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Green ICT framework to reduce carbon footprints in universities

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Abstract. The world today has reached a certain level where it is impossible to get the quality education at the tertiary level without the use of Information and Communication Technology (ICT). ICT has made life better, communication easier and faster, teaching and learning more practical through computers and other technology based learning tools. However, despite these benefits ICT has equally contributed immensely to environmental problems. Therefore there is the need to use ICT resources efficiently in universities for environmental sustainability so as to save both the university environment and the world at large from the effects of global warming. This paper evaluates the carbon footprints from the use of ICT devices and comes up with a proposed green ICT framework to reduce the carbon footprints in universities. The framework contains techniques and approaches to achieve greenness in the data center, personal computers (PCs) and monitors, and printing in order to make ICT more environmentally friendly, cheaper, safer and ultimately more efficient. Concerned experts in their respective departments at Asia Pacific University of Technology and Innovation (APU) Malaysia evaluated the proposed framework. It was found to be effective for achieving efficiency, reducing energy consumption and carbon emissions.

Keywords: green ICT; environmental sustainability; green practices; carbon footprints; data center

1. Introduction

Green ICT is the efficient use of IT resources. Murugesan (2008) defines green ICT as the responsible act of designing, manufacturing, acquiring, installing, using and disposing IT equipment's in an efficient and effective manner with little or no impact on the environment. Green ICT plays a very important role in improving the efficiency and processes of doing things in order to reduce energy consumption and carbon footprints. Its goal is to minimize the negative impact of technology on the global environment and increase efficiency at reduced cost (Suryawanshi and Narkhede 2013). Even though the concept of greenness has been around since the early 1990s through bodies like Energy Star that ensure the manufacturing of energy efficient devices, green ICT is only gaining more popularity in recent times due to the reality of global

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warming, e-waste and concerns on global climate change which have led to renewed and more concerned interest in greening ICT (Jochi 2011).

In the educational sector, green ICT can help to establish solutions that offer educational and societal benefits; by developing innovative ways and aligning IT processes with the core principles of sustainability to better utilize available resources and increase performance and efficiency in higher institutions of learning and the society at large (Donnellan *et al*. 2011). One of the major challenges facing the environment today is that of global warming due to carbon emissions; hence universities and other institutions around the world are under pressure to implement more sustainable approaches to ICT so as to save the environment. The datacenter which houses most of these energy hungry devices that provide IT services consume enormous amount of energy and their number is increasing by the day due to increased dependence on IT thereby putting the world at the danger of global warming and other environmental disasters (Uddin and Rahman 2012b). According to McKinsey and Co's 2008 analysis the amount of energy used to store and handle data between 2000 and 2006 doubled due to the increase in the number of data centers, and the number is increasing (Stewart 2009). This impacts negatively on the environment therefore it is necessary to find ways of reducing these emissions so as to reduce their negative impact on the environment and achieve sustainability through technologies like cloud computing, virtualization and consolidation of servers (Uddin and Rahman 2012a). Implementing these green practices will improve energy efficiency in the datacenter, it will help to achieve 'economic viability and improvement of the eco system thus enhancing energy efficient computing and serve as means for achieving green ICT (Masud and Malik 2012). Green ICT is not only about reducing cost and the environmental impact of IT infrastructures, it is a means of gaining higher efficiency, new opportunities, a strong environmental profile and an image of being green which in itself is an advantage (Frazen and Wallgreen 2010).

2. Problem background

In recent times more standards and regulations are implemented not just to encourage but also to enforce the practice of green ICT. Due to the increased dependency on ICT to fulfill daily life needs and academic requirements it is important to use IT infrastructure efficiently in order to solve sustainability problems. This can be achieved by ensuring that the applications themselves are green so as to reduce pollution and minimize environmental footprints incurred during the use and at the end of a product's life cycle. According to Molla *et al*. (2009) green practice is not just a requirement anymore; it is a responsibility because the world is at risk of global warming due to green house energy emissions.

