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Green Computing: Environmentally Friendly Information Technology Knowledge and Use by University Students

Adrian Schroeder Esquivel Guemes*
Autonomous University of Yucatán,
México

Pedro José Canto Herrera
Autonomous University of Yucatán,
México

Abstract—

Green Computing is an environmental movement that has gained relevance in the last few years, advocating for the regulation of Environmentally Friendly Practices in production, use, recycling and disposal of computer equipment. However, knowledge of this practices are not well known among the common populace. This research project had the objective of identifying the level of knowledge of this phenomenon between college level students, and the degree in which them apply sustainable Information and Communication Technologies practices in their daily lives. Among the results it was found that, while most participants had no knowledge of the term Green Computing, most of them do apply this practices to some extent.

Keywords— Green Computing, Environmentally Friendly Information Technology, Environmentally Friendly Computer Practices,

I. INTRODUCTION

1. Green Computing

In the last few years, there has been a noticeable increase in the number of discussions related to sustainable development and other environmental issues, with a proposed branch of this research area being the field of Green Computing. This being a recently developed term, a strict definition has yet to be found, with one of this proposed interpretations being that: "Green computing refers to energy-efficient computing practices and environmentally responsible use of the computer and its associated subsystems. It is both a field of study and a set of eco-friendly computing practices" (Tunkuh-Ahmad & Nordin, 2014, pp. 64) [1].

Another definition is the one proposed by Harmon & Moolenkamp (2012), who define Green Information Technology as: "The practice of maximising the efficient use of computing resources to minimise environmental impact. This includes the goals of controlling and reducing a product's environmental footprint by minimising the use of hazardous materials, energy, water, and other scarce resources, as well as minimising waste from manufacturing and throughout the supply chain. Green Information Technology goals extend to the product's use over its lifecycle and the recycling, reuse, and biodegradability of obsolete products" (pp. 5). As it can be derived from this denotation, some of the main factors concerning Green Computing are the manner in which computational systems can be produced, used, disposed and recycled in order to minimise their impact on the environment [4].

Due to this, it is difficult to specify the direct objective of Green Computing in observable terms, as it encompasses a variety of issues and procedures. One proposed delimitation is that: "The objective of Green Computing is to promote environmentally friendly computer technologies and efficient systems with less or no hazardous materials, and promoting recyclability of biodegradability of used products and factory waste" (Bello & Tunkuh-Ahmad, 2012, pp. 13) [2].

However, that definition esteems from a corporate perspective and does not take into account what can be done from the perspective of their users, of which Yang, Si &Wing (2016) say that: "The research focus of Green Computing is to study how to use computing resources efficiently and put that knowledge into use, with the overarching goal of minimising pollution. Green Computing has a significant impact on the environment because modern societies depend on Information Technology for jobs and operations, and the production and disposal of computing waste pollutes the environment" (pp. 70) [12].

Expanding on this, they also remark that: "Green Personal Computing includes activities such as green disposal and recycling of computing resources (e.g., used DVD/CD and printing papers) and efficient use of computing resources (e.g., using reusable data storage devices, dimming PC monitors, and powering off PCs when not in use)". It is worth noticing that these practices are easily put in practice on a daily basis and in a personal level. As Tunkuh-Ahmad & Nordin (2014) remark: "An individual who practices Green Computing by buying ENERGY STAR and EPEAT-certified hardware, donating old hardware to schools and organisations, turning off the PC when not in use, and recycling used hardware can be said to display Pro-Environmental Behaviour" (pp. 65) [1].

It can be derived from the previous discussion that Green Computing takes the form of a holistic approach towards environmentally friendly computer use, which encompasses all manners of interactions. As other authors make note: "Green Information Technology strategy is not only about buying more carefully and efficiently, but is also an approach in terms of how we go about thinking about the resources, energy and products that we use. One goal is to stay

focused on saving energy for the organisation, the individual and also the government, which is a worthy and practical perspective, but not the only one. The employment of alternative approaches and technologies, including emerging infrastructure technologies, for example, virtualisation and distributed computing, can help to offer a higher level of flexibility and environmental sustainability" (Wang, Chen y Ling, 2013, pp. 135) [5].

