Soomro & Sarwar, 2012).

Reducing the power consumption of the data center is a crucial strategy. Running multiple virtual servers on a smaller number of more powerful servers helps data centers to simplify their physical server infrastructure, which results in less power usage. The data center would also be streamlined. Virtualization requires less floor space for the data center, fewer energy requirements, and it makes better use of computing power (Ozturk, et al., Green ICT (Information and Communication Technologies): A review of academic and practioner perspectives, 2011).

Virtualization has then emerged as one of the most critical design criteria for modern computing facilities, such as data centers to encourage Green Computing and environmental sustainability because they continue to consume vast amounts of electrical power. Therefore, it is clear that virtualization plays an essential role in ensuring Green Computing and, consequently, environmental protection and sustainability as envisioned by the second theme in the second-millennium goals (Motochi, Barasa, Owoche, & Wabwoba, 2017).

Virtualization is also considered to be an excellent strategy for companies and individuals. It allows the sharing of hardware and exploiting the usage of equipment to save extra hardware, environment, and by default money. “Virtualization became an essential strategy for addressing growing business computing needs. It is mainly about IT optimization in terms of energy efficiency and cost minimization. It enhances the utilization of existing IT resources while decreasing energy use” (Harmon & Auseklis, 2009).

A small company with less than 327 employees could have a domain controller combined with DNS, DHCP, file server, print server, and much more on just single hardware. This feature will allow only the hardware that is used for virtualization to consume more electrical power. However, it will not consume the same amount of electricity as installing each server role or feature on a single hardware. This will also cause a reduction in cooling costs. Microsoft has integrated a server role called "Hyper-V". "Hyper-V is a role used for virtualization, allowing administrators not to need a 3rd party software.

According to Jeff Daniels, “Virtual machine is an abstraction layer or environment between hardware components and the end-user. Virtual machines run operating systems and are sometimes referred to as virtual servers. A host operating system can run many virtual machines and shares system hardware components such as CPUs, controllers, disk, memory, and I/O among virtual servers” (Daniels, 2009).

"Bare metal" is the hardware that has the main OS, having all the virtual machining on it. Bare metal will share its hardware resources or parts with the virtual machines that are installed. There are multiple ways to access a virtual machine, either by accessing the bare metal and working on the virtualization software or by using the "Remote desktop connection," where you can access it either by the name or the IP of the target virtual machine. (Daniels, 2009)

Virtualization has other benefits. Especially when it comes to fault tolerance plans. In businesses and private sectors, it is essential to have a fault tolerance plan in case a disaster has occurred. Here, virtualization can save the day. An IT specialist could take a copy of the virtual machine and keep it safe in case of loss of data.

Imagine the following scenario: A company with headquarter is in Germany; however, a new branch opens in Dubai, UAE. The office in Dubai has no IT professionals. How easy would it be to configure and prepare the virtual server in Germany and then transfer the virtual machine through the internet to Dubai, or merely handing over the virtual machine on USB to an employee that is traveling to Dubai? This certainly would make things easier.

Another dimension to be taken into account here is cost. For instance, the “lifespan” of the hardware of the host server is as limited as it is for other hardware. An exciting thing to do would be to copy a virtual server on new hardware instead of renewing both. The process is straightforward and requires a negligible amount of time (Daniels, 2009).

Virtualization can also impact the server hardware, storage, networks, and application infrastructure. On the one hand, thanks to virtualization, IT professionals can pool applications on a smaller number of servers. Data centers can then support applications with minor usage of energy, physical space, and human resources. Not only can virtual servers use less power, but they can be more efficient than standalone servers.

On the other hand, the continuous call for having a better higher performance in data centers with the need for reduction of electrical consumption turned the eyes of businesses, individuals, and IT professionals towards cloud computing. Local server virtualization is excellent, and having a data center is essential, but it also requires more management and expenses. Servers also need disks to store data. As a matter of fact, with all the new applications and social media, the amount of data is increasing the bill of costs rapidly. Green Cloud computing will not only help in minimizing the electrical costs but also could help in optimizing the infrastructure. Of course, efficiency and compatibility are also crucial. This is why the architecture of the infrastructure is essential (Ravi, Chinnaiah, & Abbas, 2019).

According to “Parkavi Ravi", "Cloud Computing is a model for delivering services in which resources are retrieved from the internet over web-based tools and applications, rather than the shortest connection to a server." (Ravi, Chinnaiah, & Abbas, 2019). It is enough for the device to have access to the internet to get access to the data. This enables the capability of hosting a variety of applications. This process will allow organizations to reduce material, management fees, and environmental costs (Ravi, Chinnaiah, & Abbas, 2019).

According to “Parkavi Ravi", multiple services could be offered through green cloud computing:

Infrastructure as a Service “IaaS": This is a service that would help costumers save the costs of buying hardware servers and all other resources, including IT staff, to manage the infrastructure. To make things short, the service is an outsourcing virtualization service (Ravi, Chinnaiah, & Abbas, 2019).

Desktop as a Service “DaaS": This service could be described as a virtual desktop infrastructure. The most renowned organizations that offer such service are VMware horizon, Amazon Workspaces, and Citrix Xen. The service helps with migration and provides better security since the provider will administer the hardware, software, and performance. Users have the option of using the service through their personal computers or smartphones (Ravi, Chinnaiah, & Abbas, 2019).

Software as a Service “SaaS": The idea is to replace companies installing software on their desktops and having the software on the SaaS provider for a specific fee (Ravi, Chinnaiah, & Abbas, 2019).

Disaster Recovery as a Service known as (DRaaS) in the traditional disaster recovery plan, companies, take backups on magnetic tapes or hard disks. DRaaS is a cloud backup solution, which makes a replica of the virtual infrastructure allowing the restoration in case of a disaster (Ravi, Chinnaiah, & Abbas, 2019).

Backup as a Service “BaaS": Losing personal data could be quite painful for a professional. However, losing business data could be disastrous. IT staff usually monitor their backups once in a while; however, sometimes, IT staff become distracted. Once a disaster happens, the IT staff faces the inevitable. This is where green cloud backups help by using an online data backup provider (Ravi, Chinnaiah, & Abbas, 2019).

2.3. Use of Renewable Energy Resources

Renewable energy (RE) is extracted from natural resources. Such energy is clean and environment-friendly. As traditional energy is produced by coal or fuel, and as it can be harmful to the environment, renewable energy is much preferred. RE could be produced from sunlight by using solar panels or by winds by using a windmill, or by using a water dam on a river. More renewable energy is increasingly produced; however, depending on the renewable energy itself, the cost could be high. Thus, in addition to optimizing ICT power consumption, it is essential to use renewable energy in ICT systems. Data centers, in particular, can be located in renewable energy production sites. One thing to take into consideration, however, is that these sources are not predictable. Solar energy, for instance, varies according to day and night. This means that data would need to be migrated from one data center to the next following a chase-the-wind or follow-the-sun scenario. In this case, high bandwidth networks and specific architectures will be required (Van Heddeghem, Vereecken, Pickavet, & Demeester, 2009).

However, it is still important to raise the share of renewable energy resources in ICT. Some good work has been done up to now about it, but much more needs to be done. This is especially true since huge steps have been made with a variety of technologies such as the photovoltaic cell industry. Cells have become much more powerful, and installation and implementation are far from being rocket science. Instead of merely thinking of how to save energy and how to design energy-efficient devices, we should also be thinking of rapidly decreasing our consumption of fossil energy and making it an absolute requirement for certified green products to be made from renewable energy.

2.4. Other Approaches

Although the Murugesan approach remains the most popular one as Dr. Murugesan wrote extensively on approaches of Green Computing, some other researchers have also dedicated time and energy in finding approaches that would make it easier for organizations and individuals to apply concepts of Green Computing in operations and daily practices.

2.4.1. Orgerie's Approach

In her article on Green Computing and sustainability, Orgerie states that in addition to the increase in energy efficiency and to the reduction of energy consumption, it is also necessary to improve the use of resources. Using renewable sources like as solar and wind energy, as well as the harvesting and storage of energy is paramount for its subsequent utility.Unused but powered-on resources consume specific amounts of electricity. In 2010, a study of idle servers was performed by the Green Grid alliance in 188 data centers, mostly in the United States. They predict that 10% of the servers will never be used on average, thereby wasting energy (Orgerie, 2016).

Another 2008 study shows that the use of data center servers only reaches 6%. Since the servers' energy consumption is not proportional to their workload, they consume large amounts of power even when they are not used but merely powered-on– or 40% and 60% of their potential consumption when fully charged. Therefore, these servers must have standby (more energy-efficient mode) capabilities and remote wake-up mechanisms to adapt the processing power to the demand of users (Orgerie, 2016).

Two solutions to reducing this energy waste are widely used: sleeping techniques and slow down techniques. The first is to place idle resources in sleep or standby mode and to use remote wake-up mechanisms such as IPMI (Intelligent Platform Management Interface). This is common hardware that operates independently of the operating system and allows administrators to control a device via a direct connection remotely. One can also use this interface to turn on and off nodes remotely (Orgerie, 2016).

The use of sleeping mode can be increased with consolidation algorithms consisting of resource allocation policies that accumulate workload on fewer resources needed to support it without degradation of performance. Virtualization technologies such as virtual machine isolation and live migration can significantly benefit these algorithms. However, it produces empty servers that can be placed into sleep mode by moving virtual machines between different physical servers (Orgerie, 2016).