ICT equipment's contain of toxic materials such as chromium, lead and mercury that produce harmful chemical substances that contaminate the air and waterways thereby causing pollution, global climate change and respiratory diseases (Masud and Malik 2012). Several studies have suggested that ICT is responsible for 2% of global carbon emission and desktop computers are the most energy consuming devices (James and Hopkinson 2009, Masud and Malik 2012, Molla *et al*. 2009, Murugesan 2008). In a study on the energy consumption of ICT use by Gartner, the researchers found that PCs and monitors consume 40% of energy, data centers 23% and other sources including telecoms, LANs, printers consume 37% as shown in Fig. 1. In a similar study by James and Hopkinson (2009) on sustainable ICT in further and higher education with case studies of three universities in the UK (University of Sheffield, Lowestoft College and City

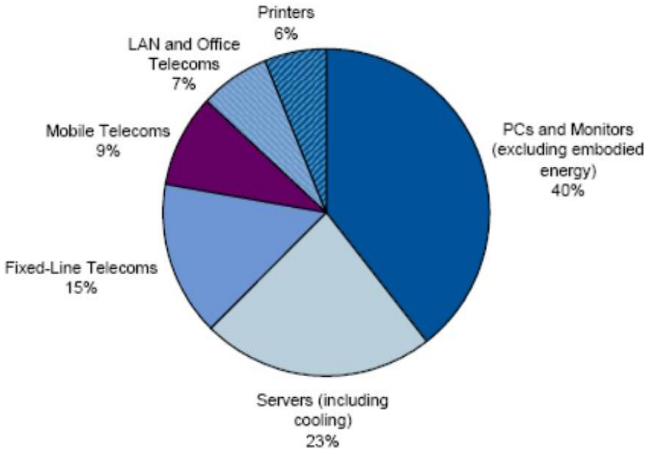

Fig. 1 Estimated distribution of global CO_2 attributed to ICTs Source: (Kumar and Mieritz 2007)

College, Norwich) the researchers found that PCs and monitors consume 42% of energy while servers consumed 21%. To reduce these harmful effects, the carbon footprints and environmental problems caused from the use of ICT equipment's, users of these equipment's are urged to green their devices and the way they use them. Likewise, a study on the sustainability of ICT and energy efficiency in the UK's Higher Education Institutions (UK's HEIs) revealed that computing devices and printing are responsible for about 66% of total electricity consumed by ICT devices in the UK's HEIs. The study also revealed that an average of 10,000 sheets are printed annually and over a million pounds budgeted for copying and printing (Chai-Arayalert and Nakata 2011). In yet another study on the state of green ICT at the University of Technology Malaysia (UTM), the University spent about RM 106 million on electricity consumptions in 2009 as against the approved RM 79.3 million (Aghasian *et al*. 2013). These statistics show that there is the strong need for the implementation of green practices in Universities to save cost and increase energy efficiency. More so, the implementation of Green ICT can save the environment from harmful effects of global warming and other health related issues caused from CO_2 emissions as well as to achieve greater efficiency and sustainability in universities. Murugesan (2008) emphasizes that "we are legally, ethically and socially required to green our IT products, applications, services and practice" because despite the dangers posed by the use of ICT equipment, the practice of green ICT has enormous benefits both to the user and the global environment. It increases user satisfaction, improves energy efficiency, lower greenhouse gases and further encourages the reuse and recycling of ICT devices.

2.1 Why universities implement green ICT practices

Universities should implement the practices of green ICT not just to cut down on the amount of energy needed to power ICT devices and reduce carbon footprints but also to evaluate the impact of ICT on the environment and improve the processes of doing things within the university community. ICT has both positive and negative impacts, by implementing the practices of green ICT universities can minimize the negative impact of ICT and maximize the positive impacts through cost efficiency gains, the use of environmentally friendly technologies and better ways of

doing things as outlined below:

New opportunities for teaching and research: The field of green ICT is still emerging thereby creating new areas for teaching and research. This creates more opportunities for students in universities where green ICT is implemented and awareness carried out to do better after school because they are more equipped with the knowledge needed to serve as employees and advisors on matters of greenness, which has become an area of great interest in the world today.

New ways of working: Implementing green practices creates new ways of doing things, for example conferencing can be used as an alternative for travels to meetings especially for universities that have campuses in different cities and locations. This will help to reduce CO_2 emissions incurred from transportation. Also virtual classrooms can be used to facilitate e-learning where the instructor and students are logged into a virtual learning environment at the same time and engaged in teaching and learning just like in a physical classroom.

Energy and cost savings: Following simple rules and policies of green ICT practice leads to drastic reduction in the amount of energy used and power needed to keep IT devices working as expected, thereby reducing the amount of money spent by the university on electricity bill.

