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PRIORITIZATION OF E-WASTE MANAGEMENT STRATEGIES TOWARDS GREEN COMPUTING USING AHP-QFD APPROACH

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A B S T R A C T

Green computing is the emerging and growing global concern in the current era. Though the information and communication technology turned the earth into paradise, it has environmental impacts through the manufacturing, operation and disposal of computing devices. In fact, computer is the basic need of every one and using it for their own purpose but no one is recognized about the harmful effect of its use on our environment. The concept of green computing emphasizes the improvement in using the computing devices efficiently and minimizing its negative impact on human beings and environment. The one of the important concerns under green computing is the e-waste management. In order to ensure green computing, there must be appropriate mapping between environmental requirements and e-waste management strategies. In this paper Quality Function Deployment (QFD) approach is presented to tackle this issue. The proposed approach serves the purpose of prioritizing e-waste management strategies in addition to the deployment of environmental needs into the measures to be taken to ensure green computing. On the basis of the priorities, the e-waste management strategies can be implemented to achieve green computing in the organization. The proposed approach is demonstrated through a case study carried in an educational institution.

1. INTRODUCTION

In the current Information era, Internet is the decisive technology that has become embedded in every aspect of human lives. The exponential growth of the Internet and decreasing cost of computer hardware are the some of the causes for enhancing the use of computers enormously in various fields for the past few decades. It is the fact that personal computers (PCs) have become ubiquitous in homes, offices, educational institutions etc. In most of the countries a stage is reached that hard to imagine human life without computers. One recent survey explored that nearly two-thirds of the global population will have Internet access by 2023. It

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wasforecasted that about 250 millions of PCs to be shipped around the world in 2020.As technology is progressing with lightning speed, it is foreseeable to develop new computers with high data volumes and latest technical features. In the present scenario, the pandemic caused by COVID-19 has also forced to operate variousactivities like business, banking transactions, education, entertainment, health etc. through online mode. When a computer is in the online mode of operation, there must be interfacing with other computers, peripherals, display and communication systems to carryout various tasks. To meet all the requirements it is inevitable to enhance the improvement in hardware infrastructure and data centers. On the other hand, there is a greater impact on environment with the enormous consumption of energy. In addition to this the disposal of computing hardware components produces harmful emissions. The average lifespan of a personal computer and its electrical and electronic components is decreasing rapidly. Obsolesce rate of the devices is also increasing due to short innovation cycles against technological advancements and turning into to e-waste form. In the half a decade ago, nearly 41.8 million metric tonnes of e-waste were generated in the world (Debnath et al., 2016). According to the latest United Nations University (UNU) report, the amount of e-waste is expected to increase to 52.2 million metric tonnes by 2021. The e-waste is usually consists of both hazardous materials like lead, chromium, cadmium, mercury, lithium etc. and non-hazardous materials. Certain precious materials such as gold, silver, copper etc. are also present in it.

The e-waste management practices such as recycling and disposal to landfills have been shown to pose significant risks to the environment (Kiddee et al., 2013). The disposal of e-waste in landfills creates negative impact on environment and causes contamination of ground water and soil in addition to the loss of useful reserve in e-waste. The open incineration of e-waste creates toxic gases which severely effects on human beings and environment. As primitive techniques are employed in manual e-waste recycling there is a scope for harming the health of the person who is involved in recycling in addition to pollute the environment. As there is a large amount of toxic substances associated with e-waste, it is highly essential to focus on implementing effective e-waste management practices so as to minimize the contamination of the environment and to addressthe threat of e-waste toxicity to human health.

To achieve greener, healthier and safer environment without compromising the technologicalneeds of the present and future generations, Green computing could be a balanced and sustainable approach (Mohapatra et al., 2019). The term ‘Green Computing’ came into existence by the U.S. Environmental Protection Agency (EPA) in the year 1992 and it refers to thepractice of using energy intelligently and efficiently, causing negligible degradation to environmental resources and parameters alsomaintaining feasibility on the other hand.It aims at reducing electronic waste and power consumption that helps in efficient use of computing devices. Primarily two issues are associated withgreen computing i.e., minimizing energy consumption and controlling the pollution of environment. The proper use of computers and hardware with less power consumption will address the first issue. The later one can be achieved through reducing usage, adopting less toxiccomponents in making the devices and implementing appropriate recycling policies.