Also, the slow down technique for processors or Dynamic Voltage and Frequency Scaling (DVFS) provides processors with the ability to adjust their working frequency and power consumption to save energy. To determine when and how to switch between the available processor frequencies depending on the workload, it is then necessary to implement smart algorithms (Orgerie, 2016).

Technology also does not avoid the ever-growing energy needs, which are exacerbated by the proliferation of applications available. In 2014, a survey showed that smartphone owners have an average of 35 installed apps, 11 of which are used only once per week, and 12 are never used. Numbers are believed to have raised since 2014. All these built programs, however, consume resources in computation and storage. An application that is never used is still configured to send regular updates to remote servers (e.g., location data) and therefore have a large consumption of energy (Orgerie, 2016).

Eco-design software consists of reducing the carbon footprint on the atmosphere and making real energy gains. It relies on the use of more energy-efficient algorithms, reducing execution time (and thus using the CPU), creating detailed specifications to remove unnecessary features, and optimizing data volumes produced. All of these techniques are worth maintaining, increasing, and even becoming part of the IT professional culture for better protection of the environment (Orgerie, 2016).

3. Environmental Certifications

Environmental (green) certifications or green labels have emerged mostly as a communication tool with consumers (Vertinsky & Zhou, 2000) to convey that a specific product will have a minimal negative impact on the environment in comparison with other similar products. Green product certification first appeared in 1978 with "The Blue Angel" label created by the German federal ministry of interior. In light of increasing concern about the environment, this type of label has gained quite some track record since then. In fact, according to the latest report, the EU label has granted 2,010 licenses to cover 44,051 products and services from different sectors in 2015 (Sandoval, Alfaro, Villa, & Ormazabal, 2016).

Green labels can help consumers make more environmentally-sensible purchasing decisions. They are usually part of a framework set around rules with a third party to evaluate it to ensure that the label is placed where it is deserved. Nowadays, green labels are made for a wide variety of products. When you choose a product with an eco-label, it usually means that this product uses less energy or water and that it is less likely to be a polluting element, that the natural world, animals, and recycling or re-use have been taken into consideration during the manufacturing of this product.

In other words, an eco-label is a believable symbol. For the consumer, this symbol means that the product is simply better for the environment than others that do not have the label. Due to United Nations Environment Program (UNEP, 2010), eco-labels are voluntary, and governments should encourage organizations to use eco-labels and help green consumers make a responsible decision.

Benefits of eco-labels are numerous for a variety of audiences:

1. Benefits to Consumers: Consumers who are aware and sensible to protecting the environment can choose the products they use while being confident that they are making the right choices. Providing the consumer with clarity is then essential to help preserve the environment. In addition, seeing the labels on a multitude of products helps raise awareness among people (Salman, 2016).
2. Benefits to Industries: There is no doubt that a greener public "face" can help outgrow the competitor nowadays. Consequently, it becomes a criterion for purchasing decisions,

and organizations gradually conclude that they cannot avoid being green if they do not want to lose their clientele or if they want to penetrate a new market. It then makes commercial sense to use eco-labels (Salman, 2016). Due to the International Standards Organization (ISO), the objective of ecolabels is

".()..Through communication of verifiable and accurate information, that is not misleading, on environmental aspects of products and services, to encourage the demand for and supply of those products and services that cause less stress on the environment, thereby stimulating the potential for market-driven continuous environmental improvement" (Murugesan.S, 2008).

3. Benefits to Government: With green certifications, governments refer to third party organizations such as the International Organization for Standardization (ISO) and Global Eco-Label Network (GEN). With green labels, it has become much easier to monitor claims that sellers or vendors make about their products (Salman, 2016).

Figure 3.1 One of the world's most trustworthy and rigorous eco-labeling schemes, the European Union (EU) Eco-Label Source (Eco labeling)

Documents that had an enormous contribution in setting a framework for environmental products policy and promoting more awareness and demand for sustainable products include *The promotion of sustainable consumption and production (SCP)* popularized into EU in July 2008 to the advertisement of the SCP & SIP Action Plan. The action for making or giving labels can be done by NGOs or by the government, the EU, which has developed specific legislation for the creation and implementation of green labels for a variety of products, services, and buildings (Brilhante & Skinner, 2015).

There are multiple scenarios for creating labels. They can be voluntary schemes or programs based on their standards. Compulsory labels are generally made to align with a government directive. The directive would convey the multiple dimensions related to this label, such as the entity that would be responsible for monitoring or managing the label, administration, liabilities, and technical aspects as well as conformity mechanisms (Brilhante & Skinner, 2015).

As for energy efficiency, it is now typical to see compulsory labels for products. In this case, vendors are required to display the certification symbol and energy use of the product. Also, any technical specification mentioned initially in the directive related to the label itself should be offered to dealers free of charge upon their request. As green products have become increasingly popular, the number of consumer logos has risen as well (Brilhante & Skinner, 2015). This is because companies are now well aware that this has become a market advantage. All types of terms have appeared, such as "recyclable", "eco-friendly", "low energy", etc. The challenge is then not to allow any misuse or false claims from sellers too enthusiastic to see their quarterly incomes rising (Brilhante & Skinner, 2015).

The table below (Table 3.1) below clarifies some of the terminology related to the certifications and eco-labels, and it was taken as-is from (Brilhante & Skinner, 2015)

"Eco-label (green label); a visual communication tool is indicating environmentally preferable products, services, or companies that are based on standards or criteria. Note: Eco-labels may be referred to as tiered, pass-fail, Type I, II, III, multi-attribute, single attribute, etc."
"Eco-labelling programme or scheme; refers to the organization that creates an eco-label, and is responsible for its ongoing management and use."
"Certification; is a confirmation that a product meets defined criteria of a standard. According to ISO certification is: "any activity concerned with determining directly or indirectly that relevant requirements are fulfilled".
"Standard; is a set of guidelines and criteria against which a product can be judged. ISO defines a standard as: "a document, established by consensus, approved by a recognized body that provides for common and repeated use as rules, guidelines, or characteristics for activities or their results." "Common standards related to building practices are created through consensus processes by organizations such as ANSI, ASTM, or ASHRAE."
"Green product certifications; are intended to outline and confirm that a product meets a particular standard and offers an environmental benefit. This is most respected when an independent third party is responsible for conducting product testing and awarding the certification. Many product labels and certification programmes certify products based on life-cycle parameters (multiattribute programmes), which could include energy use, recycled content, and air and water emissions from manufacturing, disposal, and use. Other product labels focus on a single attribute, which could be water, energy, or chemical emissions that directly impact the indoor environmental quality."
"Third-party assessment; means that the evaluator is independent of the product manufacturer, contractor, designer, and specifier that has no financial interest or ties to the outcome of the assessment.
Second-party assessment; refers to when the evaluation is performed by an interested party such a trade

association."   **"First party assessment;** refers to when the evaluation is coming directly from an organization that is associated with the entity making a claim or that benefits from the claim."   **"Green building rating or green certification system;** this broadens the focus beyond products, to consider the project/building as a whole. Rating systems are a type of building certification system that rates or rewards relative levels of compliance or performance with specific environmental goals and requirements. Rating systems and certification systems are frequently used interchangeably. A few of these programmes are single-attribute, focusing solely on water or energy. In contrast, others are multiattribute, addressing emission, toxicity, and overall environmental performance in addition to water and energy."   **"Attribute;** The characteristics or elements of products or services that determine the type and extent of their short and longer-term impacts on the environment or human health. Environmental attributes include, for example, biodegradability, recyclability, energy efficiency, water efficiency, indoor air emissions, hazardous waste, carcinogenicity, etc."   **"Single – attribute criteria labels;** Type of environmental claim that captures one aspect or quality of a product's performance. It focuses on one environmental issue, e.g., energy efficiency, water, or sustainable-wood harvesting. This kind of criteria keeps things simple but can inadvertently mislead consumers into thinking the product is green overall."   **"Multiple – attribute criteria labels;** As the name suggests, these labels examine two or more environmental impacts; looking at several characteristics of a product or even a product's entire life cycle or impacts of a product."

Table 3.1 Eco-Label Terminology Source (Brilhante & Skinner, 2015)

Also, Table 3.2 below highlights three typologies of environmental or green certification labels according to the International Standards Organization). The table was taken as-is from (Brilhante & Skinner, 2015)

ISO-defined Types of Environmental Labels			
Type	**ISO Number**	**What the label does**	**Parties**
Type I (ecolabel)	ISO 14024	"This is a voluntary, multiple-attribute criterion-based, third party programme that <u>awards a license or seal of approval</u>, authorizing the use of environmental labels on products indicating overall environmental preference of a product within a product category based on life cycle assessment[1]."	This kind of ecolabel needs a third-party certification
Type II (self-declaration claims)	ISO 14021	"These labels are also voluntary. <u>Verifiable single-attribute environmental claims</u> for issues such as energy consumption, emissions, or recycled content. It can be first-party, the self-declared manufacturer claims. However, many manufacturers are beginning to seek third-party verification of those claims in response to industry demand."	This ecolabel only needs a first-party self certification issued by the manufacturer
Type III (environmental declarations)	ISO 14025	"This kind of label is also voluntary, consists of <u>qualified product information based on life cycle impacts</u>. A qualified third party determines the environmental parameters, and then companies gather the required information into the reporting format, and these data are independently verified. (E.g. Report cards/information labels."	This kind of ecolabel needs a third-party certification

Table 3.2 ISO-defined Types of Environmental Labels Source (Brilhante & Skinner, 2015)

TIMELINE:

Figure 3.2 highlights a timeline of eco-labels. Some of which are not included in this research.