Improved reputation and enhanced image: As the call for green practices and awareness on the need to use ICT devices in the most efficient ways possible continues to grow, universities who respond to this call will have better reputation and be the preferred choice for study and work for new students and workers. Likewise being certified green will enhance the universities image and bring about global recognition.

Preserve the Climate: As much as ICT contributes to global climate change, carbon footprints and environmental problems, it is equally hugely part of the solution. For instance ICT is used in monitoring water and air pollution, improve disaster warning, agricultural practices and improve energy efficiency through green practices. Hence, it is of utmost importance that universities implement green ICT so as to save the environment and preserve the climate due to the increased dependence and use of ICT to meet daily needs and equally promote the need for other sectors to do the same.

Compliance to legal requirement: With the increasing focus of climate protection, new policies and rules are emerging on the best way to use IT and ICT devices to save the environment and improve efficiency. There is the need for universities to comply with these laws and legal requirements on the proper usage and disposal of ICT equipment so as to contribute positively to climate protection and also help in tackling global warming and environmental degradation.

3. Problem statement

The need for green practices to reduce carbon footprints and greenhouse gas emissions for environmental sustainability cannot be over emphasized. ICT is responsible for 2% global emissions (James and Hopkinson 2009, Masud and Malik 2012, Molla *et al*. 2009, Murugesan 2008). PCs and monitors are responsible for 40%, data centers 23% and other sources including printing 37% (Kumar and Mieritz 2007). Therefore, there is the strong need for the implementation of green practices in these areas to save the environment from global warming and other health related issues caused from CO_2 emissions as well as to achieve greater efficiency and sustainability in universities.

3.1 Existing green IT/ICT frameworks

Table 1 Green ICT Framework. Adapted from: (Philipson 2010)

Attitude	Equipment life cycle	End user computing	Data center equipment	ICT as low carbon enabler
Policy	Procurement	Personal computing	Cloud computing	Policy and compliance
Practice	Recycle and reuse	Departmental computing	Data center equipment	Carbon footprints management
Technology	Proper disposal	Printing	Cloud computing	
Metrics Measure	Monitor	Manage	Mitigate	

Frameworks are used in order to provide a structured approach to achieve efficiency, effectiveness, measure performance and ensure continuous improvement of a process or system for which the framework has been developed, designed or created (Costello 2013). To achieve this feat in the area of Green ICT few researchers have developed Green ICT frameworks to help reduce carbon footprints from the use of ICT devices and measure the effectiveness of Green ICT implementation at different levels. The area of green ICT is still an emerging research area, hence not many frameworks are available. Some of the frameworks that have been developed include: Zhang and Liang (2012), developed a green ICT framework based on innovation systems approach, the framework was developed to help Chinese policy makers in the formulation of policies that will help to address failures within the system that hinder the development of green ICT in China.

(Uddin and Rahman 2012a) developed a green IT framework for datacenters to address the problem of huge energy consumption and greenhouse gas emissions from complex data centers. The framework proposed the use of virtualization, cloud computing and green metric technologies as techniques to reduce carbon dioxide emissions, mitigate the effects of global warming and achieve green datacenters. Chai-Arayalert and Nakata presented a green ICT framework for analyzing the strategy, practice and measurement of Green ICT practice in the UK's HEI. The framework was focused on addressing the social, economic and environmental pressures on the UK's HEIs to implement green ICT (Chai-Arayalert and Nakata 2011).

Connection research in conjunction with RMIT University developed a green ICT framework for the implementation of green ICT at organizational and national levels. The framework is mainly concerned with the metrics and measurements to guide progress and ensure successful implementation of green ICT across board. The Connection Research-RMIT Green ICT framework which has four pillars (Equipment lifecycle, End user computing, Datacenter and ICT as a low carbon enabler) across five actions (Attitude, Policy, Practice, Technology and Metrics) with four phases (Measure, Monitor, Manage and Mitigate) as shown in Table 1 argues that green ICT goes beyond reducing the energy consumption and carbon footprints of ICT functions, it aims at maximizing the efficiency of a product during its life time and promote its recyclability. This study follows the Connection Research-RMIT Green ICT framework because it is a tested and practical framework that puts into consideration all aspects of Green ICT.

4. The proposed green ICT framework

Green ICT does not necessarily require huge spending or technological solutions in all areas.