In view of taking strategic decisions on e-waste management a number of attempts made and reported in the literature. Kim et al. (2013) proposed Delphi-AHP (Analytic hierarchy process) method to determine the priority target recycling products for the expansion and promotion of e-waste recycling. Baidya et al. (2015) used Analytic Hierarchy Process (AHP) for prioritizing the different criteria which effects on e-waste recycling practices for implementing green computing approach. Debnath et al. (2015) employed Quality Function Deployment (QFD) tool to find different parameters which affect the e-waste recycling practice as green computing approach. Their study helps to identify the prioritized areas which are to be looked into by the stakeholders and the legislative body. Bisoyi and Das (2018) emphasized that e-waste management is a factor of green computing approach and they discussed various factors that motivate companies to adoptedgreen initiatives. Kumar and Dixit (2018) employed an interpretive structural modeling (ISM) and Decision Making Trail and Evaluation Laboratory (DEMATEL) for understanding thehierarchal and contextual relationship structure among the barriers of e-waste management. Their model helpsthe policy and decision maker’s to find out the mutual relationship and interlinking among the barriers. Xu et al. (2018) proposed capacity-based multi-criteria decision making approach for the purpose of evaluating and prioritizing e-waste recycling innovation strategies. Khoshand et al. (2019) developed a model using fuzzy-AHP approach for evaluating different alternatives for collecting e-waste and carried a case study in Iran. Theyconcluded that the use of multi-criteria analysis would be helpful to achieve successful e-waste management. Ramzan et al. (2019) conducted a field survey at high ranked educational institutions located in the North-west region of China to investigate young consumer awareness, knowledge, and participation in sustainable e-waste management practices. Their study revealed that the respondents have strong environmental consciousness, while they have low awareness about e-waste-related rules and regulations, recycling programs, and the formal and informal recycling sector. Rimantho et al. (2019) attempted to analyze strategies forminimizing the risk of e-waste management. They used AHP for prioritizing the strategies. Leclerc and Badami (2020) discussed critically the policy drivers and challenges to implement the extended producer responsibility for e-waste management. Xu et al. (2020) proposed a new risk-based performance evaluation approach forevaluating the e-waste management strategies.

Green computing could be a well-balanced and sustainable approach for achieving a greener, healthier andsafer environment without compromising the technologicalneeds of the current and future generations. The goals of green computing are primarily to maximize energy efficiency during product life cycle time, to reduce the use of hazardous materials in electronic items and to promote recyclability. E-waste management is also one of the critical issues under green computing. To establish effective e-waste management policies in an organization, it is necessary to deploy environmental needs. In this paper a methodological approach is proposed by using Quality Function Deployment (QFD) with a view to explore effective e-waste management strategies in anyorganization. The techniques have been used to develop the methodology are discussed in brief in the Section 2. The methodology is described in Section 3 and subsequently a case study is presented in Section 4. The conclusions of the study are mentioned in Section 5.

2. METHODS USED TO DEVELOP THE PROPOSED DECISION APPROACH

2.1 Analytic hierarchy process

Analytic hierarchy process (AHP) is one of the most widely used multi-criteria decision making techniques in various studies in diverse field. This method uses pair-wise comparison between criteria on the basis of scale of importance called Saaty scale which guides the decision makers to assign importance of one criterion over the other. There are four major steps involved in AHP procedure for prioritizing a certain criteria considered during decision-making process. These steps are discussed below (Subbaiah et al., 2011).

Step 1: Set-upa matrix of pair-wise comparisons

A pair-wise comparison matrixis in the form of a square matrix has to be established by the decision makers and its order is depending on the number of criteria involved in decision making problem. A pair-wise comparison matrix of order $n \times n$ indicates that there are n number of rows and n number of columns and n number of criteria considered in the decision environment.

Step 2: Perform pair-wise comparisons of all criteria

The pair-wise comparison matrix has to be established by the experts who are involved in decision-making. Saaty scale (Saaty, 2008) is used to perform pair-wise comparison between the criteria. The scale enables the decision-maker to express intuitively the preference between each pair of criteria with his experience and knowledge. The preferences are usually expressed in verbal form such as equally preferred, moderately preferred, strongly preferred, very strongly preferred and extremely preferred. These preferences are then translated into numerical values 1, 3, 5, 7, 9respectively, with 2, 4, 6 and 8 as intermediate valuesfor comparison between two successive judgments. The reciprocals of these values are used for thecorresponding transposed judgments.