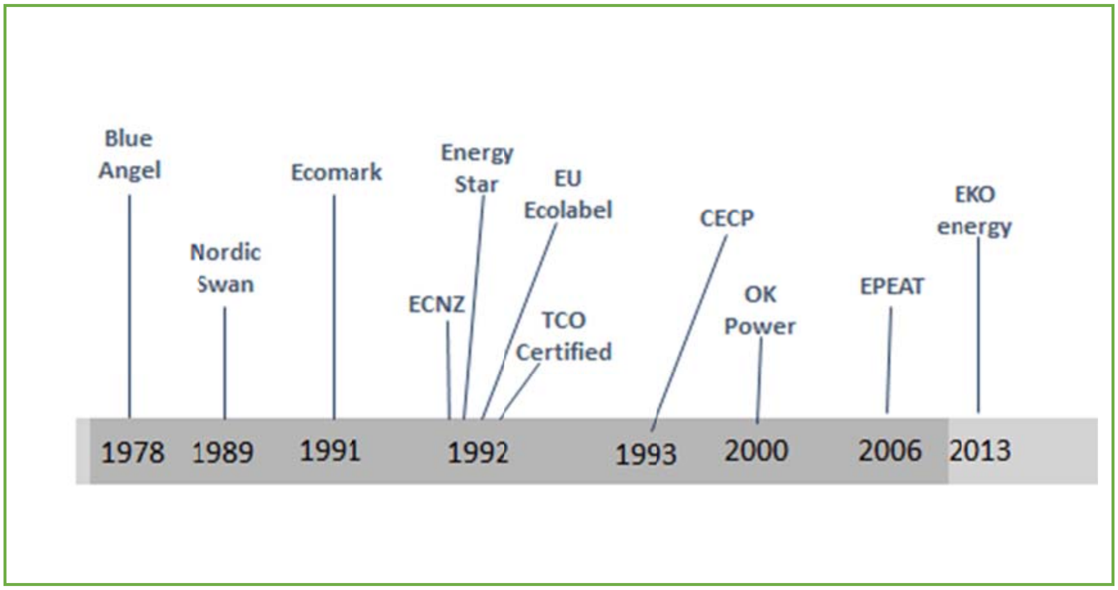

Figure 3.2 Timeline of Green Ecolabels

While they have many benefits, eco-labels also have some drawbacks.

1. Authenticity of claims: It might be easy for organizations to divert from being authentic in their claims on eco-friendliness. If the consumer loses trust in the label because of some false claims, it can lose its credibility (Salman, 2016).
2. Cost: It is essential to keep in mind that third-party organizations award eco-labels, and the cost of this process can be very high. There could be a cost for each different market, and the cost could be quite high (Salman, 2016).
3. Utility: Until today, eco-labels are awarded for some product categories and not for all. For instance, in India, there are only sixteen product categories that have been awarded the Indian ecolabel: Ecomark. Thus, many product categories are still being marketed and purchased without an eco-label (Salman, 2016).
4. Effectiveness: An eco-label is only effective if it is well received, accepted, and adopted by a significant number of consumers (Salman, 2016).
5. Increased Consumption: Consumers will sometimes use more of an eco-labeled product to deal with some guilt they might feel towards the environment (Salman, 2016).

In summary, it is important not to lead consumers to confusion. The purpose is ethical, and marketing should be genuine. In addition, claims should be validated. Otherwise, instead of raising environmental standards and designing an eco-friendly environment, green certifications would become merely the shadow of they were established to be.

In the remaining parts of this chapter, a description of Blue Angel, Energy Star, Nordic Swan, EU Eco-Label, and EPEAT will be made.

3.1. Blue Angel

Blue Angel is defined as “the environment label of the domestic authority of Germany since 1978. This makes it the oldest and first eco-label ever. Blue Angel sets great qualifications for environmentally friendly product design and has shown itself for several decades as a reliable guide for more sustainable consumption” (Label, Blue Angel). It is considered to be an ecolabel that protects human health as well as the environment. It now covers more than 10,000 products throughout more than 80 categories, such as waste management and recycling. Four institutions support Blue Angel: the “Federal Ministry for the Environment, the Nature Conservation and Nuclear Safety”, “Umwelt Bundesamt”, “Jury Umweltzeichen” and “RAL gGmbH” (Label, Blue Angel).

Fortunately, Blue Angel has targeted a large number of ICT products, such as data centers. As for computers, Blue Angel eco-labeled products meet very strict requirements to enable recycling even through material selection. This approach indeed leads to better protection of natural resources (Label, Blue Angel).

Blue Angel addresses energy consumption but also the capability of the resource itself – in data centers, for instance- by requiring professionals to oversee data center operations for optimization's sake. This is of paramount importance as data centers, and servers’ number is increasing worldwide, and there is a rapid growth of the use of ICT devices. (Label, Blue Angel).

Another example for Blue Angel is that it promotes the use of energy-efficient air conditioning, which is quite an essential dimension in cooling data centers. In addition, to be certified, the product needs to meet quality standards to optimize the time of its use. It even addresses noise-making, which is an added benefit (Label, Blue Angel).

Computers, laptops, and accessories are all categories that can be certified by the Blue Angel label. Nowadays, most employees have either laptops or desktops or even both at work and very often as home as well. Blue Angel certification specifies that raw material used in computers should enable a long life to benefit the most out of the resources that were purchased (Label, Blue Angel). Interestingly enough, even with Voice over IP, Blue Angels requires reduced power consumption in addition to sound voice quality, compatibility with data networks, and a warranty time of a minimum of five years (Label, Blue Angel).

As the Blue Angel eco-label focuses on the scarcity of elements like gold, indium, cobalt, and tantalum, which are rare resources, it enforces strict requirements to guarantee the maximum benefit of computers made of these elements. This is how Blue Angel eco-labeled computers are highly recyclable and made of low-emission materials to reduce potential threats to the environment and human health (Label, Blue Angel).

The list of criteria/requirements is long. Blue Angel has dedicated a list for each product category. For the sake of this research, we have first selected to report as conveyed in Table 3.3 below requirements for important ICT devices: computers and keyboards.

Requirements	**Details**
Energy and Power Consumption of Computers	Meeting ENERGY STAR Program Requirements for Computers applicable to the specific type of computer

Durability	**Spare Parts Availability**
	• Guaranteeing the availability of spare parts for appliance repair at a reasonable cost for at least five years from the time that production ceases
	Capacity Expansion
	• Ensuring easy accessibility to the replaceable components and expansion interfaces
	• Providing the following options and interfaces:
	  ◦ Replacement or expansion of Random Access Memory (RAM)
	  ◦ Replacement or expansion of the mass storage
	  ◦ Existence of two or more USB 3.0 or later ports
	  ◦ Connectivity to external monitors

Recyclable Design	**Structure and Connection Technology** • Allowing easy disassembly for recycling purposes • Allowing easy removal of batteries/accumulators • Allowing easy removal of electrical/electronic components **Material Selection**

Requirements	Details
	• Using a maximum of 4 types of plastic parts with a mass greater than 25 and keycaps with a total weight greater than 25 grams • Marking plastic parts with a weight greater than 25 grams each and an even surface area of more than 200 sq.mm in accordance with ISO 11469 with due regard to ISO 1043 • Avoiding the application of metallic coatings to plastic housing parts • Using recyclate material in housing parts and chassis

Material Requirements	**Plastics used in Housings and Housing Parts**
	• Avoiding the use of substances that the Regulation (EC) No 1906/2006 (REACH) 8 have identified as substances of very high concern
	• Avoiding the use of substances that the CLP Regulation17 have classified in the following hazard categories:
	  ◦ Carcinogenic of category Carc. 1A or Carc. 1B
	  ◦ Mutagenic of category Muta. 1A or Muta. 1
	  ◦ Reprotoxic of category Repr. 1A or Repr. 1B.
	• Avoiding the use of halogenated polymers in housings and housing parts
	• Avoiding the use of halogenated organic compounds as flame retardants
	• Avoiding the use of flame retardants classified under the CLP Regulation as carcinogenic of Category Carc. 2 or as hazardous to waters of Category Aquatic Chronic 1
	Use of Biocidal Silver
	• Avoiding the use of biocidal silver on touchable surfaces

Noise Emissions	• Evaluating the noise emissions based on the specification of the declared A-weighted sound power levels LWAd in decibel (dB) to the first decimal place
	• Determining The A-weighted sound power levels LWA(1..4) in accordance with ISO 7779 in the operating modes
	  ◦ L_{WA}(1) determined in the C.15.3.2 mode – "idle mode"
	  ◦ L_{WA}(2) determined in the C.15.3.3 g) mode – "active mode"
	  ◦ L_{WA}(3) determined in the C.19.3.2 mode "optical drive"
	  ◦ L_{WA}(4) determined in the C.5.3.1 "keyboard"