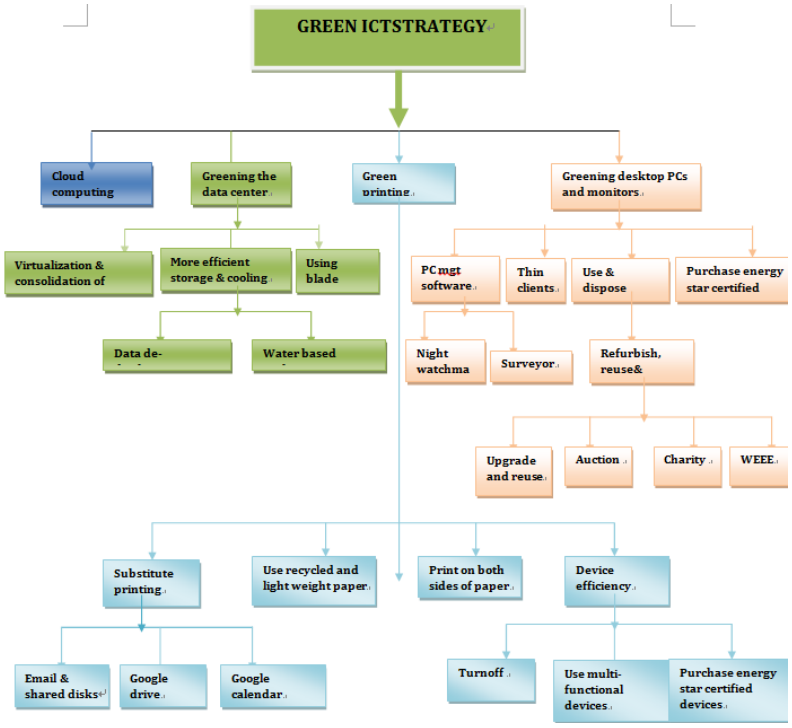

Fig. 3 Proposed Green ICT Framework

The right attitude, implementation of simple policies and practices otherwise taken for granted is enough to cause significant changes in the reduction of carbon footprints and CO_2 emissions. According to the Connection Research-RMIT Green ICT framework, which has four pillars across five actions with four phases, as shown in Fig. 2, green ICT goes beyond reducing the energy consumption and carbon footprints caused by ICT, rather focus should be more on sustainability and maximizing the efficiency of a product. Therefore to make a real difference ICT must be harnessed to greater purposes to ensure that it is managed properly to improve the way things are done, thereby making ICT processes more efficient with fewer steps and greater effects. Following this concept, the proposed framework by this study advocates using simple approaches that can significantly reduce the energy consumed to power ICT devices and minimize the negative impact from these devices while improving sustainability and environmental friendliness. Therefore, this paper proposes a green ICT framework as shown in Fig. 3 for implementing effective green strategies in universities through:

1. Cloud computing adoption
2. Greening the data center
3. Green Printing
4. Greening desktop computers and monitors

4.1 Approaches and techniques for effective green ICT practice

4.1.1 Cloud computing adoption

The cloud technology offers efficient use of computing resources and the opportunity to spend

less in running and delivering IT services. It reduces the number of physical components needed by replacing them with remote cloud systems hosted by cloud service providers. This reduces the amount of energy needed to power and provide cooling which also lowers energy cost as well as cost of hardware, software and maintenance (Gupta and Gupta 2013). Adoption of cloud computing reduces cost and increases savings, it reduces energy consumption and environmental pollution thereby creating a more friendly and healthy environment which is what green ICT is all about.

According to a report by the global e-sustainability initiative (GeSI), the increased use of cloud computing decreases dependence on energy and greenhouse gas emissions by 95%. The research which was conducted by a team of researchers from Harvard University, Reading University and Imperial College on 11 countries revealed that using the cloud for applications such as email, CRM and groupware solutions can reduce the energy consumed yearly by over 80% which is equivalent to reducing 4.5 mega tones of CO_2 emissions yearly (Kar 2013). In a similar study by Berkeley laboratory, the researchers found that moving common applications to the cloud can reduce energy consumption and carbon footprints by 87% or the equivalence of 23 billion kwh (Cruz 2013). Likewise, the US general services administration which had 324 servers now maintains only 61 servers because of their adoption of cloud computing, as a result of this reduction in the number of servers their direct power requirement has been reduced from 163 kw to 22 kw with an annual energy consumption of 20 kwh/user as against 175 kwh/user before their adoption of the cloud technology, thereby giving them a saving of 93% and reduction in carbon emission by 85% (De Borja 2012).

