Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 06, June, 2023

Assessment of E-Waste Management and Potential for Laptop Reuse and Recycling

Giao Thanh Nguyen [1*], Trinh Thi Kieu Lam [1], Nhien Thi Hong Huynh [1]

[1] *College of Environment and Natural Resources, Can Tho University, Can Tho City 900000, Vietnam.*

Received 08 January 2023; Revised 17 April 2023; Accepted 04 May 2023; Published 01 June 2023

Abstract

Reusing and recycling laptops has many positive benefits, both environmentally and economically. Therefore, this study was conducted with the objectives of assessing (1) the current state of ownership, (2) the current state of use and disposal, and (3) quantifying the potential reuse and recycling of laptops for students at Can Tho University, Vietnam. Based on data collected by document review and face-to-face interviews with students, with a usage rate of 1 laptop per student, it is estimated that the whole of Can Tho University has 42,918 laptops in use. The actual use lifespan of the laptop is 5.28 years, lower than the expected lifespan of 6.8 years. The results of the correlation analysis show that the actual usage life does not have any correlation with the consumption behavior of students. In addition, the study estimates that 96.67% of laptops will be disposed of before 2031. In which, the potential for direct reuse is 2.33%, reuse with support is 88.33%, and recycling is 9.33%. The results show that universities have great potential to implement safe e-waste collection and treatment activities.

Keywords: Notebook; Quantification of Potential; Circular Economy; Can Tho University; E-Waste Management.

1. Introduction

Nowadays, information and communication technology devices have been widely applied in most socio-economic fields. In particular, in the context of the complicated development of the COVID-19 pandemic, it has forced learning and working activities to change from face-to-face to online. This conversion has contributed to the rapid increase in demand for technology devices, notably laptops. The proof is that the Greek school system were distributed 8,400 computers in 2020 [1]. According to statistics, about 340 million PCs will have been shipped worldwide in 2021 [2]. For laptops alone, about 216 million units were shipped in 2022 [3].

With a strong increase in usage demand and a shortening of the average life expectancy of only 3-6 years [4, 5], a large amount of laptop waste is forecast to arise in the near future. This poses a great challenge to the management of this type of waste. Because discarded electronic devices in general and laptop waste in particular are types of hazardous waste. If not handled properly, the heavy metals (cadmium, mercury, chromium, zinc, lead, etc.) in this waste can accumulate in soil and groundwater [6-8]. More seriously, they can cause changes in lung function, thyroid, neurological, endocrine disorders, and they can even cause cancer [7, 9]. In contrast, the recovery of materials found in laptop waste such as plastic, glass, base metals (aluminum, steel, copper, zinc, etc.), precious metals (platinum, gold, silver, etc.), and some rare earth elements will help reduce resource exploitation in nature [1, 10–12]. On that basis, many countries around the world have prioritized the application of reuse and recycling methods to prolong the use life of equipment, take advantage of valuable raw materials, and reduce environmental pollution [6, 13–19].

* Corresponding author: ntgiao@ctu.edu.vn

http://dx.doi.org/10.28991/CEJ-2023-09-06-013

In Vietnam, the collection and treatment of e-waste in general have not been implemented effectively. In addition, only a few related studies have been carried out to estimate the generation of household e-waste in households such as mobile phones, personal computers, televisions, refrigerators, etc. [20–22]. The results of these studies show that laptops are not commonly used in households. Meanwhile, many other studies have recorded a very high percentage of students using laptops at universities, averaging 0.95-0.97 laptops/student [23, 24]. Students are considered to represent a group of young consumers with high demand for the use of technological devices along with strong access to current technological advances. Therefore, this study assesses the potential for reuse and recycling of laptops by students at Can Tho University, a key university training institution in Vietnam with about 40,000 students being trained each year [25]. The objectives of the study are to assess (1) the current state of ownership, (2) the current state of use and disposal, and (3) quantify the potential reuse and recycling of laptops at Can Tho University. The results of the study will be a useful database for planning the future implementation of laptop waste collection and treatment. At the same time, the research also helps raise awareness among students about the importance of smart consumption and safe disposal of electronic devices.

2. Research Methodology

To achieve the set objectives, the study has collected and processed data through five steps (Figure 1).