Product Documents	• Providing the following user information for desktop computers:
	  ◦ Energy consumption (ETEC) in kilowatt-hours per year (kWh/a) and the power consumption in different operating modes
	  ◦ Instructions for setting the devices into energy-saving operating modes and

Requirements	Details
	information on further energy-saving options • Information on the provision of spare parts • Options for expanding the capacity • Sound power level in all operating modes • Instructions for environmentally sound disposal at the end of the life cycle abiding by the German Elektrogesetz (Electrical and Electronic Equipment Act), • Information on manufacturer-operated product take-back programs to allow reuse • Providing the following additional user information for notebook computers: • Instructions on how to remove and replace the battery/accumulator or battery/accumulator pack • Indication of nominal capacity, voltage and type designation • Indication of the minimum achievable full charge • Information on the software tools for battery/accumulator status reading and battery/accumulator protection • A note advising the user that batteries/accumulators must not be disposed of with the normal waste but must betoken into waste collection facility
Notebook Computer Requirements	**Rechargeability** • Using batteries/accumulators that include one or more battery cells coupled together by a housing, plastic film or in other suitable forms **Replaceability** • Designing the computers to allow easy replacement of the batteries/accumulators **Battery/Accumulator Capacity** • Measuring the battery/accumulator capacity in accordance with standard EN 61960 **Battery/Accumulator Marking** Providing the following information: • Nominal capacity (N) • Nominal voltage • Type designation • Date of manufacture • Indication of the metal with the greatest mass percentage • Indication of substances contained in the battery/accumulator that hinder the recycling process

Requirements	Details
	Battery/Accumulator Durability • Providing a battery/accumulator that achieves a minimum of 500 full charge cycles **Battery/Accumulator Status** • Providing software that allows the reading and display of the battery's/accumulator's "state of health", "state of charge" and the number of full charge cycles already performed from the battery/accumulator **Battery/Accumulator Protection Software** • Providing software that is able to limit the battery's/accumulator's charge to a value smaller than the maximum amount of usable electricity
Separate Keyboard Requirements	**Ergonomics** • Testing keyboards for the ergonomic properties in accordance with standards DIN EN ISO 9241-400 and DIN EN ISO 9241-410

Table 3.3 Requirements for Important ICT Devices: Computers and Keyboards Sources (Label, Blue Angel) (Blue Angel Basic Award Criteria, 2017)

Also, and as this research's objective is to include significantly green trends in software the following Table 3.4 has been developed to report Blue Angel criteria for software products

Time of Submission: At the Time of Application	
Requirements	**Details**
Resource & Energy Efficiency	**Minimum System Requirements** • Minimum processor architecture incl. generation • Minimum local working memory required • Minimum local permanent storage required • Requirements for other software • The required external services that are not available on the reference system • The required additional hardware **Hardware utilization and electrical power consumption in idle mode** • Average processor utilization • Average working memory utilization • Average permanent storage utilization • Average bandwidth utilization for network access • Average electrical power consumption **Hardware utilization and energy demand when running a standard usage scenario** • Processor utilization

	• Working memory utilization • Permanent storage utilization • Volume of data transferred for network access • Average energy demand **Support for the energy management system** • Elimination of restriction to the functionality of the software product
Potential Hardware Operating Life	**Backward compatibility** • Providing the possibility to run the software product on a reference system at least five years before the time of application.
User Autonomy	**Data formats** • Submitting the manuals • Providing examples of other software products • Stating the data formats and assigning them to an open standard **Transparency of the software product** • Including a template for the interface documentation • Including information on the extent to which the software product has been published as open-source code • Including an explanation of what will happen to the software product after the end of support • Including information on the license under which the software product will be sold and the rights that the license provides • Including information on the licenses for all software components **Continuity of the software product** • Providing the possibility to use the software product over a long period of time eliminating any risk of serious disadvantages arising **Uninstallability** • Providing the possibility to remove the software product completely from the computer system after the end of its operating life without leaving any unnecessary traces of data. **Offline capability** • Eliminating any influence of external factors on the functionality and availability of the software • Providing the possibility for the software product to remain largely functional even without a network connection **Modularity** • Providing information on how individual modules of the software product can be

	deactivated during the installation or the use of the software product. **Freedom from advertising** • Restricting any advertising except for advertisements for the manufacturer's own company or provided services **Documentation of the software product, license conditions and terms of use** • Describing the processes for installing and uninstalling the software • Describing the data import and export processes • Providing information on reducing the use of resources • Providing information on the licensing terms and terms of use • Providing information on software support • Providing information on the handling of data • Providing information on data security, data collection, and data transmission
Time of Submission: During the Term of the Contract	
Requirements	**Details**
Further Development and Update of the Product	Ensuring the software product still complies with all of the criteria even after the application of any changes
Time of Submission: At the End of the Term of the Contract	
Requirements	**Details**
Final evaluation	Submitting a Resource Efficiency Report to RAL gGmbH at the end of the relevant term of contract including the values measured and the measures that were taken to increase the resource and energy efficiency of the software during the term of the contract

Table 3.4 Criteria for Software Products Sources (Label, Blue Angel) (Blue Angel Resource and Energy Efficient Software, 2020)

3.2. Energy Star

In 1992, the Environmental Protection Agency (EPA) launched a program to help the environment and save energy leading to saving a significant amount of money. The name of the program was Energy Star. This program aimed to guide companies and individuals to minimize emissions of carbon dioxide, save some money, and also to provide a product that also meets quality and performance requirements (Energy Star EcoLabel).

Energy Star is a single attribute criterion, voluntary eco-label, and is now considered a government-backed symbol of energy efficiency. The European version is controlled by an agreement between the United States and the European community. A variety of office devices, such as computers and printers, carry the logo. Such devices would only use a predefined limit allowed of energy consumption when it is on stand-by mode (PSM). The Energy Star label can today be found today in Australia, Canada, Japan, New Zealand, Taiwan, and the EU. Requirements are updated and often tightened every two years (Energy Star EcoLabel).

Energy Star would superintend that each product goes through a particular procedure before it is crowned with a label. This type of steps has helped the buyers to gain trust in labels and labeled products. Which optimized the purchases for certified products (Energy Star EcoLabel).

As for criteria, and according to the Energy Star official website, for a product to be certified, certificates should be awarded by a partner recognized by the U.S. Environment Protection Agency (EPA). Also, a specific total energy consumption (ETEC) in kilowatt-hours per year shall be calculated as per a particular formula, and the total energy consumption should not exceed a total allowable also predefined by an explicit formula as well (Energy Star EcoLabel).

It is said that once the label has expanded its scope of product categories and has targeted homes and even plants to enable more energy-saving but also improved quality and comfort, it has created around two million jobs worldwide, through individuals hired to help certify a large number of products (Energy Star EcoLabel). Indeed, around 90 % of households in the US market are now familiar with the Energy Star ecolabel. Energy Star is also said to have allowed the US market to save more than 450 billion US dollars and over 3.5 trillion kWh of electricity (Energy Star EcoLabel). Another shining example of the wins achieved through the eco-label is that, for instance, an Energy Star certified residence with enhanced water piping to minimize water depletion saves up more than fifteen percent of the energy compared to a typical residence with no certificate. (Energy Star EcoLabel). "Overall, Energy start commercial buildings are reported to have reduced energy consumption to 35% less than for those not similarly labeled. All of these reasons led to above 30 percent of the Fortune 500 to partner with the United States of America EPA to deliver cost-saving energy efficiency solutions that improve air quality and protect the climate" (Energy Star EcoLabel).

Although most Energy Star programs are directed towards specific products and have been successful so far, it is less likely that it will be as successful in the future for two reasons:

1- First, it is becoming more challenging to distinguish between products, such as, for instance, televisions and computer displays. TV sets used to be categorized as consumer electronics while computer screens were considered part of office equipment resulting in different specifications, such as stand by and sleep mode. We now see a proliferation of devices that can function both as computer displays and TVs. In this case, where would the product belong under Energy Star, and this is just one example of how products are converging, splitting, and re-combining. For the sake of mandatory efficiency, this is important because they address 100% of the products: All stakeholders need to agree on the energy test procedure, which takes several years. When a product has modes more varied than simply "on" and "off", it is essential to have tests for every single mode, and it makes it harder (Murugesan S. , Harnessing Green IT: Principles and Practices, 2008).

2- Energy Star version 4.0 regulates the energy performance of external and internal power supplies. It gives power consumption specifications for idle, sleep, and standby modes for several different devices, which isincluding PCs, desktops, and of course the gaming consoles. PC meeting the new standards will save power in any mode of state. Regulations for PCs in idle mode are not so old, as before standards addressed only sleep and standby modes (Murugesan. S, 2008).

Table 3.6 below requirements for Energy Star label for Computers.