Mittal and Kaur (2013) add that: "Green computing is all about designing, manufacturing, using and disposing of computers and its resources efficiently and effectively with minimal or no impact on environment. it is efficient approach towards electricity saving and less amount of heat generated by the computers. The goals of green computing are power management and energy efficiency, choice of eco friendly hardware and efficient software and material recycling and increasing the product's life." (pp. 1200) [9].

On this topic, Shah (2012) comments that:"Eco-friendly Information Technology, also known as Green Computing, in particular, is geared towards utilizing Information Technology in creating a more environmentally friendly and cost-effective use of power and production in technology. Eco-friendly Information Technology starts with manufacturers producing environmentally friendly products and encouraging various departments to consider more friendly options like virtualization, power management and proper recycling habits" (pp. 4) [11].

We can then conclude that Green Computing is an issue of great importance that must be paid full and swift attention, as its benefits are too valuable to ignore. As the previous authors state: "Green Information Technology can help to benefit the goals of global environmental sustainability. Few can argue against the fact that environment conservation is essential, and that Green Information Technology can be used to help alleviate many of the problems normally associated with pollution, urban sprawl, and emissions from manufacturing facilities" (pp. 136) [9].

With this in mind, it is worth nothing that Green Computing not only deals with issues related to computational technology, but rather have an effect on a much larger variety of environmental issues. As these authors digest: "Green Information Technology benefits the environment in many ways including improving energy efficiency, lowering greenhouse gas emissions, using less harmful materials, and encouraging reuse and recycling" (pp. 136) [9].

Jindal and Gupta (2012) make the observation that: "The triple bottom line is what is important when it comes to anything green and the same goes for green computing. This considers social responsibility, economic viability and the impact on the environment. Many business simply focus on a bottom line, rather than a green triple bottom line, of economic viability when it comes to computers. The idea is to make the whole process surrounding computers more friendly to the environment, economy, and society" (pp. 15) [7].

2. Current Status and Challenges

Despite being a recently developed term, Green Computing initiatives have already been undertaken. While at first this were relegated to the corporate area, it has quickly transitioned towards other venues. As Bello & Tunkuh-Ahmad (2012) explain: "Green computing is now gaining attention of not only environmental organisations, but all sectors of human activities. Business organisations, institutions and industries are beginning to realise the necessity for protecting the environment and energy savings along with computing operational expenses. Companies in the computing industry have come to realise that the urgency for going green is in their best interest both in terms of public relations and cost reductions." (2012, pp. 13) [2].

However, some challenges have already been determined in this short time, with one of the most important being that, while Green Computing practices are presented as desirable, in many occasions these goals are not pursued due to being deemed (falsely) as a waste of resources whose benefits do not justify the allocation of resources. As Harmon & Moolenkamp (2012) note: "The information-technology business is unforgiving in its performance requirements. For demand, availability, and capacity management, the technology must capable, work as expected, and all systems need to be ready all the time. It must be cost effective, deliver value, and generate positive returns on investment. Sustainable IT will not be embraced if it does not grow the business" (pp. 3) [4].

Related to this, they also note that: "In an ecological context, Information Technology services must be able to deliver customer and business value while ensuring that the Earth's resources are being used at a rate that ensures replenishment" (pp. 4). That said, finding balance between offering top of the line services while still maintaining a sustainable profile is not an easy endeavour [4].

Efforts must be made towards finding alternative solutions to this problem, as the consequences of keeping with the current computer use processes have an impactful toll on the environment. One example of this is that: "Wasteful computer use releases unnecessary carbon emissions into the air, thereby increasing global warming. These carbon emissions, also called carbon footprint, combine with other greenhouse gases to cause increased global temperatures, smog, acid rain, droughts in some countries and floods in others" (Tunkuh-Ahmad & Nordin, 2014, pp. 64) [1].

As Saha (2014) notes: "Information Technology affects our environment in different ways. Each stage of a computer's life, starting from its production, throughout its use, and into its disposal, poses environmental problems. Manufacturing computers and their various electronic and non-electronic components consumes electricity, raw materials, harmful chemicals and water and generates hazardous waste. All these directly or indirectly increase carbon dioxide emissions and impact the environment" (pp. 47) [10].