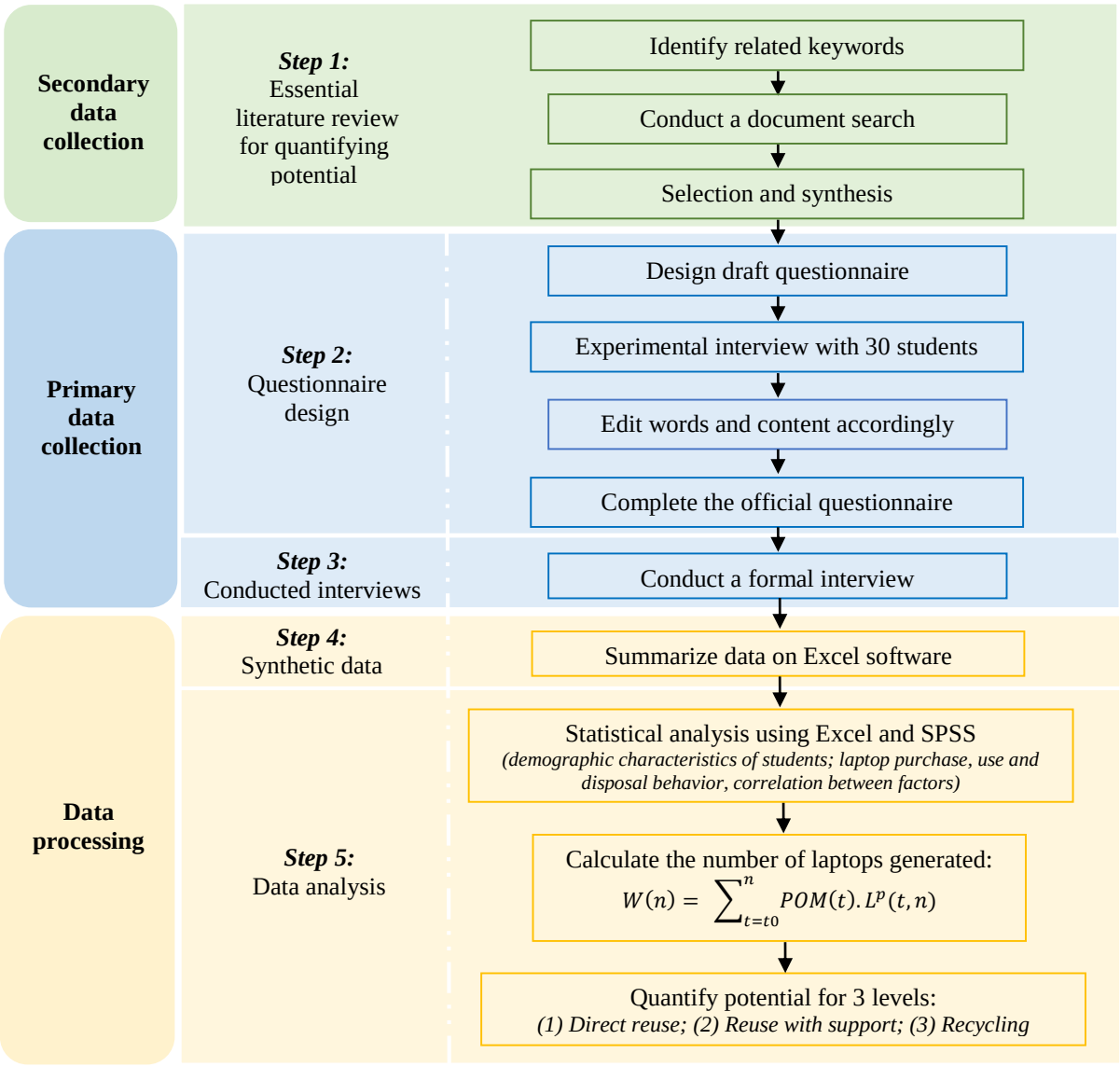

Figure 1. The process of methodology

2.1. Data Collection

First, the study collects secondary data through scientific articles published in specialized scientific journals to strengthen the theoretical basis related to the research objectives. The data search is performed with various keywords, such as "laptop management", "e-waste management", "LCA for laptops", "LCA for e-waste", "impact of laptops", etc. The data mining platforms used mainly in the study were Elsevier-ScienceDirect and Google Scholar.

Next, primary data was collected through direct interviews with students at Can Tho University. After the experimental interviews were adjusted, the official questionnaire consisted of four parts (Step 2). Including (1) general information about the respondents, (2) current ownership status, (3) consumption behavior, and (4) laptop disposal behavior. The study conducted interviews for two months, from February to April 2022. With the goal of building a data set including the information of 300 students, the research conducted a parallel interview and data entry process at the end of the day to promptly remove the interview forms that did not meet the full information (Steps 3 and 4). This is done to ensure the quality of the dataset. At the end of the interview process, the research team completed the data set of 300 students from 312 questionnaires conducted. There were 12 questionnaires that were rejected because they did not fully meet the necessary information; the rate of satisfactory questionnaires was 96.2%.

2.2. Data Processing

After data synthesis, descriptive statistics on student demographics, laptop lifespan, laptop purchase, use, and disposal behavior were performed using Excel and SPSS. In addition, the correlation between a laptop's lifespan and consumer behaviors (intensity of use, reading manuals, practicing recommendations, and device maintenance) was also analyzed using IPM SPSS Statistics 26 software.

Next, the potential for reuse and recycling was assessed by the quality and quantity of the laptops generated. The time of purchase and the expected time of disposal of the laptops were used as input data for the calculation of the number of laptops produced per year [26]. The estimated formula is as follows:

$$W(n) = \sum_{t=t0}^{n} POM(t).L^{p}(t,n) \quad (1)$$

where: W(n) is the number of laptops made in five n (pcs); $POM(t)$ is the number of machines purchased in year t (units); $Lp(t,n)$ is the probability that a laptop purchased in year t becomes obsolete in year n (%).

The potential to reuse and recycle laptops was classified into three levels (Table 1). In the study by Messmann et al. [27], the condition of the equipment was assessed directly at the collection site. However, in keeping with the conditions and objectives of the study, the quality of the laptops in this study was determined by the students' intention to dispose of laptop.

Table 1. Quality and potential classification of laptops

Level	Potential	Quality of laptop	Detailed description	Component state	Surface state
1	Reuse directly without going through any repair/ refurbishment	Very good	Good as new	Full	New
		Good	There is very little sign of wear	Full	New/ Medium
2	Reuse but must be through repair/refurbishment or recycle	Medium	There are signs of moderate wear (small scratches/breaks, noticeable defects/damages, etc.)	Missing	Medium
		Poor	There are signs of heavy wear (large scratches/breaks, noticeable defects/damages, etc.)	Missing	Medium
3	Recycle	Very poor	The damaged component is an integral part of the product's function	Faulty	Old
		Unusable	Complete loss of structural/functional integrity of the product	Faulty	Old

3. Results and Discussion

The survey at Can Tho University has collected information from 300 students, 48% male and 52% female. In which the proportion of freshman, sophomore, junior, and senior is 19.3%, 35%, 20%, and 19.3%, respectively. The remaining 6.3% are postgraduates.