Product	**Requirements**
Computer	The device should consist of at least one central processing unit (CPU) in order to fulfill logical operations and process data. It should also be able to accept input devices, and to be connected to an output device such as monitor to show processed data.
Desktop Computer	Designed to be in a specific location, not to be portable, usually connected to external devices such as display, keyboard and mouse. Integrated desktop computers consist of display and the computing hardware in one unit.
Notebook Computer	Designed for portability and should function whether connected to power source or not. The device should contain a mouse, keyboard and a display to output the processed information. A two in one Notebook should be designed to have a detachable display, once the display is separated, it could work as a tablet. A mobile workstation, should meet the specs of a Notebook and has a (MTBF) mean time between failures of at least 13000 hours, also should get at least two certifications from Independent Software Vendors (ISV), the system should support of not less than 32GB of memory and hold either of at least 4GB of memory with a hundred thirty four GBps bandwidth integrated GPU, or a discrete or integrated GPU holding at least ninety six GBps of a buffered bandwidth.
Portable All in	A portable device with a touchscreen of at least 17.4 inches. And containing a wireless network

Product	Requirements
one computer	unit and internal battery. The touchable screen could be used as an input device.
Thin Client	Should contain a non-rotational storage device and purposed to be in a specific location.
Workstation	Should be sold as a workstation, able to provide error correcting code, do not base changing frequency or voltage above CPU and GPU. Also should have at least two of the following: 1) at least on GPU, at least four slot of PCI express, support multi-processor and certified by at least two independent software vendors.
Rack mounted workstation	Should have the specs of a workstation, and follow the international dimensions of IEC 60297-3-101:2004.
Energy consumption	For Desktop, integrated desktop, notebook computers, tables and portable all in one computer. The energy consumption should be equal or less than the maximum energy consumption specified taking E(TEC) as typical energy consumption and E(TEC_MAX) as the maximum TEC. E(TEC)=(8760/1000)(P_OFFxT_OFF+P_SLEEPxT_SLEEP+P_LONG_IDLExT_LONG_IDLE+ P_SHORT_IDLExT_SHORT_IDLE) E(TEC_MAX)=(1+ALLOWANCE_PSU)x(TEC_BASE+TEC_MEMORY+TEC_GRAPHICS+TEC_STORAGE+TEC_INT_DISPLAY+TEC_SWITCHABLE+TEC_EEE+TEC_MOBILEWORKSTATION)
Energy consumption	For Workstations, the P(TEC) weighted power consumption should be less than or equal to P(TEC_MAX) maximum weighted power consumption. P(TEC)=P_OFFxT_OFF+P_SLEEPxT_SLEEP+P_LONG_IDLExT_LONG_IDLE+P_SHORT_IDLExT_SHORT_IDLE P(TEC_MAX)=0.28x(P_MAX+N_HDDx5)+8.76xP_EEEx(T_SLEEP+T_LONG_IDLE+T_SHORT_IDLE)
Energy consumption	For Thin Clients, E(TEC) should be less than E(TEC_MAX), where E(TEC)=(8760/1000)(P_OFFxT_OFF+P_SLEEPxT_SLEEP+P_LONG_IDLExT_LONG_IDLE+ P_SHORT_IDLExT_SHORT_IDLE) E(TEC_MAX)=TEC_BASE+TEC_GRAPHICS+TEC_WOL+TEC_INT_DISPLAY+TEC_EEE

Table 3.6 Requirements of Energy Star for Computers Source (ENERGY STAR Program Requirements Computers, 2018)

Table 3.7 below requirements for Energy Star label for Computer Servers/Enterprise Servers.

Product	Requirements
Computer Server	• Transparency and clarity with the product, where it should be offered to the market and merchandised a Computer Server. • Designed to support at least one Operating system.

Product	Requirements
	• Should aim to host applications for users and others. • Support showing ECC, DIMMs, BOB configurations. • Contains or sold with AC-DC or DC-DC power-supply. • Created with capability of all CPUs being able to use the shared memory and seeable to the OS.
Blade Server	• Designed to fit in blade frame or chassis. • Contain a minimum of one CPU and memory slot.
Blade chassis	It should contain a frame in order to contain blade devices such as blade server and storage, etc...
Blade storage	It should be designed to contain storage and to fit in a blade chassis.
Fully fault tolerant server	It should be designed with the availability of each node twice, in case of a failure of one node, the other would work without any interruptions.
Resilient Server	• Containing RAS Processor, where the processor is able to find, fix and hold data errors. The processor should recover errors, in case of a fault; a retry attempt should be followed. A detection Error should also be provided on first level of cache. And correction on the cache level involving single bit error correction. • Resilience and recover of the System, which includes at least 6 of: Containing and recovery of errors. Processor able to work in a system of four or more sockets. Mirroring the memory. Sparing the memory. Addition of resources without system rebooting. Capability of holding excessive input-output devices. Hot swappable adapters and storage devices. Recognize processor to processor lane failure. Ability to segment the system to run OS instances on separate partitions.
RAS Power Supply	The power supply/s should be preserved with concurrency and redundancy.
RAS cooling	Cooling items shall be preserved with concurrency and redundancy.
Server Appliance	The server should contain customized software and hardware setup by the supplier and shouldn't run user-software
High Performance Computing System	Should be offered to the market as optimized computer server, designed to run intensive and parallel applications. Supporting several nodes to optimize the computation abilities. And it should contain rapid speed between nodes.
Computer Server forms	Where the Rack mounted server should follow the 19 inch standard. And the tower server should be similar to the tower user computer.
Server Components	• Power Supply Unit: Should be independent and able to be attached and detached from the system with a wired connection. • Motherboard: Should consist of connectors to connect additional boards, RAM, CPU,

Product	Requirements
	and expansion slots. • Processor: Should be capable to be attached to the motherboard by a socket. • Memory: Should be able to store data in order to be used by the processor. • Storage device: Should contain nonvolatile data storage, such as HDD, SSD and tapes.
Large network Equipment	It should consist of at least 12 network ports, and the throughput of the item should be more than 12 Gigabit per second.
Uninterruptible Power Supply	The system should provide power in case of power shortage, and it may contain energy storage items.

Table 3.7 Requirements of Energy Star for Computer Servers Source (ENERGY STAR Program Requirements Computer Servers, 2019)

Table 3.8 below requirements for Energy Star label for Displays

Product	Requirements
Monitor	Should be designed to display the view for one individual.
Signage Display	Should be designed for multi-views at places such as point of sale, malls, hotels, stores and it Should comply to at least 3 criteria of: 1) Diagonal display perimeter more than 30 inch. 2) Density of a pixel should be less than 7001pixels per square inch. -maximum lightness more than 400 candles in a square meter. 3) No stand ships should assist the display on the desktop, or be designed to stand on a wall vertically. 4) Should have RJ45 actual real port or RS232. RS232 is known as VGA port.
Tiled Display System	Known as several signage displays that are next to each other closely, in order to show one big screen. The maximum tiled setup should be configured with all the needed external modules as to setup a two tiled panels.
General for Monitors and Signage Displays	• External Power Supplies (EPS) weather they are single or multiple voltages, then they should meet at least level 6 concerning the requirements of the performance for worldwide protocol of efficiency marking for energy consumption. • The product should also be shipped with a user manual as hard copy, box, and package or electronic, which should contain info about Energy Star, energy consumption changes and how to optimize energy consumption.

Product	Requirements
	• Forced Menu, where product that promoted a start-up forced menu should either display a choice of mode, or information with Energy Star mark. • Power Management: where product should provide a minimum of one feature that is on by default. Also product should contain a default timer or sensor to go to an off or sleep mode. Sleep mode of off mode shall be triggered with five minutes of being in a disconnected status. • Energy requirement for Monitors: E(TEC)should be less than or equal to (E_TEC_MAX+E_EP+E_ABC+E_N+E_T+E_C+E_HDR+E_USB)xeff_AC_DC. Where E(TEC)=8.76 x (0.35xP(ON) + 0.65xP(SLEEP)), E_TEC_MAX is the maximum TEC, and TEC is the total energy consumption.

Table 3.8 Requirements of Energy Star for Displays Source (ENERGY STAR Program Requirements Displays, 2020)

Table 3.9 below requirements for Energy Star label for Data Center Storage.

Product	Requirements
Storage Product	Storage Product should contain a storage system where it should be completely functional and is able to be attached to storage devices or connected through a network. And the product should be able to be bought in one order, and to be contained of one or more SKUs.
Storage Device	It should be able to be bought in one order, and to be contained of one or more SKUs. And should be recognized as nonvolatile data storage, such as Solid State Drive (SSD), Magnetic tapes and Hard Disk Drives (HDDs).
Network Attached Storage (NAS)	Contains at least one storage device and must be connected to a network in order to provide storage services. And contained of one or more SKUs, and be bought in one order.
Storage Area Network (SAN)	It should contain a network with storage devices and systems of computers that communicate, bought in one order, be contained of one or more SKUs and provide a secure data transfer.
Network Equipment	Should be a device that brings connectivity of data from and to devices through physical ports. Routing of data packets should follow internet protocol. And to be bought in one order, and to be contained of one or more SKUs.
Capacity of storage	It should follow at least one of the storage units, decimal bytes or binary bytes.

Product	Requirements
Storage operational states	Should follow two states, Active and idle. Where in active state the storage should be processing input/output requests. And in idle state it divided into two, ready-idle where product can respond to input/output requests following the MaxTTFD limits for the category of taxonomy, and deep-idle where the product is not able to follow the MaxTTFD limits.
Power Supply Unit (PSU)	The device should be able to provide current from AC to DC or from DC to DC, in order to provide power to the storage units. The device should be able to connect and separate from the system by electric wire. And to be bought in one order, and to be contained of one or more SKUs.

Table 3.9 Requirements of Energy Star for Data Center Storage Source (ENERGY STAR Program Requirements for Data Center Storage, 2013)

Table 3.10 below requirements for Energy Star label for Imaging Equipments.