It is for this reason that Green Computing has expanded rapidly since its inception, as Harmon & Moolenkamp (2012) note: "The primary driver of Green Information Technology adoption is the rapid increase in computing-related energy use and the expectation that the recent trend for higher energy prices will likely continue in the future. Although reductions in energy use also reduce carbon footprint, that favorable result is a byproduct of the major effort to reduce energy costs of datacenters, desktop computers, and Information Technology operations" (pp. 6) [4].

That said, the extent of this transformations should be not overestimated, as there are still many issues that will need to be addressed before Green Computing can be fully integrated in our current climate. Wang, Chen y Ling (2013) add to this that: "It should be understood that the transition to a sustainable, low-carbon footprint economy represents an enormous challenge. It is concerned with allocating sufficient resources so as to transform our economy in a relatively prompt manner, but also keeping in mind the critical need to maintain environmental and green considerations, while at the same time not undermining the prospects for prosperity in the future. Specifically, investments in Green Information Technology, technologies, and technologies will need to focus on resource productivity, renewable energy, clean technology, green business, climate adaptation and ecosystem protection, to name a few" (pp. 129) [5].

Another related issue is that, while Green Computing practices are known to have many benefits, it is sometimes hard to assign them an easily observable value, with some of these actions taking years decades to show any indicators of progress. The previous authors expand on this issue with the statement that: "One problem lies in the fact that investments in green infrastructure are difficult to assess in terms of a quantified value. However, it is also a fact that the creation and designation of green spaces has had a proven positive effect on people living and working, in a given neighbourhood. In order to convince the public and other stakeholders of the usefulness of investments in green spaces, it is necessary to give a correct, understandable and easily repeatable method to value these kinds of investments" (pp. 130) [5].

II. LITERATURE REVIEW

3. International Law and Regulations

In order to facilitate and enforce the implementation of Green Computing practices globally, both the Governmental and Private State have instituted a series of laws and regulations to be followed by those institutions who wish to be counted as among those certified as sworn to undertake in environmentally friendly practices. As Chandar (2009) states:"The government has to play a major role in reducing the E-Waste by comprehensive law and regulations. The awareness should be created among the computer user to access the channels to deliver unwanted computer system safely and responsibly. The government-public initiatives would be taken to help consumers to realise the impact of E-Waste on the environment" (pp. 64) [8].

While too many to completely enlist under the scope of this article, Harmon & Moolenkamp (2012, pp. 12-13) provide a list of some worldwide regulations related to Sustainable Information Technology:

- The 2003 European Waste and Electrical Equipment Directive mandates producers to take back old equipment, free of charge, in order to reduce electronic waste.
- The 2007 European directive on the Restriction of Hazardous Substances restricts six substances, including lead, mercury, and cadmium, which are used in the manufacture of electronics
- The European Union's 2007 Restriction, Evaluation and Authorisation of Chemicals regulates the production and use of chemicals to minimise their impact on human health and the environment.
- The European Union's 2007 Eco-Design of Energy Using Products is a directive on the lifecycle energy efficiency of products.
- The Energy Star 5.0 2009 standard regulates energy performance for desktops, workstations, and notebooks to help buyers identify the most energy-efficient computers and peripherals.[4].

4. Adoption and Practices

As can be derived from the previous chapter, while Green Computing has been studied heavily in recent years, much of it has focused on what can be done from an industrial and corporate perspective, research from the consumer and user perspective is minimal, and as a consequence knowledge of this issues is almost inexistent on this population groups.

Khan, Ahamed & Ravinath (2014) note: "Green Information Technology was primarily researched from the corporate perspective and its influence on consumers' purchasing behaviour is unknown so far. Today, though the green Information Technology considerations are beginning to have an importance in consumer and business purchasing decisions; the holistic approach of Green Information Technology is not clear from the consumer viewpoint to the present Information Technology market" (pp. 9). Taking this into account, it becomes necessary to conduct research that can help to determine what actions can be takes in order to facilitate the transmission of this knowledge towards the general populace [6].

An important part of this consists in determining what motivates people to integrate Green Computing in their daily lives, with some previous research from Yang, Si &Wing, (2016) maintaining that, in most cases, it is the due to the presence of an extrinsic motivator rather than an intrinsic one (pp. 71). An example of this would be participating in Green Computing activities in order to be seen as person who cares for the environment by peers [12].