3.1. Current Status of Owning a Laptop

The survey results show that 100% of the interviewed students own a laptop. Thus, a total of 300 laptops are being used in the observed sample size of the study at Can Tho University (n = 300). According to the research's speculation, the actual ownership rate of this device may be lower than 01 laptop per student because a small number of students will not use laptops. However, the study believes that this percentage will be insignificant because the results of studies at universities in Australia and China have both recorded a very high rate of laptop use. These rates were 0.95 and 0.97 laptops/student, respectively [23, 24]. Compared with the research results conducted on household subjects, students have about 8 times higher rates of laptop ownership. Specifically, the survey results in 120 households in Can Tho city with 507 people recorded only 60 computers in use, which is only 0.12 units/person [20]. Thereby, it can be seen that the university is the place where a large number of laptops are used, and students are an important contributor to the increase in the number of these devices. Statistical results show that newly purchased laptops have increased sharply in

the period 2018–2021, especially in 2020 and 2021 (Figure 2). This number is forecast to continue to increase in 2022 because the results collected as of mid-April 2022 have recorded a 40% increase in the number of new computers purchased compared to 2021. One of the reasons to make the rapid increase in laptop purchasing power is the change from face-to-face learning at schools to online learning during the period of application of COVID-19 prevention measures. During this period, 81.33% of students confirmed that they had to increase their laptop use time by an average of about 2.6 hours per day. Not only in Vietnam, COVID-19 is also the cause of increasing demand for laptops in other regions and countries [1, 28].

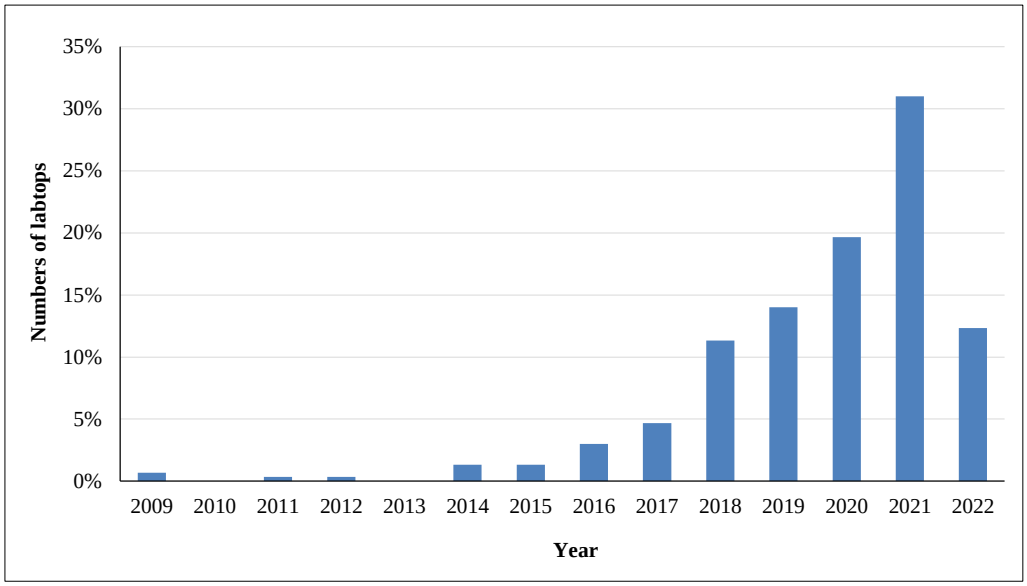

Figure 2. Number of laptops purchased over the years

The surveyed laptops belong to 11 different brands (Figure 3). In which, the 03 laptop brands that students choose to buy the most are Asus (31.67%, or 95 units), Dell (24.67%, or 74 units), and HP (20.33%, or 61 units).