Product	Requirements
Printer	The device should be capable of receiving information from various devices, accept electrical input, marketed as printer, and able to print information on paper as output. The product should have automatic duplex capability by default.
Scanner	The product should be marketed as a scanner, and to be able to convert a paper into an electronic image in order to be stored or edited.
Copier	The product should be marketed as copier, and is able to duplicate papers.
Fax	The product should be marketed as a fax machine, and able to scan papers to be sent to a remote destination, and to receive scanned data from remote destination to be printed out.
Multifunction device	The device should be able to perform as a printer and a scanner. The device could also be used as a fax machine. The product should have automatic duplex capability by default.
Electric consumption	The TEC should be less than or equal to the TEC_MAX, where TEC is the typical electric consumption, and TEC_MAX is the Maximum TEC. TEC=(5(E_JOB_DAILY+(2xE_FINAL)+(24-N_JOBS/16-(2xt_FINAL))xE_SLEEP/t_SLEEP)+48xE_SLEEP/t_SLEEP) TEC_MAX=TEC_REQ+Adder_A3+Adder_WIFI E_JOB_DAILY=1/4(2xE_JOB1+(N_JOBS-2)x(E_JOBS2+E_JOBS3+E_JOBS4)/3)

Table 3.10 Requirements of Energy Star for Imaging Equipment Source (ENERGY STAR Program Requirements for Imaging Equipment, 2019)

Table 3.11 below requirements for Energy Star label for Large Network Equipments.

Product	Requirements
Router	The device should route packets from one network to another, using network layer 3.
Switch	The device should deliver packets to certain ports, depending on the destination, using network layer 2.
Security Appliance	The device should be able to provide protection from external attacks or traffic. The device should also be able to provide VPN service to remote users. Such devices are known as firewalls.
Access Point	The device should be able to manage wireless local area network; this could be done by one or more access points.

Table 3.11 Requirements of Energy Star for Large Network Equipment Source (ENERGY STAR Program Requirements for Large Network Equipment, 2016)

3.3. Nordic Swan

During the making of "Vision 2015", a voluntary environmental eco-label was developed: The Nordic Swan: "The Nordic Ecolabel considers the environmental impact of goods and services during their whole life cycle, from raw materials to waste products". (O'Sullivan, 2009)

This ecolabel is meant to help consumers find products that would have a less negative impact on the environment and consequently make purchases with the environment in mind. It was introduced in 1989 by Nordic countries as Ecolabel to minimize the impact on the environment and imposes requests on the life cycle of the product, chemicals in the products, and stimulates sustainable development through the production of the product. The label also guides companies to sustainable solutions. The label is known in Denmark, Sweden, Norway, Finland, and Iceland and follows ISO 14024 (Nordic Swan EcoLabel).

The Nordic Swan places a focus on power consumption and waste resulting from the computers since the computer is sometimes made of not-so-green elements and that their time of use is not as long as it could be (Nordic Swan Label, 2013). Some of the eco-label requirements are for products to be limited to a predefined low level of energy consumption, not to contain mercury and to limit the number of specific substances, while at the same time directing that the computer be upgradable and recyclable (Nordic Swan Label, 2013). A wide variety of private-computers can be Nordic-Swan certified as long as product suppliers follow label requirements, such as desktop, integrated desktop, notebook, thin client computers, workstations, and small scale servers (Nordic Swan Label, 2013)

3.4. EU Ecolabel

EU Ecolabel is part of a large European Union action plan on sustainable consumption adopted by the European commission in 2008. This certification is linked to other EU policies such as Green Public Procurement (GPP) and Eco-design of Energy using products. This green label an environmental and voluntary scheme established in 1992 by the European Commission to encourage for-profit organizations to sell and market products and services that meet high environmental as well as quality and performance requirements: "Ecolabel seeks to minimize the diverse environmental influences at each phase of a product's life. The principles are set at layers that advertise products which have a lower overall environmental impact". (European Commission EcoLabel, 2016)

This label concerns a many products, services, and groups that are continuously added to its list of certified products. EU Ecolabel enables the identification of services and products with less environmental impact from raw material extraction to production, use, and disposal. The EU ecolabel is considered to be a Type 1 label. This means that the product certified has been independently evaluated and that it has met the stringent environmental criteria, not just energy consumption. In other words, it is considered a best-in-class label (European Commission EcoLabel, 2016).

At the state level, the management of the label is carried out by a competent body chosen by the European Commission. The certification is awarded according to criteria set by subject matter experts, by the industry as well as NGOs and consumer organizations at European level. The EU Eco-label criteria were set for more than 30 non-food and non-medical products. These criteria are reviewed every 3-5 years (European Commission EcoLabel, 2016).

Some of the labels criteria are listed in Table 3.5:

Energy Consumption	The total energy consumption of the computer should be under "Regulation (EC) No 106/2008" and improved by "Energy Star v6.1"

Power Management	The device will be in energy save default settings, but once a user tries to disable the settings, a note shall popup notifying the user assuming that he will hold on.
Graphics Capabilities	Graphic cards shall be functional. However, GPU shall go off once the computer is in idle state.
Enhanced Performance Displays	Whereby default, they can adjust the lightening/brightness depending on the light in the room.
Product Lifetime Extension	Where portables run durability tests: Three mandatory durability tests for notebooks to testify the "resistance to shock", "resistance to vibration", and "accidental drop". Other tests could also be done, such as "temperature stress", "screen resilience", "water spill ingress", "keyboard lifespan," and "screen hinge lifespan".
Tablets and 2 in 1 Computer	Only two mandatory tests are applied: "accidental drop" and "screen resilience".
Rechargeable Battery Quality and Lifetime Criteria	"Minimum seven hours of rechargeable battery life after the first full charge of notebooks, tablets, and 2 in one computer". Also, models that users can change the battery with no usage of tools shall preserve 80% of capacity after 750 charges. In comparison, models that require tools to change the battery shall maintain 80 % of capacity after 1000 charges. The battery will have a minimum of two years guarantee. And provide info on the life of the battery.
Data Storage Drive Criteria	A drive of stationary computer should have a yearly rate of fail of less than 0.25%, and for servers, drive an annual rate of fail less than 0.44%. However, for portable PCs, the drive should conserve the data and drive against any impact of shake.
Upgradeability and Reparability	The aim if for old components to be replaced or upgraded, so the design of the product should allow that. Such components can be replaced or upgraded: "storage", "memory", "keyboard and trackpad", "cooling fans". Also, batteries that are removable and replaceable should be changed by one person.
Disassembly and Recycling Design	Computers shall be made in a way it is effortless to disable the parts.

Table 3.5 Aspects and Criteria of EU Eco-Label Source (European Commission EcoLabel, 2016)

The certification is not as overwhelming as it could sound. Any trader, retailer, service provider, or manufacturer can fill out an application and send it to the label representative or to the “competent” body who would evaluate the application, make a decision, and a response within two months of receipt unless additional information is needed. In addition to the application, the representative would make a visit to assess compliance, and upon approval, the applicant would be authorized to use the label on products. To maintain the certification, the authorized party needs to preserve conditions of compliance and which evidence through documentation about test results, for instance. If the product is considered not to be compliant anymore, this should be communicated to the representative for them to make a decision. The label representative could make unplanned visits to the site of the product manufacturing without previous notice, and the applicant is required to give them access at all times. (European Commission EcoLabel, 2016)

3.5. Electronic Product Environmental Assessment Tool (EPEAT)

EPEAT was developed due to a need for an assessment tool that would enable the selection of electronic products based on their environmental performance. This tool was established by the Green Electronics Council (www.greenelectronicscouncil.org). EPEAT offers a method for purchasers or purchasing authorities to compare and select devices such as desktop computers, notebooks, and computer screens according to environmental criteria. At the same time, it helps manufacturers promote their products and services as being good for the environment (EPEAT).

The tool highlights 23 required and 28 optional criteria. These criteria are grouped into eight performance categories. (EPEAT Criteria)

These eight performance categories are:

- Reduction or Elimination of Sensitive Materials
- Materials Selection
- Design for End of Life
- Product Longevity/Life Cycle Extension
- Energy Conservation
- End of Life Management
- Corporate Performance
- Packaging

There are three certification levels: bronze, silver, and gold. A bronze product meets all 23 required criteria, whereas the silver products would meet the 23 required criteria and at least 14 optional ones. In contrast, the gold products meet all 23 required criteria and all of the 21 optional criteria. To improve their EPEAT score, manufacturers can select among criteria that are optional only to achieve a higher level (EPEAT).

As for devices close to ICT, such as computers, it is noteworthy to know that all EPEAT approved computers have reduced levels of substances such as mercury, lead, and cadmium, known to be harmful to human health. Besides, EPEAT registered products need to offer safe recycling options. The label is trusted now that major government agencies in the US, for example, making mention to EPEAT in their contracts (EPEAT).