In an earlier study, we conducted on the effectiveness of cloud computing adoption, we found that APU through adoption of the cloud technology achieve a savings of 95% in the number of servers used, as 10 servers were effectively used to do the same job of 200 servers. As a result of which there's reduction in the amount of energy used and CO_2 emitted (Okai *et al*. 2014). The multi tenancy attribute of the cloud ensures that less power is used for cloud based applications since the cloud service provider can simultaneously serve numerous users from the same infrastructure at the same time thereby reducing energy consumption and the corresponding carbon emissions as compared to when they are provided on premise. In a study by Accenture, WSP and Microsoft on the environmental benefits of cloud based applications over on premise applications, the results revealed that for large deployments of ten thousand users Microsoft cloud offerings reduced the energy consumed and CO_2 emissions by 30-60% and over 90% reductions for small deployments of one hundred users (Accenture and WSP 2010).

The cloud technology ensures better utilization of servers, measuring the exact portions of the servers' capacity that applications can actively use without redundancies unlike on premise data centres that are faced with "what if" scenarios and the IT managers in an attempt to make provisions for future use in-case of higher demands acquire more servers, storage and networking facilities so they can meet up with demands, but most of these are not being fully utilized. The cloud equally reduces power loss through improved cooling and power conditioning. Beyond the common advantages of cost savings and better mobility of cloud based offerings over on premise applications, with the cloud there is better performance and less dependence on IT support. The cloud also offers better deployment speed and performance than on premise applications and cloud based applications can be easily upgraded and enhanced without the risks of losing past data. The University of Virginia and Eastern Washington University in the US, Lakehead University in Canada and Loughborough University UK are some universities that have achieved savings and reduction in their carbon footprint due to their adoption of cloud computing. Although the cloud

computing technology has its challenges especially regarding the security and privacy of data stored in the cloud, the benefits that come with its adoption greatly out weights the risks because these risks can be reduced to the barest minimum if appropriate and suitable models are chosen for deployment and a reliable cloud service provider is used.

4.1.2 Greening the data center

The data center is the heart and powerhouse of any IT network. It contains very high power consuming and energy emitting devices such as servers and storage equipment needed for high-speed computational activities as well as the storage, management and dissemination of very large amount of data. Therefore, it needs to be managed in the most efficient way possible for maximum performance and environmental friendliness by using more energy efficient devices and techniques such as:

Virtualization and Consolidation of Servers: with server virtualization one physical server can be partitioned into several virtual servers with each of the virtual servers running their own operating system, applications and performing as though it is an individual server; while with server consolidation different applications can be made to run on a single physical server. With both approaches the number of physical servers needed is reduced, hardware and maintenance costs are also reduced. Also more physical space is made available thereby giving the data center a better appearance than a room flooded with machines and cables. Most importantly, the amount of energy consumed is drastically reduced likewise the carbon footprints and GHG emissions hence making ICT more sustainable and environmentally friendly.

Using blade servers: these are servers optimized to reduce the amount of physical space used and power consumed while having all the required components needed for maximum performance. Using blade servers save IT staff time on infrastructure management and enable them to ensure higher availability. Similarly, the amount of cooling required is less thereby saving on power and reducing carbon footprints from the data center. In a survey conducted by James and Hopkinson (2009) in 11 higher institutions of learning in the UK on sustainable ICT, 8 of the institutions responded to using the blade server technique to reduce energy consumptions in their data centers. More efficient storage and cooling: most of the devices needed for delivering efficient IT services need to be permanently on, therefore more efficient storage is needed to keep the cost and energy consumed manageable. This can be achieved by data de-duplication, a technique that avoids having several copies of the same data. With this approach there will only be a single reference copy with different pointers to it. According to James and Hopkinson (2009), the University of Sheffield has used this along with other techniques to achieve up to 90% savings. Also adopting water based cooling in the form of sealed chilled water circuit built into the server racks has been identified as an alternative heat removal solution and is said to be a more effective means of cooling and heat transfer than air.

4.1.3 Green printing

Quite an amount of energy is consumed by printing; hence the following measures should be put in place to substitute printing where applicable and actions taken to make printing more environmentally friendly.

• Multiple people can share and work on the same document at the same time using Google drive freely available over the Internet, instead of printing and re-printing to effect changes or make corrections on a document. With this approach only the final copy will be printed if needed.

• Meetings can be scheduled using Google calendar also available free over the internet and

notifications sent to all concerned parties via email instead of printing and distributing meeting invitations individually to those concerned.