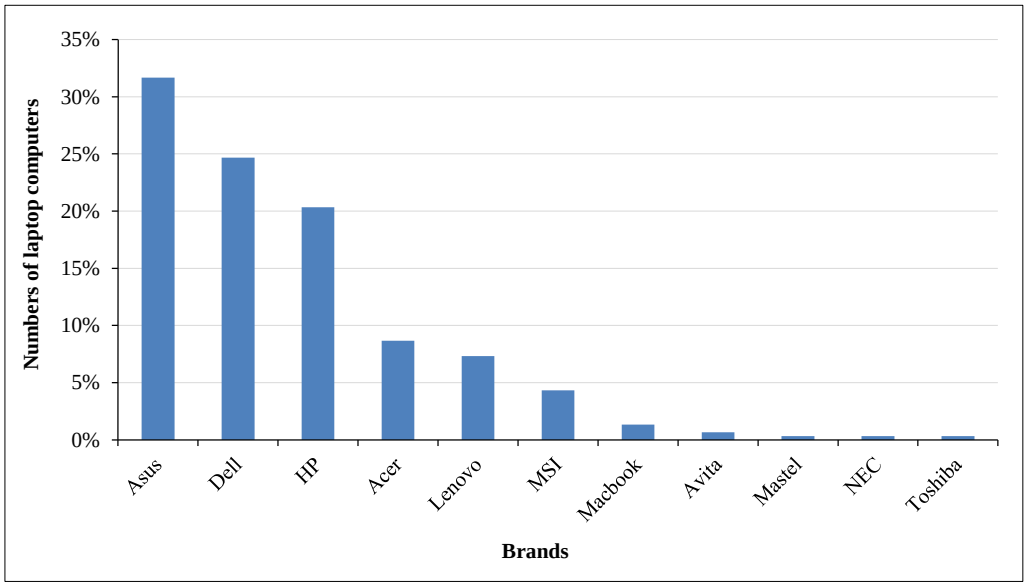

Figure 3. Laptop brands being used

To decide whether to buy a laptop, students often consider many factors (Figure 4). In which the factors of price, brand, and features are considered the main factors when over 75% of students are interested. Next are the elements of style, warranty period, and installment program. Meanwhile, the environmental label factor has not really attracted the attention of students. This factor only contributed to the purchase decisions of 7.67% of students and only accounted for 2.19% of the total selection. The study of Liao and Chuang [29] also identified price as the most important factor in a laptop purchase decision. They are given priority over the criteria describing the environmental friendliness of the product. This shows that it is necessary to raise awareness of green consumption among consumers to improve their level of interest in and willingness to pay for environmentally friendly products.

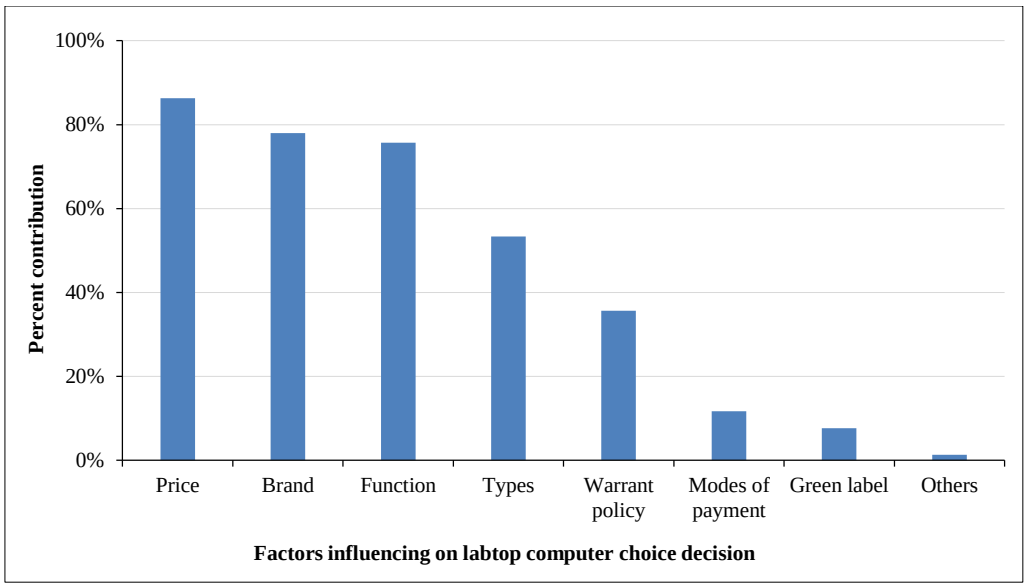

Figure 4. Factors affecting the decision to buy a laptop

3.2. Current Status of Laptop Consumption and Disposal

3.2.1. Actual Usage Life of the Laptop

In addition to determining the current state of laptops in use, the study looked at consumption habits and the lifespan of previously discarded laptops. This serves as the basis for considering the correlation between the actual lifespan of laptops and the consumption behaviors of students. The survey results showed that 54 units were disposed of in the years 2015–2022 (Figure 5). The colors in the data columns represent the year these computers were purchased. It can be seen that 2021 has the highest number of discarded laptops (accounting for 31%). Notably, 17% of laptops will be discarded in the first 4 months of 2022.