A related study is that of Khan, Ahamed and Ravinath, who interviewed in 2014 a set of 500 staff members from 272 public and private businesses in Saudi Arabia, in order to find the impact level of 15 different factors on their decision to implement Green IT compliant systems in their organisation. The study found that clearing government regulations on carbon emissions and their associated taxes was the primary motivator for transitioning towards Green IT, while factors such as environmental consciousness and corporate social responsibility did not have a significant impact [6].

However, it has been found that the most important factor related to the low amount of people who integrate Green Computing activities is the simple fact of not knowing the repercussions of their normal practices , as Bello &

Turku-Ahmad (2012) suggest in their paper: "It is evidently that most computer users do not have knowledge of the amount of electricity the computers consume daily, and that is why users don't mind to switch off or log off their computers when not in use. It is a common practice to find Governments libraries, laboratories and offices computers left permanently on, even after working hours which is a clear indications that users of such computers, and managements are not aware of the electricity they consume and the amount of Carbon dioxide they emit into the atmosphere" (pp. 14) [2].

This is seconded by the work of Tunkuh-Ahmad & Nordin (2014), who note that: "Ideally and logically, an individual cannot begin to adopt an idea, system or device if he or she knows little or nothing about it. Recent research has identified users' lack of knowledge as the biggest barrier to the adoption of green computing behaviour, practices and solutions in the IT industry. Existing evidence also shows that although end-users feel it is desirable to go green, many do not know much about what it really is and what is going on, nor do they understand why there is a need to go green." (pp. 65) [1].

As such, it is necessary to direct efforts towards making this information reach those who most need it, in hopes that this newfound knowledge results in them adopting much more environmentally friendly practices in their daily routine. This would be likely, as Tunkuh-Ahmad & Nordin (2014) defend that:"It makes sense to suggest that greater subjective knowledge as a product of direct experience would more likely persuade individuals to adopt a new idea or product, and increase the likelihood of engaging in Pro-Environmental Behaviour" (pp. 65) [1].

This same authors note that one group of particular interest is that of university students, as they are among the people who make use of computational systems the most, and thus are in a position to contribute with greater impact on the lowering of energy combustion and E-Waste emission. Specifically, they comment that: "Given the increasing importance of green computing adoption, subjective green computing knowledge of a multidimensional nature should be adequately conceptualised and tested, especially among university students as they constitute a huge population of Information and Communication Technologies users worldwide. University students engage in a large number of on and off campus computing activities that contribute significantly to global carbon emission. Accordingly, it must be ascertained that they possess the knowledge to use Information and Communication Technologies effectively in responsible and eco-friendly ways as this knowledge impacts their pro-environmental computing practices" (Tunkuh-Ahmad & Nordin, 2014, pp. 66) [1].

Though it is important to note that students are not the only group who can contribute, as everyone can make a difference by virtue of having Environmentally Friendly practices in mind at all times. As Wang, Chen y Ling (2013) explain: "The future of a Green Information Technology environment will depend on everyone; however, people are often unaware as to the ways in which to contribute to environmental conservation or to the linkages between the environment and seemingly unrelated business decisions" (pp. 136) [5].

5. Previous Research

Bello & Tunkuh-Ahmad recollected in 2012 information from 180 students and 60 lecturers from six different faculties of a Malaysian university, including both postgraduate and undergraduate participants who answered a 27 items questionnaire. Some results were that 64% of the participants had either very low or null knowledge of Green computing, and that there was no statistical difference between the answers of students and lecturers [2].

In 2012, Dookhitram, Narsoo, Sunhaloo, Sukhoo and Soobron applied a 56 items questionnaire to 900 college students. The contents of this instrument focused on the frequency with which they made use of computer technologies, and their level of knowledge and attitude towards Green Computing practices. Among the results it was found that 80% of the participants had at least a minimum knowledge of what Green Computing constitutes, however only 50% of the students mentioned to have a positive attitude towards it, while 44% of the research population considered that the industry itself should lead in the transition towards Environmentally Friendly Computer Practices [3].

In 2014, Tunkuh-Ahmad & Nordin applied to 842 undergraduate students from ten Malaysian public universities a 16 items questionnaire regarding their knowledge of green computing and PEB, using a five point Likert scale. Among the results of the study, it was found that higher levels of subjective knowledge were reliably associated with eco-friendly computer purchasing and hardware disposal practices [1].