Step 3: Estimate the eigen values of the matrix

In order to synthesize the pair-wise comparison matrix and to obtain priority weights for the decision criteria, Saaty has developed the eigenvalue method. In this method, first sum the values ineach column of the pair-wise comparison matrix and then divide each element in a column by the sum of its respective column. The resultant matrix is termed as the normalized pair-wise comparison matrix. Finally sum the elements in each row of the normalized pair-wise comparison matrix and divide the sum with the number of elements. The result of this computation is referred to as the priority matrix and is an estimation of the eigen values of the matrix (Prasad et al., 2017).

Step 4: Check the consistency of pair-wise judgments

As large number of pair-wise comparisons is involved, there is a possibility of increasing the consistency error. To address this issue, Saaty suggested consistency index (CI) and consistency ratio (CR) to verify the consistency ofthe pairwise comparison matrix and are defined below.

$$\text{CI} = \frac{\lambda_{\max} - n}{n - 1}$$

$$\text{CR} = \frac{\text{CI}}{\text{RI}}$$

Where $\lambda_{\max}$ = Maximum principle eigen value of the comparison matrix
n= Number of criteria involved in decision making
RI = Average consistency index

If the value of CR is less than or equal to 0.1, then the estimate is accepted; otherwise, a new comparison matrix is solicited until CR $\leq$ 0.1 (Chang et al., 2007).

2.2 Quality Function Deployment

Quality Function Deployment (QFD) isa customer focused proactive product development technique. QFD is a structured approach thathelps to define customer requirements and systematically translating them into specific plans for producing products to meet those customer needs. A number of articles have been reported in the literature for the implementation of QFD in various fields.Initially QFD was largely applied inmanufacturing companies.Later on, it was adopted in several other fields like healthcare, education, finance, marketing planning, software development, supply chain management etc (Prasad et al., 2018). Some researchers (Killen et al., 2005; Sofyaliogluet al., 2008) made an attempt to applyQFD in strategic planning and decision-making also. Though QFD methodology possesses four sequentially linked matrices, most of the studies employed first matrix of QFD called House of Quality (HOQ).

The HOQ matrix consists of two principal portions. The horizontal portion is named as 'customer portion' that contains customers' needs and their priorities.

The vertical portion is known as 'technical portion' in which technical requirements to meet the customer needs. The intersection of these horizontal and vertical portions form a matrix called inter-relationship matrix, where the exact translation of customer needs into technical requirements takes place. The cell values of the inter-relationship matrix indicate the strength of therelationship between customer needs and technical requirements (Prasad et al., 2019). Design team is usually establishes the inter-relationship matrix of HOQ using a rating scale 0-1-3-9 to represent no, weak, medium and strong relationships respectively (Prasad et al., 2020).The absolute importance of each technical requirement is calculated by summing the products of the weightages of the customer needs and the corresponding inter-relationship values in the respective technical requirements column. The normalization of the absolute importance scores of the technical requirements gives the relative importance values of the technical requirements. These relative importance values indicate the priority order of technical requirements. This outcome of HOQ guides the design team to focus on technical requirements in priority order to meet the customer requirements.

3. METHODOLOGY

The objective of green computing is to minimize the garbage and to reduce hazardous impactof e-waste on environment. Therefore, e-waste management is necessary policy for all the organizationsusing computers and electronic equipment in large scale for making green computing as an initiative. While establishing effective e-waste management strategies in any organization, it is required to consider environmental requirements of the stakeholders related to the organization. In this context, a methodology is developed by using QFD technique. The HOQ of the QFD is used for the purpose of capturing the voice of stakeholders in respect of environmental needs and translating them into e-waste management strategies. The customer needs and design requirements in HOQ are replaced with environmental requirements (ERs) of stakeholders and e-waste management strategies (EMS) respectively. In this methodology AHP is used to obtain the priority order of the ERs. The outcome of the HOQ provides the priority order of EMS in view of achieving green computing. The methodology is demonstrated through a case study in the following Section.