• Emails and shared disks can be used to substitute printing, hence printing should be done only when it is absolutely necessary using recycled and light weight papers.

• Projectors should be used and soft copies of documents sent to members instead of printed documents during meetings, though this may seem more expensive initially but over time the positive effect will be felt.

• Encouraging students and staff to print on both sides of the paper.

• Replacing single devices with multifunctional devices will save cost of purchasing and maintaining multiple devices as well as make printing and photocopying more efficient by reducing the energy they consume.

• Purchasing more energy efficient devices that meet the current standards specified by energy star at the time of purchase can increase efficiency by 25% or more.

• Turning off machines when not in use and most importantly turning off the control switch to these devices at the end of every day's work, weekends and holidays.

4.1.4 Greening desktop computers and monitors

Several studies have shown that desktop computers are the most energy consuming systems of ICT devices. Therefore the following actions are recommended as ways to reduce energy emitted from PCs and monitors.

• Despite the fact that recent computers are made to automatically go into energy saving modes when not in use, some of them don't, hence it is important that users ensure they program their computers to go into low energy using mode after a certain period of inactivity.

• Using PC management software such as night watchman or surveyor that can detect and shutdown inactive PCs. These software place active computers on a network in low energy modes from the central administration to maximize energy and reduce carbon footprint without interfering with the users' productivity, maintenance, back up and upgrades of computers. They also reports how much power every PC or monitor consumes, this can help to spot out PCs/monitors that consume more power so that its use and reason for higher consumption is investigated and appropriate actions taken. Based on a market research conducted in the UK it was discovered that over 40% of the working adults use computers and one sixth of this population leave their computers on overnights and at weekends, it is estimated that using the night watchman management software to turn off centrally networked PCs/monitors can save up to 1.5 billion kwh equivalence of 700,000 tonnes of CO_2 emissions per annum in the UK (National Energy Foundation 2006).

• Awareness to students and staff on the need for green practice and how they can contribute to that change by reducing the number of items on their start up menus and avoid the use of screen savers. However, if they must use them, they should be encouraged to opt for blank screen savers against those that display moving objects because they interact with the CPU to make the display thereby using up more energy. Also emphasis should be made on the need to turn off the computers completely when it will not be used for an extended period of time as against leaving it in sleep or hibernate mode for very long period of time.

• Purchasing energy efficient computers that are energy star certified, because energy star equipment's are 25% more energy efficient than traditional models. They run cooler and last longer. Also computers with black screens should be used as they equally help to conserve energy.

• Using thin client computers, these are computers that communicate directly with the server,

they have no hard drives and simply display what is on the server. They are useful alternatives to desktop PCs, they are less expensive to purchase, maintain and they use a whole lot less energy than traditional PCs.

• Turnoff not just individual computers but the switch controlling all computers especially those in the schools café and computer centre after every day's work, weekends and public holidays.

• Finally, old and unwanted computers should be properly disposed following the three Rs' of greening unwanted computers: Reuse, Refurbish and Recycle. Instead of disposing old computers simply because they have been used for a long time or considered out-dated, they can be refurbished, upgraded and used again. The computers can also be auctioned or given up to charity. If these options are exhausted, such computers can be sent to computer engineers who know best how to dispose computers that cannot be used further or the regulatory bodies responsible for electrical and electronic equipment waste (WEEE). They should not be thrown into waterways, burnt or left in garbage to decay because computers contain toxic substances like mercury and lead that are harmful to human and the environment.

5. Evaluation of the framework

The proposed framework was evaluated using the expert evaluation approach. The framework was presented to experts in APU in the area of Green ICT to evaluate its effectiveness in achieving green ICT in Universities. Six (6) different experts in different departments evaluated the framework. A questionnaire was prepared comprising questions related to the effectiveness, efficiency and its implementation at different levels across university. The results of the survey questionnaire clearly show that the experts agree that the approach and techniques proposed in the framework for achieving green ICT are simple, straightforward and easy to implement. They also agreed that the framework suits green ICT needs at University level and can help to reduce carbon footprints and achieve environmental sustainability.