In 2016, Yang, Si &Wing asked 267 university students a series of questions related to their attitudes and motivations towards Green computing actions such as recycling and efficient use of computing resources, by way of a five point Likert scale questionnaire. Among the results it was found that the most frequently mentioned activities were recycling printing paper (88%), using read/write DVDs or USB drives (87%), powering down the PC when not using it (84%), dimming PC monitor brightness (75%), and recycling CDs and DVDs (68%) [12].

III. PURPOSE AND OBJECTIVES

6. Purpose

The purpose of this study was to identify the knowledge level about the term Green Computing and the frequency of Environmentally Friendly Computer Practices between students of a higher education institution located in the state of Yucatán, México.

7. Objectives

Three main objectives were established for the purpose of this study:

- Identifying the level of knowledge of the term Green Computing and its implications between higher educations students.

- Determine the frequency with which higher education students incorporate Environmentally Friendly Computer Practices on their activities.
- Determining if there exists any correlation between knowledge of the term Green Computing and the implementation of Environmentally Friendly Computer Practice by higher education students.

IV. METHODOLOGY

8. Design

This study was developed under the positivist paradigm, with foundation on the quantitative method. Data was recollected using a non-experimental design, and the results interpreted in relation with the generalisation theory.

9. Participants

For this study, a non-probabilistic sample of 30 college students, from 8 different career programs, participated answering a survey. Students were approached directly by the researcher during normal school hours, and were handed printed copies of the instrument.

10. Instrument

The questionnaire was designed based in the literature review, adapted in order to fit the research context.A total of 15 questions were divided in 2 sections: Knowledge of Green Computing and Environmentally Friendly Computer Practices Frequency.

The first section consisted of 5 single choice questions (Yes or No), with an extra space provided for any additional commentary, which were:The second section consisted of 10 Likert scale items, whose response options ranged from 1- Never to 5.- Alway. Participants were asked to indicate the frequency in which they:

For validation, a pilot test was done with a group of ten students, taking note of their observations as a basis for survey modifications.

V. RESULTS

Regarding the first section of the instrument (Knowledge of Green Computing), the following information was found (refer to Figure 1):

- Only 13% of the participants (4 persons) knew what the term Green Computing referred to.
- The impact degree of Information an Communication Technologies on the environment was the most well know factor between the participants, with 40% of positive responses (12 persons).
- A third part of the participants (30%) identified which actions they could do in order to engage in Pro-Environmental Behaviour (10 persons).
- A reduced number of participants (23%, 7 persons) affirmed to have knowledge of how to properly dispose of E-Waste.
- The less know factor between the participants was if their institutions had any plans related to Environmentally Friendly use of Information an Communication Technologies, with only 10% of positive answers (3 persons).

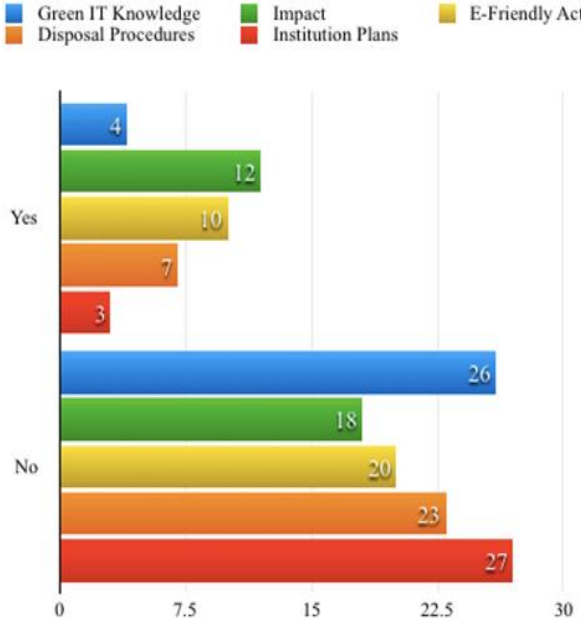

Fig. 1.Knowledge of Green Computing

In relation to the first five items from second part of the instrument Environmentally Friendly Computer Practices, the following information was found (refer to Figure 2):

1. Turning off their PC was the most frequently done action, with 66% of students answering with "Always" (20 persons).
2. The use of flat monitors was common among the participants, with 83% answering with a minimum frequency of "regularly" (25 persons).
3. Verifying compliance with environmental regulations before acquiring equipment is the least prevalent practice between the participants, with one-third (36%) not doing it all (11 persons).
4. The use of small monitor has no significant presence between the participants, with only little more than half of the sample (56%, 17 persons) having it in mind when acquiring a new device.
5. Hibernation and stand-by modes are used regularly between the participants, with 70% positive answers (21 persons).