4. CASE STUDY

India with large population becomes a keyattraction for rapid expansion of electronic goods manufacturing and its market. In terms of e-waste generation, India has ranked fifth position (Sharma et al., 2020).The 'Global E-Waste Monitor, 2017'published by the United Nations University estimated that India generates about 2 million metric tonnes of e-waste annually. A recent study conducted by the Associated Chambers of Commerce and Industry of India (ASSOCHAM) revealed that up to 70% of the total e-waste generation in India has been contributed by the computer equipment (Borthakur & Govind, 2017). Therefore, these predictions and survey reports stressed the urgent need of addressing the problem of e-waste in India.

Educational institutions are one of the prime sources of e-waste in India along with the government organizations, public and private industries,banks etc.To demonstrate the proposed methodology a study has been carried in a multidisciplinary and non-governmental technical university, which was established in 2002 and located in southern India. It is running with two undergraduate and three post graduate schools with over 1400 teaching and non-teaching staff and it offers 15 undergraduate programs along with 25 postgraduate programs and 12 doctoral programs to over more than 10,000 students and about600 research scholars from across India and different countries in the world.The study is initiated with capturing the opinions of stakeholders through rigorous discussions and the Table1 shows the list of ERs.

Table 1. List of environmental requirements

Sl. No	Environmental requirements (ERs)
1	ER-1: Efficient utilization of computers, accessories etc.
2	ER-2: Recycling of materials
3	ER-3: Incineration of cables should not be allowed
4	ER-4: Use of small classes of devices
5	ER-5:Segregation of components in e-waste
6	ER-6: Dumping of e-waste must be avoided

An expert group was constituted with the environmental policy makers and the experts in the institution relevant to environmental engineering, computer science and engineering, chemical engineering for conducting the present study.On the basis of opinions of the expert group, pair-wise comparison matrix of ERs has been developed using Saaty scale and is shown in Table 2.

Table 2. Pair-wise comparison matrix (PCM) of ERs

	ER-1	ER-2	ER-3	ER-4	ER-5	ER-6
ER-1	1	2	2	2	3	2
ER-2	1/2	1	2	2	1/2	2
ER-3	1/2	1/2	1	1/2	1/3	1/3
ER-4	1/2	1/2	2	1	1/3	2
ER-5	1/3	2	3	3	1	2
ER-6	1/2	1/2	3	1/2	1/2	1

Then normalized decision matrix was prepared as discussed AHP methodology in Section 2.1and is presented in Table 3. The weightages for the ERs are computed as discussed in step 3 of the AHP methodology in Section 2.1and are shown in Table 4.

To check the consistency of pair-wise judgments, the CR is calculated as discussed earlier in Section 2.1. The value of CR obtained is 0.086, which is less than 0.10 and hence the AHP results were consistent. In order to translate the environmental requirements in to e-waste management strategies towards green computing in the institution, several discussions made among the members of the expert committee.

In order to translate the environmental requirements in to e-waste management strategies towards green computing in the institution, several discussions made among the members of the expert committee. The outcome of the discussions explored six e-waste management strategies and is summarized in Table 5.

Table 3. Normalized PCM of ERs

	ER-1	ER-2	ER-3	ER-4	ER-5	ER-6
ER-1	0.300	0.308	0.154	0.222	0.530	0.214
ER-2	0.150	0.154	0.154	0.222	0.088	0.214
ER-3	0.150	0.077	0.077	0.056	0.058	0.035
ER-4	0.150	0.077	0.154	0.111	0.058	0.214
ER-5	0.100	0.308	0.231	0.333	0.177	0.214
ER-6	0.150	0.077	0.231	0.056	0.088	0.107

Table 4. Weightages of ERs and their importance order

Sl.No	Environmental requirements (ERs)	Weightages	Importance order
1	ER-1	0.288	1
2	ER-2	0.164	3
3	ER-3	0.076	6
4	ER-4	0.127	4
5	ER-5	0.227	2
6	ER-6	0.118	5

The inter-relationship matrix of HOQ for the ERs and e-waste management strategies is established as shown in Table 6.