4. Evaluations

It would be interesting to share a sum of approaches (Table 4.2) gathered by E. Kern and her colleagues and was takes as-is from (Kern E. H., 2018)

Approach by	Objectives	Outcomes	Criteria (Examples)
Method (i)			
Albertao [21] Albertao et al. [22]	"Assessing properties of software for environmental, economic and social aspects; Introducing a set of metrics to assess the sustainability of software products, demonstration how to use the metrics"	"Sustainability performance metrics and strategy on how to improve follow-up releases by using the metrics"	"Modifiability, Reusability, Dependability, Usability, Efficiency, and Predictability"
Calero et al. [18] Calero et al. [23]	"Extending the ISO 25010 quality model by including sustainability aspects; definition of ''greenability.''"	"Model for software sustainability that can be added to the ISO software product quality model"	"Energy efficiency, Resource Optimization, Capacity Optimization, Perdurability"
Method (ii)			
Taina [24]	"Developing the criteria set ''green software factors.''"	"Framework for green quality factors: related to software development and execution"	"Feasibility (Carbon Footprint, Energy, Travel, ...), Efficiency (CPU-intensity, Idleness, ...), Sustainability (Reduction, Beauty...)"
Kern et al. [25]	"Summarizing existing approaches in a ''quality model'' for green and sustainable software"	"Quality model to classify green software and its engineering and exemplary corresponding metrics"	"Feasibility, Social Aspects, Portability, Efficiency, Reflectivity, Product Sustainability"
Method (iii)			
Abenius [26]	"Evaluation of ''Green IT'', especially ''Green Software'', and pointing out possibilities to use software in a more energy-saving way"	"Examples of actions towards Green IT mapped to software life cycle phases"	"Choice of Material, Reuse Refurbish Recycle, Production Logistics"
Naumann et al. [1]	"Mapping potential effects of software to sustainable development"	"Life cycle model for software products including effects relevant to sustainability"	"Working Conditions, Manuals, Data Medium, Download Size, Accessibility, Hardware Requirements, Backup Size"

Table 4.1 Comparison of approaches on criteria for sustainable software Source (Kern E. H., 2018)

In the previous chapter, several green eco-labels and certifications were mentioned, described, analyzed, and at least generally evaluated. It is reassuring to see that there a genuine improvement in selection, purchase, and use of products that leave a minimal effect to the environment and that this improvement is benchmarked with genuine certifications among which some have been in the market for decades and have continuously improved. It is also promising in order to see that there is a multitude of certifications in a variety of countries and that this green certification approach is not exclusive to a specific part of the world only.

Also, a significant number of companies have invested effort, capital, and research in reducing their carbon footprint. In August 2019, Forbes.com published a list of renowned companies very close to ICT with evidence of their commitment to Green Computing. Companies and initiatives are described in Table 4.1 below

Google	Google is depending on renewable energy and buys needed renewable energy to meet the electricity it consumes.
Dell	The company is using big data analytics to locate the origin of energy consumptions and make needed actions, along with replacing its packaging to a wheat straw leading to more than 39 % less energy to make.
eBay	eBay has been for many years promote selling used items, and provides a very good return policy rather than allowing customers to dispose items.
IBM	Sustainability and IBM are just like one. IBM is implementing smart buildings to reduce water consumption and optimize sustainable energy.
Adobe	The company is known for awards gained due to net-zero energy and to provide LEED-certified locations and minimize water usage by more than 59 %.
Amazon	Company has been using energy-efficient lights and solar panels, and many around the world renewable energy farms that supports Amazon Web Services (AWS) Data Centers.
Facebook	Facebook has intentions to minimize greenhouse gas footprint by more than 70 % and planning to use only renewable energy by 2020.
Apple	Apple is working on 100% renewable energy and has reduced the energy produced of its products by more than 65 % in the last decade.
Intel	Intel is concentrating on water preservation and target to decrease its per-unit water consumption by 2020.
Microsoft	Microsoft aims to minimize own carbon footprint by more than 70% by 2030 optimizing departments for carbon emissions to be more eco-friendly.

Table 4.2 Companies and Green Computing Initiatives (forbes, 2019)

There are numerous benefits now genuinely associated with green labels, as mentioned above, among which a rise in the environmental awareness and involvement of individuals and not just companies or organizations in designing a maintaining a safer environment. Besides, while consumers choose the products that make more environmental sense, they gain a general awareness on the need to contribute to more conservative energy consumption, development and contribution in renewable energy technologies, and optimization of usage time of each product or service purchased as well as safer recyclability, disposal, and reuse.

Furthermore, and on the side of the manufacturers, they are now increasingly scrutinized on their choice of raw material, production practices, and processes, as well as their genuine concern to protect human health and the environment. On the other hand, they now have a marketing edge that can serve their lucrative ambitions as well as environmental interest.

For governments, they now have tangible tools and techniques to promote, evaluate, monitor, and improve the manufacturing of more environmentally safe products and services. With green eco-labels, the world has moved from recommendations to practice.

Nevertheless, it is essential to remain objective and evaluate all the shortcomings of current practices, certifications, and eco-labels. Lessons learned should be gathered, evaluated, and used for the sake of continuous improvement of this green movement. This is why some of the challenges, concerns, and gaps in green certifications will be conveyed in this part of the study as a basis to suggest in the development of a new green label.

In summary, even if efforts of governments and non-government (NGOs) are noteworthy for attaining a good level of performance in Green Computing and even if governments are "pushing vendors to act green; behave green; do green; go green; think green; use green and no doubt to reduce energy consumptions as well" (Sadikul, Ampah, & Musal, 2018), current challenges are still significant and affect computing performance. Efforts are also still contained in specific areas, such as energy consumption and e-waste, but more effort needs to be made in energy efficiency and green products (Soomro & Sarwar, 2012).

Several concerns were identified and are listed and explained below:

1- Lack of transparency: Despite the existence of now, a substantial number of green eco-labels and certifications, opportunities to participate in the development of the standards regulating the green labels remain limited.
2- There is still a fear that eco-labels could be the translation of agendas of domestic industries or restricted markets in disguise, or even eat away competitiveness as only players who can afford labeling or certification could stay in the game.
3- Voluntary eco-labeling that do not necessarily meet clear, stringent requirements and impact on trade could be made in related countries.
4- The definition of certification criteria could impact the effect of schemes in countries with different levels of socio-economic interests and conditions. As there is no real common international understanding, one can still fear that governments would specifically monitor and act according to the interests of their nation or region and not necessarily for the worldwide good and look at other state schemes are competing schemes and discredit them. (Nagaraju, 2013).
5- There still are ethical issues to resolve, such as in recycling where privacy, for instance, is to be handled considering old data and information.

Also, there is still a discrepancy in rules and regulations in “developed” countries vs. “developing” countries that overall have less stringent requirements because of the absence of laws and regulations or their lack of clarity (Nagaraju, 2013).

In the light of creating a new label catalogue, actions should be taken such as a selection of criteria from already existing ones and adding few non-existing. After all, labeling companies have consumed decades to reach to the current existing criteria and to cover so many ICT products. In this research, few products will be taken into consideration, and for instance some criteria could be selected from Energy Star while others could be taken from Blue Angel.

Table 4.3 below shoes a new label based on some existing and new requirements.

Product	**Requirements**
Computers	The device should contain at least one processor, memory and a storage device. A USB port should exist, at least one power supply and a built in graphic memory. The device should be able to accept input devices, expansion slots for upgrades and replacements, and should follow Energy Star regarding the electrical consumption. The Vendor/ manufacturer should provide spare parts for at least five years. At least one output port should exist, in order to display the output results. Disassemble the product with no difficulties. A manual guidance should be provided, containing information about the product and how to replace parts in case of failure. Product should contain minimal hazardous substances. It should be able to run 24/7 providing availability and reliability. Product should also support 32 and 64 bit Operating systems, and to provide virtualization. A safety feature should exist in the product, once a high temperature is reached, the product should provide a warning and later shutdown in case the temperature remained high. These measures will protect the hardware from failure, and at the same time warn the user. The product should be able to work in extreme weather conditions, such as high and low temperature. If the product is going to be sold in hot regions, then it would be a privilege to be able to have 2 cooling parts like fans. The product should be compatible with at least three different operating systems, which allows customers to install and reinstall the needed operating system without the need of a new purchase.
Notebook Computers	Should contain a keyboard and a pointing device, battery, and follow the Energy Star energy consumption. If the product has no fan or cooling feature, then the product should come with a warning feature, in order to raise alertness. And it should shutdown instantly in case of reaching a high hardware temperature. Battery should be sold out at affordable price, since many customers dispose the notebook once the battery life has shortened, due to a high battery price, leading to a new purchase. Replacements parts should be offered for at least five year at a reduced price, in order to exploit the usage of hardware as much as possible. Product should be compatible with at least