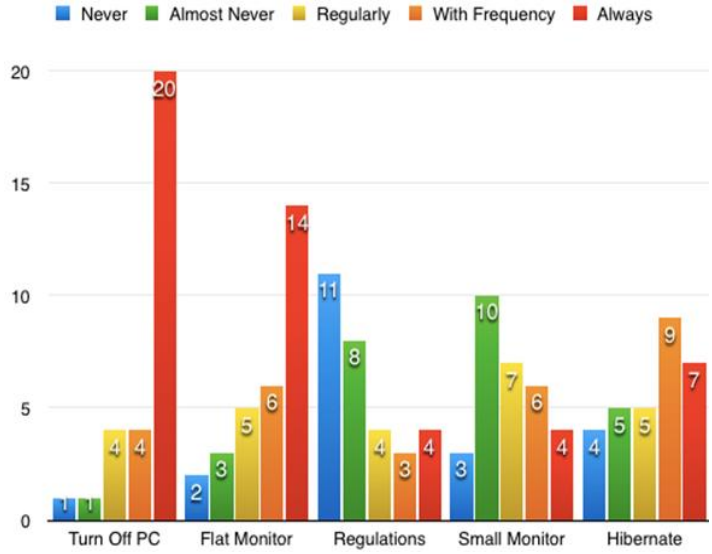

Fig. 2 Environmentally Friendly Computer Practices Frequency (Part 1)

Finally, from the last five items of this section it was found that (refer to Figure 3):

1. The lowering of monitor brightness is a common practice between the sample, with 83% of positive responses (25 persons).
2. InkJet printers are not significantly dominant over Laser ones, with 63% of students using them regularly(19 persons).
3. The use of recycled paper is common between the participants, with 60% making use of it with frequency (18 persons).
4. Rewritable media is the standard of use among the sample, with absolutely no negative answers.
5. The recycling of E-Waste is the least frequent practice among the participants, with a significant 40% never doing it at all (12 persons).

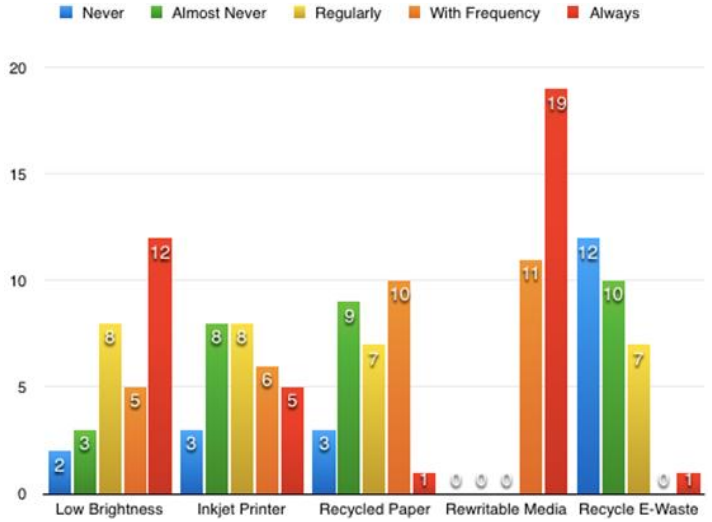

Fig. 3 Environmentally Friendly Computer Practices Frequency (Part 2)

This results were cross tabulated in order to identify any possible correlation between the variables. While not statistical significant, a low positive correlation (Pearson value of .346) was found between Knowledge of Green Computing and Environmentally Friendly Computer Practices Frequency, which can be seen on Table 1.