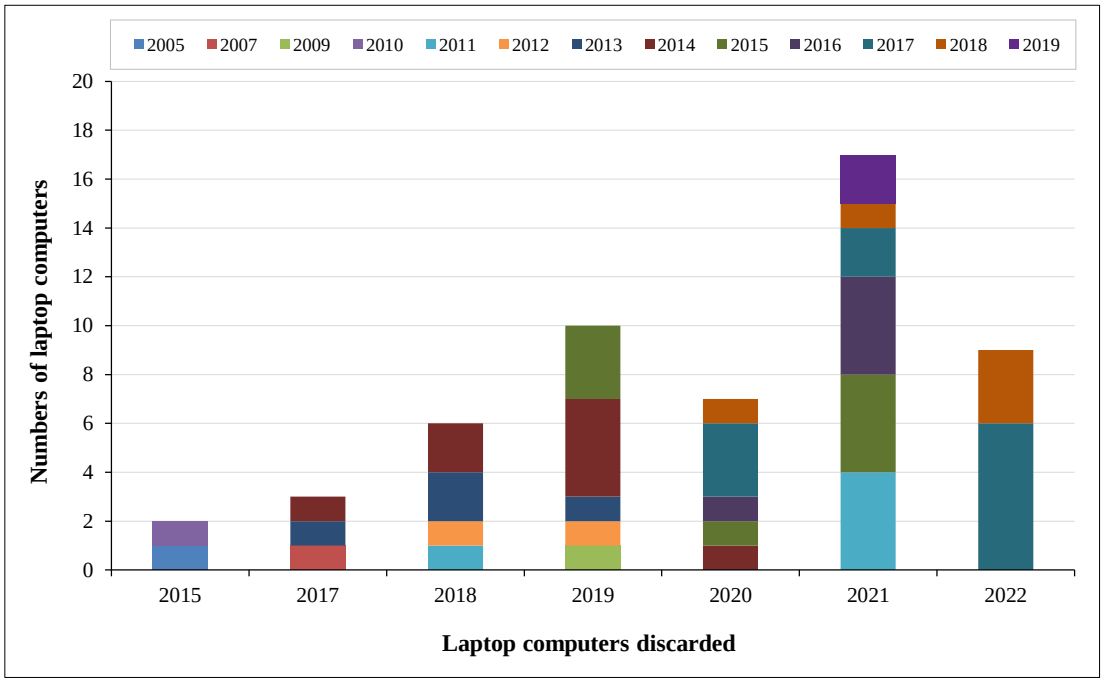

Figure 5. The number of laptops generated in the period 2015 – 2022

The actual lifespan of these laptops is 2–10 years (Figure 6a), for an average of 5.28 years. In which, the high percentage is 5 years (29.63%) and 4 years (24.07%). The results in the study of Hennies & Stamminger [4] also recorded a similar lifespan of laptops from 3-6 years, with the highest being 10 years. Meanwhile, laptops of students at a university in Sydney have a lower average life expectancy, with an average value of only 4.31 years [5]. When discarded, most of these laptops are in unusable (20.4%) or usable conditions, but the quality ranges from poor (25.9%) to very poor (35.2%). Only 3.7% of computers are still in good working condition, and 14.8% are the average state (Figure 6b).

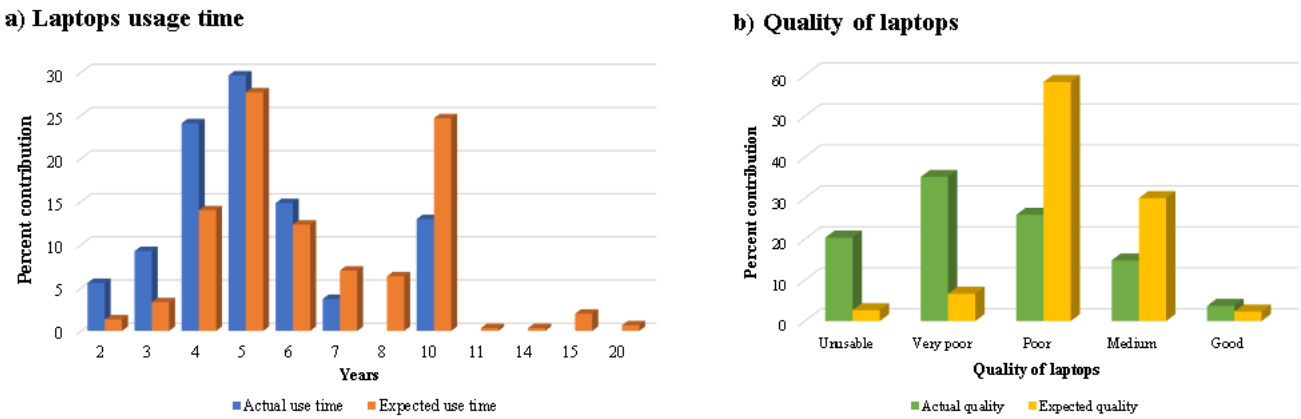

Figure 6. Discarded laptop characteristics

3.2.2. Laptop Consumption Behavior

Many previous studies have suggested that the lifespan of electronic devices in general and laptops in particular depends on many factors, from production design to consumer behavior such as usage intensity, maintenance, etc. [30, 31]. However, this study did not find any correlation between laptop lifespan and factors related to consumer behavior (sig>0.05). Behaviors considered included intensity of use, reading of user manuals, equipment maintenance, and level of recommended practices (device cleaning, preventing collisions, battery protection, secure software installation).

For electronic devices in general and laptops in particular, their service life is affected by many factors, from the design and quality of the manufacturing process to consumer behavior [30, 31]. However, this study did not find any correlation between laptop lifespan and factors related to consumer behavior (sig>0.05). Behaviors considered included intensity of use, reading of user manuals, equipment maintenance, and level of recommended practices (device cleaning, preventing collisions, battery protection, secure software installation). It should be noted that these correlations were only considered for 54 previously discarded laptops, as they accurately determined their actual lifespan. The survey results show that laptops were used for 1–15 hours per day (Figure 7a), averaging 4.3±2.5 hours per day. In which students mainly use laptops for about 3 hours per day (24.1%). However, it is worth noting that 18.6% of students use more than 8 hours per day. This is a high-intensity use. The results of the correlation analysis show that the correlation between the intensity of use and the life of the laptop is not statistically significant (sig = 0.111).