Product	Requirements
	three different Operating systems.
Server Computer	The product should provide availability and reliability, since most servers customers implement their server to run 24/7 with no interruptions. The hardware should have high level of performance as servers are expected to provide services to several users at the same time. It should contain at least two power supplies in order to provide a power redundancy in case of a power failure. Those way customers will have the option to connect two different line powers to the product. Parts should be available for upgrades and replacements for at least 7 years. Customers made an investment and they expect a long life service and support. Product should also support virtualization since customers are expected to exploit the hardware capabilities. Vendors that sold the product should also offer a service to buy the already used products from customers within 3 years of purchase. This will allow customers that are welling to upgrade to sell their used products, which later will be resold as used or refurbished rather than disposed. Product should follow the energy consumption calculations of Energy Star
Monitor	Should be sold with two cables to be connected to a computer and to a power source. And have the capabality to turn off or go to sleep once the moniter was not connected to a device. Should have by default automatic option to save energy. Follows the energy consumption as Energy Star requirements (ENERGY STAR Program Requirements Displays, 2020).
Printer	Should be able to receive data from a device and output the data printed on a paper. Should have by default an option to print on both sides of paper, in order to save paper and trees. Toner cartridge should be offered at a good price, unlike nowadays the toner costs as much as the whole printer which encourages customers to buy new printer once the toner is empty.
Energy Consumption of Energy Star	For Desktop, integrated desktop, notebook computers, tables and portable all in one computer. The energy consumption should be equal or less than the maximum energy consumption specified taking E(TEC) as typical energy consumption and E(TEC_MAX) as the maximum TEC. E(TEC)=(8760/1000)(P_OFFxT_OFF+P_SLEEPxT_SLEEP+P_LONG_IDLExT_LONG_IDLE+P_SHORT_IDLExT_SHORT_IDLE) E(TEC_MAX)=(1+ALLOWANCE_PSU)x(TEC_BASE+TEC_MEMORY+TEC_GRAPHICS+TEC_STORAGE+TEC_INT_DISPLAY+TEC_SWITCHABLE+TEC_EEE+TEC_MOBILEWORKSTATION) (ENERGY STAR Program Requirements Computers, 2018)

Table 4.3 New label requirements

5. Conclusions and Recommendations

In light of all of the approaches, work, papers, eco-labels and certifications investigated in this study, and for the sake of developing a new, improved label, the researcher would like to highlight a concluding perspective of what would make a more solid eco-label:

1- Nowadays, proper stakeholder identification and engagement is a key success criterion and factor for the success of all types of initiatives. Green Computing is an overarching strategic objective that requires the understanding, approval, and engagement of a variety of stakeholders. Without too much research, several primary stakeholders can be identified: manufacturers, users or consumers, engineers, scientists, environmental experts, governments, NGOs, and subsequent regulating bodies. In order to develop a comprehensive, all-inclusive label. Also, the requirements and expectations of these stakeholders should be identified to define better levels of required transparency, environmental kindness, and compliance. Moreover, it is paramount that a common goal among these stakeholders be the good of the environment and not simply specific national or regional motivation. In recent research of (Kern E. H., 2018), incidentally based on better inclusion of a variety of stakeholders and discussion with experts, a table was developed to better identify current and possible criteria for eco-labels (Table 5.1). A highly interesting dimension in this table is that it is focused on software; moreover, it is not organized by label but by approach. This type of categorization can give a broader perspective of criteria that could be developed or best leveraged for the development of a new eco-label.

Approach by	Objectives	Outcomes	Criteria (Examples)
Method (i)			
Albertao [21] Albertao et al. [22]	Assessing properties of software for environmental, economic and social aspects; Introducing a set of metrics to assess the sustainability of software products, demonstration how to use the metrics	Sustainability performance metrics and strategy on how to improve follow-up releases by using the metrics	Modifiability, Reusability, Dependability, Usability, Efficiency, and Predictability
Calero et al. [18] Calero et al. [23]	Extending the ISO 25010 quality model by including sustainability aspects; definition of ‘‘greenability.’’	Model for software sustainability that can be added to the ISO software product quality model	Energy efficiency, Resource Optimization, Capacity Optimization, Perdurability
Method (ii)			

Approach by	Objectives	Outcomes	Criteria (Examples)
Method (i)			
Taina [24]	Developing the criteria set ‘‘green software factors.’’	Framework for green quality factors: related to software development and execution	Feasibility (Carbon Footprint, Energy, Travel, ...), Efficiency (CPU-intensity, Idleness, ...), Sustainability (Reduction, Beauty...)
Kern et al. [25]	Summarizing existing approaches in a ‘‘quality model’’ for green and sustainable software	Quality model to classify green software and its engineering and exemplary corresponding metrics	Feasibility, Social Aspects, Portability, Efficiency, Reflectivity, Product Sustainability
Method (iii)			
Abenius [26]	Evaluation of ‘‘Green IT’’, especially ‘‘Green Software’’, and pointing out possibilities to use software in a more energy-saving way	Examples of actions towards Green IT mapped to software life cycle phases	Choice of Material, Reuse Refurbish Recycle, Production Logistics
Naumann et al. [1]	Mapping potential effects of software to sustainable development	Life cycle model for software products including effects relevant to sustainability	Working Conditions, Manuals, Data Medium, Download Size, Accessibility, Hardware Requirements, Backup Size

Table 5.1 Comparison of approaches on criteria for sustainable software Source (Kern E. H., 2018)

1. This label should address innovation. Manufacturers should show evidence that they have at least tried to apply some innovative processes, technology, research, or studies to upgrade or improve their certifications. This way, no-one would feel too comfortable with their products and services and would pursue innovation for the sake of a better environment. For instance, nanotechnology holds significant potential by making wires that are less dependent on energy, and that would not always need continuous energy. Since nanotechnology is about manipulating materials at a nanometer scale, many scientists are confident that it can transform manufacturing at a global level, from government purchasing to technological revolution. Another example of innovation would be using fully solar-powered devices of high quality, and that does not cause damage to the environment in addition to being silent. Once installed properly, solar cells do not require high maintenance: Energy is then produced at a very low cost. Photovoltaic (Pv) cells have been significantly improved thanks to the work of industrial engineers in recent decades, and their production has increased while costs keep decreasing. Furthermore, “there is also an opportunity to explore in greater depth the ecolabels from each of the eco-innovation determinants and dimensions, and their interaction in the cyclic innovation process” (Prieto-Sandoval, Mejía-Villa, & Ormazabal, 2019). Innovation should also be built on long-term green lessons learned.
2. This certification should support the green from the cradle to the grave, but should also integrate a more human dimension. Humans, users, buyers, consumers, and scientists and engineers involved all need to be aware of the damage that is yet to be made if efforts are

not integrated to develop a label that will be genuinely green. It would be very interesting to see a label where everyone involved is required to be trained on a minimum of environmental concepts, and an individual certification would be required for staff and professionals who handle or deal with the service, not just the item itself. To avoid additional costs, a volunteer framework similar to the one existing in academic research would be followed. Trainers would need a certain number of points acquired through training others to maintain their certifications, for instance.

3. A social criterion could be added, especially for software, for compliance with non-violent material for children (Kern E. H., 2018). Other dimensions could be taken into consideration, such as promoting sustainability in messages and visuals.
4. In order for the eco-label to gain and maintain international credibility and to ensure that it is meant to protect the environment in its entirety and not only specific regions or nations, the label should be initiated and designed by international parties. As long as a specific country launches an eco-label, there is a higher risk that the label is launched with a local agenda.
5. In terms of criteria, and while taking into consideration some of the existing ones and adding to them, the following list of performance categories to group criteria is suggested:
    - Material selection based on availability, durability, cost of production, localization (Raw materials should be selected among the ones that exist in very large quantities in a specific region)
    - Reduction or Elimination of harmful materials (to human health and the environment)
    - A plan for how the product should be disposed of should be made, and instructions to the consumer should be made, along with user-friendly training for it.
    - Energy Conservation and Efficiency; for instance, the more renewable energy (RE) is used, the more the product is likely to be certified
    - Integration and adaptability of the product with other products in ICT, for instance, even with products of competitors. For instance, power cords should be made for all types of computers, not just for specific ones.
    - Packaging

- Involvement of people: Training of users, train-the-trainer capacity in the organization, and frequent feedback from consumers with access to the manufacturers and simultaneous access with label representative.
- Adaptability to a variety of audiences green and greener, or in other words, audiences that are already aware of environmental challenges and audiences that needs to be made aware of them.

If such an eco-label is developed, it is more likely that ICT enables or helps contribute a transition to a lower carbon emission environment, and even help build a low carbon society and economy.

This is not just wishful thinking as governments and decision-makers proceed to walk the talk genuinely, and not only do more research on how to improve ICT products to reduce its negative impact on the environment, but lessons learned can be drawn from current eco-labels to make a new one. Lessons learned are also not just about what did not work but also what worked well and why: "For example, the EU scheme strategy could be improved by understanding the firms' level of satisfaction about the benefits perceived from the eco-labeling process and the main reasons that underlay their decision to get the EU" (Prieto-Sandoval, Alfaro, Mejía-Villa, & Ormazabal, 2016).

A new call for more awareness is to be made among software developers and software development organizations, also users and purchasers. If the engagement of all parties can be achieved, improvements, and remedies to current inconsistencies can be made. It is very likely to see much better findings and applications soon as long as a common purpose, and common ethics are set (Prieto-Sandoval, Mejía-Villa, & Ormazabal, 2019).

In summary, despite the several efforts that have been made in Green Computing, we can still consider that it is a nascent research and practice area still full of challenges and room for improvement, especially that not enough academic and professional papers and articles have been written about the topic (Prieto-Sandoval, Mejía-Villa, & Ormazabal, 2019).

Hence, more information is needed across the spectrum, and gaps between the information-rich and information-poor should be filled. More information is not just enough; engagement and motivation are needed.

“The greenest computer will not miraculously fall from the sky one day, it’ll be the product of years of improvements. The features of a green computer of tomorrow would be like: efficiency, manufacturing & materials, recyclables, service model, self-powering, and other trends” (Chakraborty, Bhattacharyya, & Nargiza, 2009) (Chand, 2014).

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Declaration

I hereby that I have written this Master's thesis by myself without the help and support of anyone or any source except the ones mentioned in the Bibliography.

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