6. Conclusions

As much as IT has contributed to make processes easier, faster and more efficient it has also contributed to environmental problems, through greenhouse gas emissions from the use of IT equipment's. This paper proposed a framework to address the challenges posed from the use of ICT equipment's, their contribution to environmental problems and how the negative impact of ICT can be reduced by following suggested green practices in the data center, on desktop PCs and in printing. The proposed framework was evaluated by experts in APU and found to be effective in practicing green ICT at university level. Unlike other technologies that have both negative and positive impacts, green ICT is not known to have any negative effects, therefore the implementation of green ICT is necessary not just for environmental sustainability but also for better health conditions and wellbeing of people, because if the natural air and waterways are freed from hazards caused from the use of IT, people will be healthier and natural resources better preserved for many generations to come.

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References

Accenture and WSP (2010), *Cloud Computing and Sustainability: The Environmental Benefits of Moving to the Cloud*.

Aghasian, E., Pourtaheri, H. and Ahmadizadeh, E. (2013), "An investigation on current situation of green ICT in university technology Malaysia-based on stage of growth and monitoring green technology standardization criteria", *Open Int. J. Informat.*, **1**(1).

Chai-Arayalert, S. and Nakata, K. (2011). "The evolution of green ICT practice: UK higher education institutions case study", *Proceedings of the IEEE/ACM International Conference on Green Computing and Communications*, August.

Costello, T. (2013), "IT Frameworks", *IEEE Comput. Soc.*, **15**(5), 56-64.

Cruz, X. (2013), *Quantifying Cloud Energy Efficiency-Study Funded by Google*.

De Borja, F. (2012), *Google: Switching to Cloud Saves up to 90% of Energy Costs*.

Donnellan, B., Sheridan, C. and Curry, E. (2011), "A capability maturity framework for sustainable information and communication technology", *IT Profess.*, **13**(1), 33-40.

Frazen, E. and Wallgreen, D. (2010), "Potential for the green ICT innovation system: A case study from the Gothenburg region", Ph.D. Dissertation, Chalmers University of Technology Goteborg, Sweden.

Gupta, M. and Gupta, G. (2013), "Green computing-a step towards better milieu", *J. Eng. Comput. Appl. Sci.*, **2**(9), 1-5.

James, P. and Hopkinson, L. (2009), *Sustainable ICT in Further and Higher Education-A Report for the Joint Information Services Committee (JISC)*, London, U.K.

Jochi, K. (2011), "Green computing-an eco friendly concept", *Int. J. Sci. Technol.*, **1**(2).

Kar, S. (2013), *Cloud Computing May Reduce 95% of Greenhouse Gas Emissions*.

Kumar, R. and Mieritz, L. (2007), "Conceptualizing green IT and data center power and cooling issues", Gartner Research Paper, No. G00150322.

Masud, M. and Malik, N. (2012), "A strategic model for evaluating energy efficient ICT infrastructures for sustainable environment", *J. Appl. Sci. Res.*, **8**(9), 4842-4853.

Molla, A., Cooper, V.A., Deng, H. and Lukaitis, S. (2009), "A preliminary report on green IT attitude and actions among Australian IT professionals", *Busin.*, (2).

Molla, A., Cooper, V.A. and Pittayachawan, S. (2009), "IT and eco-sustainability: Developing and validating a green IT readiness model", **1**, 1-17.

Murugesan, S. (2008), "Harnessing green IT: Principles and practices", *IEEE Comput. Soc.*, **10**(1), 22-33.

National Energy Foundation, & 1E (2006), *The PC Energy Report, Energy*.

Okai, S., Uddin, M., Arshad, A., Alsaqour, R. and Shah, A. (2014), "Cloud computing adoption model for universities to increase ICT proficiency", *SAGE Open*.

Philipson, G. (2010), *A Green ICT Framework Understanding and Measuriing Green ICT*.

Stewart, E. (2009), *The Sustainability Potential of Cloud Computing: Smarter Design*.

Suryawanshi, K. and Narkhede, S. (2013), "Evolution of green ICT implementation in ecducation sector: A study of developed and developing country", *Int. J. Manage.*, **4**(2), 91-98.

Uddin, M. and Rahman, A.A. (2012a), "Energy efficiency and low carbon enabler green IT framework for data centers considering green metrics", *Renew. Sustain. Energy Rev.*

Uddin, M. and Rahman, A.A. (2012b), "Validation of green IT framework for implementing energy efficient green data centres: A case study", *Int. J. Green Econ.*, **6**(4), 357.

Zhang, J. and Liang, X.J. (2012), "Promoting green ICT in China: A framework based on innovation system approaches", *Telecommun. Pol.*, **36**(10-11), 997-1013.

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