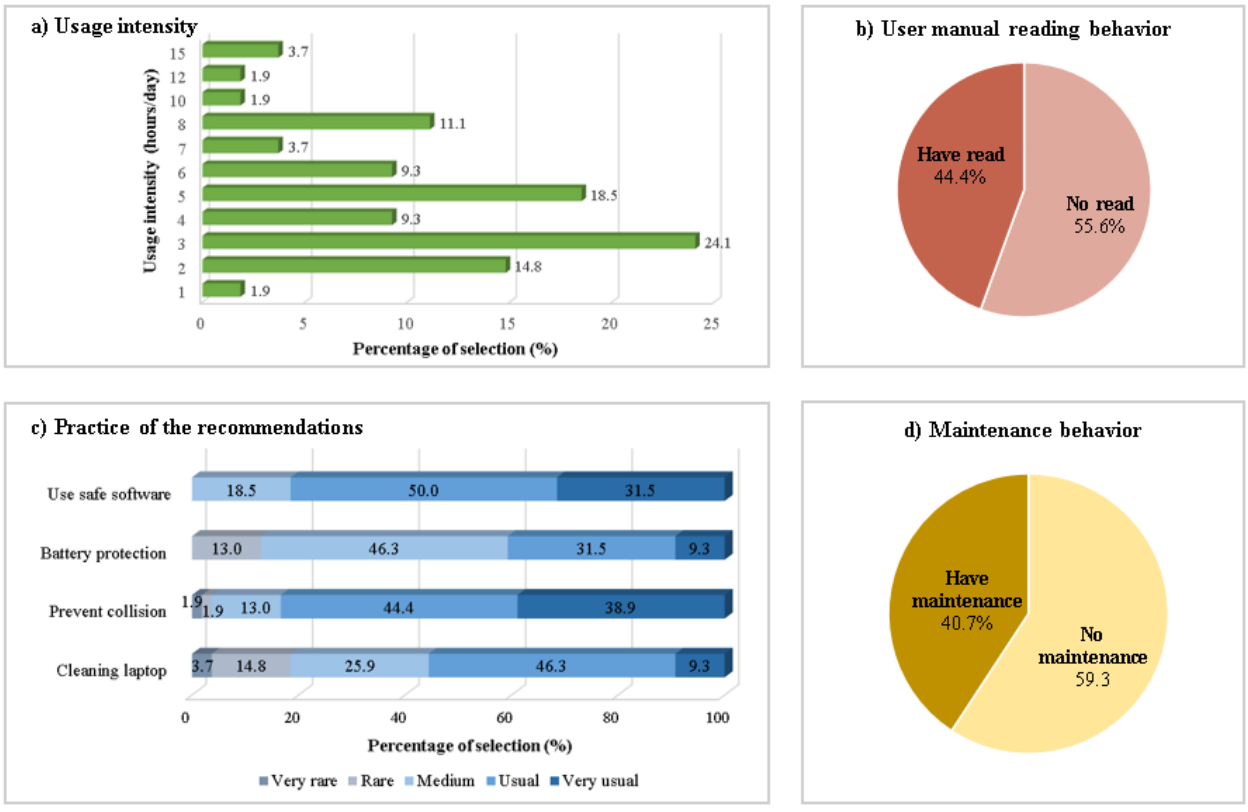

Figure 7. Laptop use behaviors

Similarly, reading the manuals is also not correlated with the actual lifespan of the laptop (sig = 0.646). The survey results showed that up to 55.6% of students did not read the instructions before using the laptop (Figure 7b). Former research [31] shows that up to 80% of consumers do not read the instructions for use. It can be seen that the habit of not reading the manual before use has become common. However, this behavior doesn't seem to have a big impact on the laptop's lifespan. As an example, the lifespan of laptops between students who read and did not read the user manual did not differ significantly, at 5.1 years and 5.4 years, respectively [31]. The lifespan of laptops for those who have a habit of reading the manual before using them was 4.6 years, and for those who do not have this habit, it was 4.8 years. Although not correlated with device lifespan, user manual reading is averagely correlated with device battery protection behavior (r = 0.458) and collision prevention behavior (r = 0.349). Both of these correlations have a statistical significance level of 1%.

Besides usage intensity and user manual reading, all recommended practices considered in the study were not correlated with laptop lifespan (sig>0.05). Of the four recommendations, the installation and use of safe software and the protection of laptops from strong collisions were performed most frequently, with 81.5% and 83.3%, respectively (Figure 7c). For the maintenance practice (Figure 7d), the average equipment lifespan of 59.3% of students who did not perform maintenance was 5.2 years. Similarly, the lifespan of laptops for 40.7% of students who performed device maintenance was 5.5 years. The results did not show a significant difference. Therefore, the correlation between laptop lifespan and maintenance practices is also not statistically significant.

3.3. The Potential for Laptop Reuse and Recycling

3.3.1. Quantity and Quality of Expected Laptops to Dispose

Of the 300 laptops in use, students are expected to dispose of them between 2022 and 2041 (Figure 8), with a total weight of up to 561 kg. The expected lifespan of these laptops ranges from 2 to 20 years (Figure 7a), with an average of 6.8 years. However, the number of computers used over the past 10 years is not significant (only 3.33%). Therefore, the majority of computers will be disposed of before 2031 (96.67%). Details about the number of expected laptops wasted are shown in Figure 8 below. The colors in the column represent the year the device was purchased for use. Calculation results show that 2025 and 2026 are expected to generate the most laptops. These laptops have a lifespan of mainly 5 and 6 years, as most were purchased in 2020 and 2021.