Table 5. List of e-waste management strategies

Sl.No	e-waste management strategies (EMS)
EMS-1	Establishment of collection center for e-waste in the institution
EMS-2	Create awareness among the e-component users regarding e-waste effects
EMS-3	Transportation of e-waste must be cost effective
EMS-4	Effective monitoring on usage of computers & electronic equipment
EMS-5	Implementation of take-back policy
EMS-6	Periodical disposal of e-waste from institution to authorized collection centers in the city

The absolute importance values (AIV) and the relative importance values (RIV) of all the e-waste management strategies are determined through QFD procedure as explained in Section 2.2. The RIV values of EMS are obtained through normalization of the AIV values of EMS. For instance the computation of AIV and RIV of EMS-1 is given below.

Absolute importance value of EMS-1 = (0.288×1) + (0.164×3) + (0.076×3) + (0.127×1) + (0.227×3) + (0.118×9) = 2.878

$$\text{Relative importance value of EMS-1} = \frac{2.878}{24.043} = 0.120$$

In the same way the absolute importance values and the relative importance values for the remaining EMS are calculated and are presented in Table 6.

Table 6. Inter-relationship matrix of HOQ

ERs	weightages of ERs	e-waste management strategies (EMS)					
		EMS 1	EMS 2	EMS 3	EMS 4	EMS 5	EMS 6
ER-1	0.288	1	9	1	9	3	1
ER-2	0.164	3	3	1	1	9	9
ER-3	0.076	3	9	1	1	3	3
ER-4	0.127	1	9	1	9	1	1
ER-5	0.227	3	3	1	1	9	3
ER-6	0.118	9	9	3	1	3	9
AIV of EMS		2.878	6.655	1.236	4.324	5.091	3.860
RIV of EMS		0.120	0.277	0.051	0.180	0.212	0.161
Rank		5	1	6	3	2	4

The outcome of HOQ provides the ranking of EMS and hence the management of the technical university has to take energetic steps to implement the strategies for the management of e-waste in the rank order. The findings of the present study shows that the management has to give top priority on EMS-2, i.e., giving awareness to users on e-waste effects and then followed by EMS-5 (take back policy) and EMS-4(effective monitoring on usage of computing devices). The lack of awareness among the users of computers and electronic components in the university is the primary hurdle for effective management of e-waste. Therefore, it is required to organize collaborative campaigns periodically to sensitise the users to recognize their responsibility in the system. To promote environmental consciousness among the users, it is important to display of posters in the areas where they are engaged continuously with computing devices and electronic equipment.It is essential to arrange e-waste collection centre to deposit e-waste. Further it is to ensure that the collection of e-waste through take- back system with an appropriate coordination between the organization and authorized e-waste collection centre or recycler as designated by the producer. As far as usage of computers, it is necessary to frame certain guidelines and then see that they are implementingin effective manner. Some of the guidelines suggested are:shut down the computer if not used for long time; unplug the power cable if computer is not used for few days, encourage the university staff on taking printouts only when there is necessity, otherwise allow them to carry their transactions through e-documents, keep printers switched off in idle state, adopt different virtualization techniques, which helps to pool physical resources and manage them in a single unit. Further it is advised to upgrade the computing and electronic devices when necessary instead of replacing total units. The study suggested the priority order of implementing e-waste management strategies in the educational institution to ensure green computing environment.

5. CONCLUSIONS

Green computing is the environmentally sustainable computing approach thatallows satisfying the growing demands for network computing without putting any pressure on the environment.As e-waste management is also one of the critical issues under green computing approach, it is necessary for every organization has to focus on establishing and implementing e-waste management strategies.While establishing e-waste management strategies, it is required to understand the environmental requirements of stakeholders. In this context, the methodology may help decision makers to establish e-waste management strategies towards green computing in any organization. In this work the proposed methodology is demonstrated through a study carried in an educational organization. But the methodology can be applied to any organization to setup e-waste management strategies towards green computing. However, the methodology merely relies on the subjective judgment in prioritizing the attributes. It may lead to explore imprecise priority order in e-waste management strategies. As ambiguity is inevitable during subjective judgments, the methodology may be extended by using fuzzy logic approach to address the issue of imprecise subjective judgment. Of course, establishment of e- waste management strategies and to know their priority is not only the solution for achieving green computing environment. The cooperation, sense of responsibility, environmental consciousness and unconditional commitment by every stake holder are essentially required to move forward the organization towards green computing.

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