Table 1 Correlation between Knowledge of Green Computing and Environmentally Friendly Computer Practices Frequency

Correlations

		KNOWLEDGE	USE
KNOWLEDGE	Pearson Correlation	1	.346
	Sig. (2-tailed)		.061
	N	30	30
USE	Pearson Correlation	.346	1
	Sig. (2-tailed)	.061	
	N	30	30

In addition to this, participants were categorised according to their mean score for both variables. For the first section (Knowledge of Green Computing) a mean score of 0 to 1.6 was considered as low, while 1.7 to 3.2 was medium and 3.3 to 5 high, while for the second section (Environmentally Friendly Computer Practices Frequency) a mean score of 10 to 23 was considered as low, 24 to 37 m as medium and 38 to 50 high.The results of this categorisation can be observed on Figure 4.

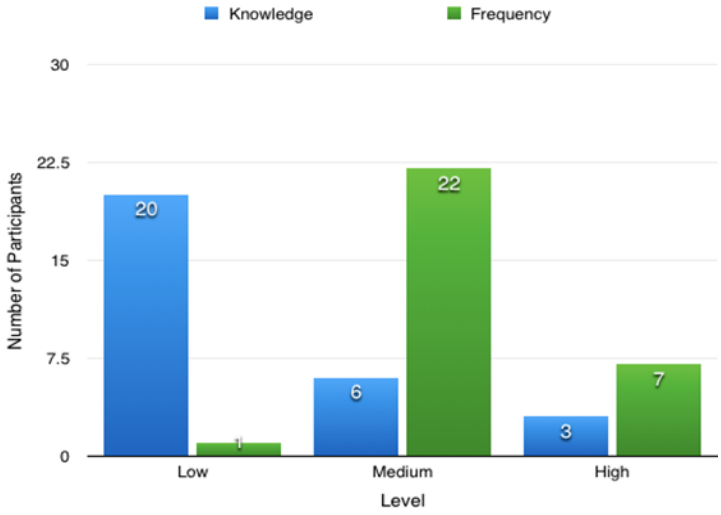

Figure 4 Participants Level

As it can be observed, this categorisation levels suggest a low positive correlation, with higher levels of Knowledge of Green Computing corresponding with equally higher levels of Environmentally Friendly Computer Practices Frequency.

VI. CONCLUSIONS, DISCUSSION AND RECOMMENDATIONS

11. Conclusions

From this data analysis, it can be derived that, while most of the participants did not have specific knowledge of what the term Green Computing referred to, they did implement some of its related practices on a daily basis.However, the majority of the participants had limited understanding of what constitutes E-Waste, and disposed of their equipment in unsafe manners due to not realising the impact of this action on the environment.

An interesting finding was that the participants declared to not have knowledge of any institutional plans for the management of these factors. This remarks the need for implementation of divulgation programs derived directly from the school administrative staff. As noted in the literature, most students will proceed to incorporate these environmentally friendly actions into their daily dealings as soon as they have knowledge of them.

Another way in which the faculty staff can promote Green Computing could be through the implementation of internal laws and regulations between students, professors and management staff, with explicit goals to achieve in a short, medium and large basis, which could be used as extrinsic motivators to facilitate the transition intro an Eco-Friendly institute.

Finally, student groups can contribute by sharing a list of Pro-Environmental Behaviour practices in common areas, in order to provide less knowledgeable peers some examples of easy to reproduce actions which they can integrate on their daily lives.

12. Discussion

The results of this study were concurrent with the findings of Bello & Tunkuh-Ahmad, Dookhitram, Narsoo, Sunhaloo, Sukhoo and Soobron, Tunkuh-Ahmad & Nordin and a Yang, Si &Wing; some of these were that students in general have little knowledge of the term Green Computing but do incur in these practices on a regular basis, specifically in relation to those ones that can be done directly on their homes and workplaces , such as turning off their computers

when not in use, activating sleep and energy saving modes, lowering their monitor brightness and printing their schoolwork on recycled paper.

13. Recommendations for Future Research

While this study limited itself to work with students from Social Sciences degrees, further research could benefit from extending the population to include students from other areas of knowledge, included but not limited to the Mathematical and Health Sciences field.

Another area of improvement would be to extend the instrument in order to include more variables related to personal information of the participants, in order to correlate aspects of their context and upbringing with their responses. Some of the proposed items would be age, gender, semester, place of birth (rural or urban community, kind of computer equipment (laptop or desktop, number of hours of daily computer equipment use and knowledge of energy saving software applications.

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