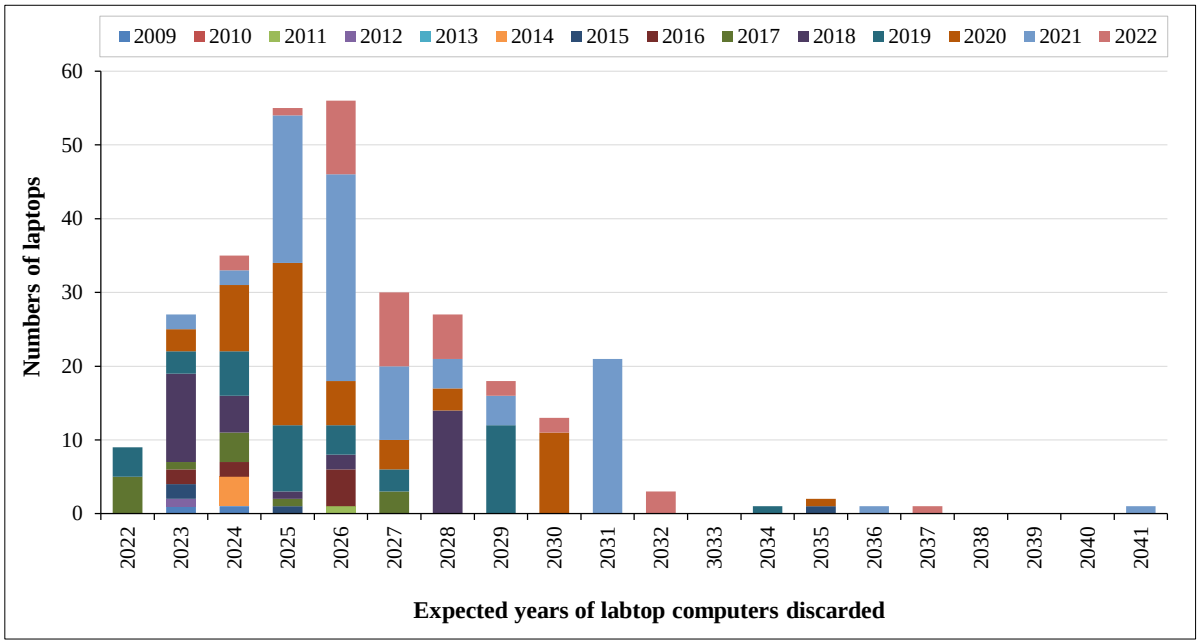

Figure 8. Expected number of laptops to be generated

Compared to the actual lifespan of 54 previously discarded laptops (5.28 years), 300 laptops in use have a longer expected lifespan (6.8 years). Similarly, the actual usage time of the laptop is only 4.7 years, while the expected usage time is 5.6 years [31]. It can be seen that the expected average lifespan of the equipment is always higher than the actual lifespan.

Besides estimating the number and volume of laptops that will be generated, forecasting the quality of the device is also important. This is considered the main factor determining the feasibility of reuse and recycling [27]. In this study, the quality of laptops was determined based on the students' intention to throw them away and was classified into 06 levels (Table 1). The survey results show that no students intend to throw away their laptops when they are still in very

good condition. Only 2.33% of laptops are expected to be replaced while still in good condition. Most of the time, students will replace laptops of medium (30%) to poor (58.33%) quality. The remainder will be used until the equipment is of very poor quality (6.67%) or no longer usable (2.67%). Figure 7-b shows that the actual quality of the discarded laptop is significantly lower than the expected future disposal. While in fact, students dispose of laptops when they are of poor quality, very poor, and no longer usable. In the future, they will dispose of laptops when they are of medium and poor quality. This may shorten the useful life of these laptops compared to expectations. Laptops that are no longer in use are mainly stored at home, exchanged for a new one at the manufacturer's distribution store, donated to others, or sold to free scrap collectors (Figure 9). In particular, the forms of storing it at home, selling it to free scrap collectors, or throwing it together with household waste are not recommended because of potential environmental risks and because they affect the circulation of materials. Unfortunately, out of a total of 54 previously discarded notebook computers, 81.5% were made using these methods. In particular, none of the students transferred their unused laptops to formal processing centers. The main reason is that they do not know the information related to formal processing. After participating in the study's survey, students made more positive choices about how to handle laptops in the future. In which, 39% of students will bring their unused laptop to the store to exchange for a new one. At the same time, laptop waste will be transferred to formal disposal centers by 1.7% of students.

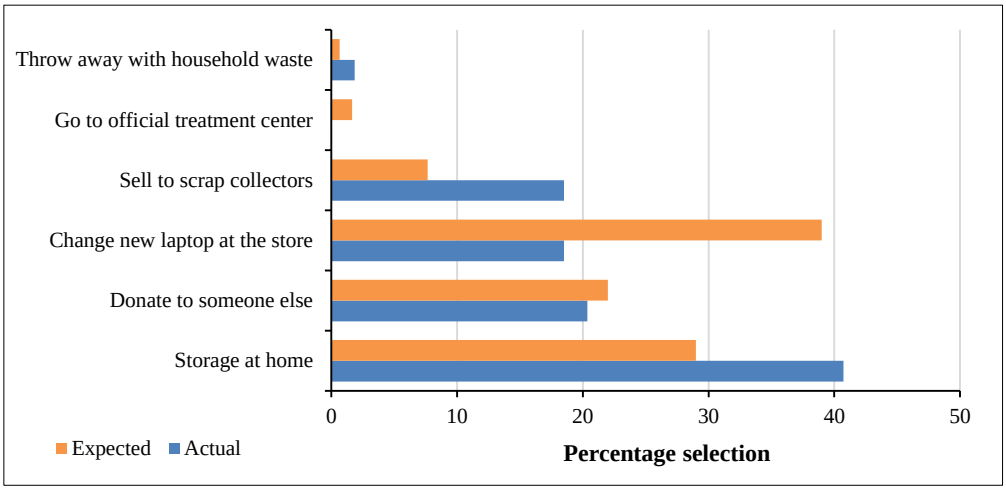

Figure 9. The method of disposing

3.3.2. Quantify the Potential for Reuse and Recycling

Percentage of laptops of 300 students at Can Tho University with potential for direct reuse (level 1), reuse through support (level 2) and recycling (level 3) is 2.33%, 88.33% and 9.33%, respectively (Figure 10). The evaluation results show that only 2.33% of laptops will be discarded when it is still good enough conditions to reused directly (equivalent to 7 machines). The largest percentage is level 2, which can be reused or recycled. However, reuse should take precedence over recycle. This level applies to 88.33% of average and poor qualities laptops (equivalent to 265 devices). Note that reusing the laptops in this case needs to be further supported by repair or refurbishment activities. The rest, 9.33% of equipment that is of very poor quality or no longer usable will be classified as recycling.

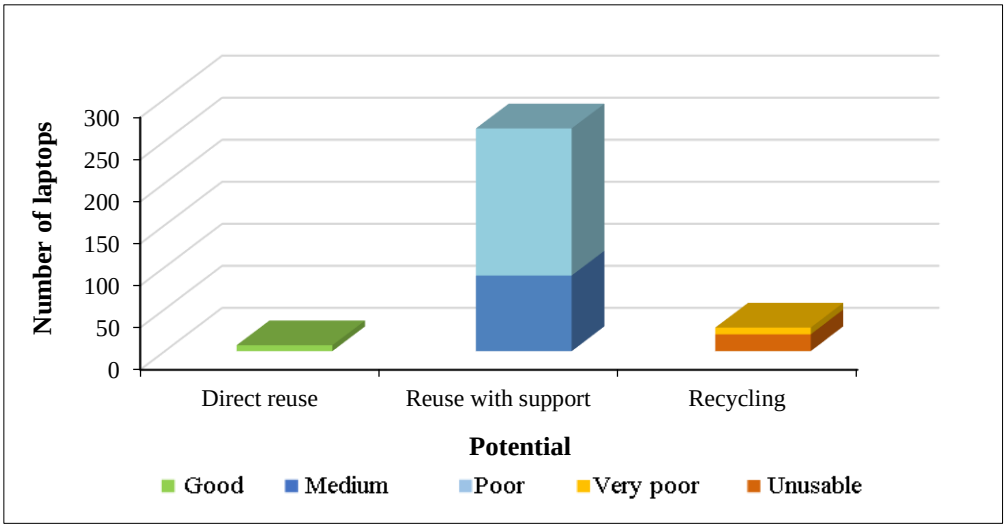

Figure 10. The potential for laptop reuse and recycling

With a sample size of 300 students, the study quantified the reuse and recycling potential of 300 laptops. The study firmly believes that the real potential of laptop reuse and recycling at Can Tho University is much greater. According to statistics, the whole university has 34,365 full-time university students and 8,553 university students trained in other forms [25]. Assuming the usage rate according to the survey results is 1 laptop per student, the whole Can Tho University will have 42,918 laptops. In addition to students, Can Tho University also have 2,873 graduate students, 1,389 officials, and about 500 other employees engaged in teaching and research [25]. All of these actors have the potential to provide laptops for the formal recycling and reuse program. Therefore, in the coming time, it is necessary to promote research and implementation of recovery, reuse, and recycling of this potential waste stream with the goal of prolonging the life of equipment, circulating the flow of valuable materials, and reducing environmental pollution.

4. Conclusion

With a usage rate of 1 laptop per student, it is estimated that the whole Can Tho University has 42,918 laptops in use. The results show that universities are a potential place to implement material collection and recycling programs for electronic devices, especially information and communication technology devices such as laptops. Of the 300 students who participated in the survey, 54 had previously discarded their laptops, with an average lifespan of 5.28 years. However, the expected lifespan of 300 laptops in use is expected to be higher, at about 6.8 years. These laptops will be discarded from 2022 to 2041, with a total weight of 561kg. Of which, 2.33% of laptops are expected to be disposed of when the quality is still good and they meet the conditions of direct reuse (level 1). Medium and poor-quality laptops (88.33%) will be reused with the assistance of repaired or refurbished laptops (level 2). The remaining 9.33% of laptops that are of very poor quality or are no longer usable will have the potential for recycling (level 3). The current findings provide useful information on laptop use and discard for promoting research on circulating the flow of valuable materials and reducing environmental problems.

5. Declarations

5.1. Author Contributions

Conceptualization, N.T.G. and L.T.K.T.; methodology, N.T.G. and L.T.K.T.; software, N.T.G., L.T.K.T., and H.T.H.N.; validation, N.T.G., L.T.K.T., and H.T.H.N.; formal analysis, N.T.G., L.T.K.T., and H.T.H.N.; investigation, N.T.G. and L.T.K.T.; resources, N.T.G., L.T.K.T., and H.T.H.N.; data curation, N.T.G., L.T.K.T., and H.T.H.N.; writing—original draft preparation, L.T.K.T.; writing—review and editing, N.T.G.; visualization, L.T.K.T. and H.T.H.N.; supervision, N.T.G.; project administration, N.T.G. and L.T.K.T.; funding acquisition, N.T.G. and L.T.K.T. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgements

This work was funded by Vingroup Joint Stock Company and supported by the Domestic Master/PhD Scholarship Programme of Vingroup Innovation Foundation (VINIF), Institute of Big Data, code [VINIF.2021.ThS.29].

5.5. Conflicts of Interest

The authors declare no conflict of interest.

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