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Comparative Life Cycle Assessment of Paper and Computer Based Exams

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Abstract

Universities around the globe consume large number of papers every year for educational and administrative purposes. A major portion of these papers are consumed for exam purpose only. Post Covid-19, several universities have moved to computer-based exams because of health and safety concerns. The purpose of this article is to compare paper and computer-based exams primarily from the perspective of their impact on the environment. Our main aim is to perform Life Cycle Assessment (LCA) for three scenarios and find out which one of them is better from the environmental perspective. The three scenarios that have been considered for LCA modelling are as follows: (1) consumed papers go to landfill, (2) consumed papers are recycled, and (3) switching to computer-based exams. The procedure of conducting the LCA follows the ISO 14040 standard method which consists of four steps: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment and (4) interpretation. This research uses GaBi educational software tool for LCA modeling and considers Global Warming Potential (GWP) as the impact category for comparison purpose. A further comparison from student performance point of view has also been made at the end of the article. The result of this research shows that computer-based exams have least impact on the environment based on the selected GWP impact category as compared to paper-based exams. Furthermore, it has been found that there is no significant student performance difference in either type of these exams.

Keywords: *LCA; Paper-based exam; Computer-based exam; Environmental impact*

1. Introduction

Traditional way to conduct exams in an educational sector is by using paper. With an expected steady increase in enrollments in Saudi higher education institutions [1], the consumption of paper will increase in the future. Most recently, the College of Engineering at the University of Tabuk (UT) temporarily shifted from paper-based exams to remotely arranged computer-based exams because of the prevailing Covid-19 situation. However, this shift was temporary, and now the college is conducting in-person exams again. Most universities are expected to resume in-person exams starting from the fall semester of 2021. This means that the paper consumption trend will continue to increase in the future.

The pulp and paper industry pose a significant challenge from the viewpoint of addressing environment and climate change issues. First, production of one ton of paper requires approximately 5-17 GJ of energy, this is extremely energy intensive sector [2]. Second, it consumes large amounts of water requiring an average of 54 cubic meters per metric ton of finished product [3]. Third, based on a study conducted in 2014, the paper and pulp industry make up roughly 26% of the 258 million tons of solid municipal waste. Over 14% of the 136 million tons solid municipal waste ended up in landfills in 2014 [4]. Because of these factors, the pulp and paper industry are attracting an increasing attention of researchers.

Environment degradation and climate change issues are forcing governments and policy makers to focus on addressing these challenges [5]. There is a greater need to integrate environmental considerations when making decisions in both private and public sectors [6]. However, making such decisions is not straightforward and requires effective tools to support such decisions.

Widespread use of computers in all facets of life has become common recently. Specifically, the use of computers in higher

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education sector has increased over the last few years. This is due to more variation of prices of computers, wider commercial applications, availability of internet services, and promotion of such technologies [7]. We argue in this research that the availability of computers in higher education sector can be exploited for conducting exams if their impact on the environment is less as compared to paper-based exams and there is no significant difference among student performance in either type of exam. Tools such as Life Cycle Assessment (LCA) can help to make comparison from environmental performance perspective.

LCA is a comprehensive tool for environmental accounting with established methods and procedures [8]. The purpose of LCA is to quantitively assess the impact on environment caused by products and processes [9] from inception to disposal more commonly known as cradle to grave. LCA is a reliable method to verify environmental impact and offers great benefits to private businesses, industries, public sector organizations as well as consumers. Organizations that apply LCA in overall management and product development can gain benefits of environmental, occupational health and safety, risk, and quality management as well as developing and applying cleaner processes leading to improvement of their brand image and value [10].

As mentioned earlier, the focus of this research work is to find out which exam method impacts the environment less than the other. For this purpose, we conducted our study in the College of Engineering at UT. The college uses A4 size papers for conducting student exams. During the academic year 2017/18, the college consumed 278,361 papers for conducting exams. The semester wise breakdown of the consumption of papers for exam purpose only is shown in Figure 1.

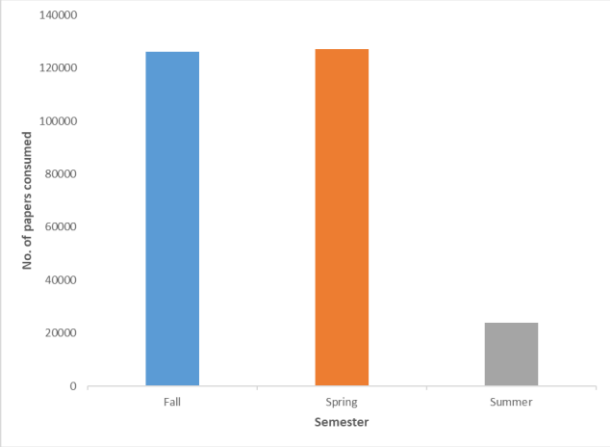

Figure 1. Semester wise consumption of A4 size papers for academic year 2017/18

To manufacture 278,361 papers consumed by the college, 33 trees will be cut, 7,35352 gallons of water will be consumed, and 50102 MJs of energy will be required [11][12][13]. This prompts a need to investigate current practice (paper-based exams) and alternative approach (computer-based exams) for environmental impact assessment.

2. Methodology

To assess and compare the environmental impacts caused by paper and computer-based exams, a life-cycle assessment (LCA) is performed for the mentioned three-scenarios for modelling and comparison purposes. The leading standards for conducting LCA are ISO 14040 and ISO 14044. This research work follows the process of conducting LCA created by ISO 14044. The four steps used in this methodology are namely (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, (4) interpretation. We describe these four steps for our work in detail in the following sections.

2.1. Goal and Scope Definition

2.1.1. Goal of The Study

The intended application of this LCA study is to support decision making in higher education sector in choosing the method of conducting student exams. The goal is to identify which method; paper or computer-based exams, has the least impact on the environment.

2.1.2. Scope of The Study

The following sections specify characteristics of product/process system used in this LCA study and describes all related assumptions:

2.1.2.1 Functional Unit

Papers and computers have varying functions depending on intended applications. However, for this study we specify that the function of these products is to use them for conducting student exams. To compare environmental impacts caused by these two product systems, we must take the common functional unit which is one student. On average, one student consumes 264 papers during one academic year for exam purpose. Similarly, each student on average will use a computer for around 51.6 hours for taking exams during an academic year.

2.1.2.2 System Description and Boundaries

This research work considers three scenarios for comparison purpose. The scenarios are described as follows:

1. Paper based exams with consumed papers going to landfill.
2. Paper based exams with consumed papers going to recycling.
3. Switching to digital-based exams

These three scenarios are depicted in Figure 2. The first scenario describes the current practice in the College of Engineering at the UT. Papers are acquired, printed, used, and disposed at the end. In the second scenario, we assume that instead of disposing of papers for landfill, they will be recycled. The third scenario represents a complete shift to digital based exams.

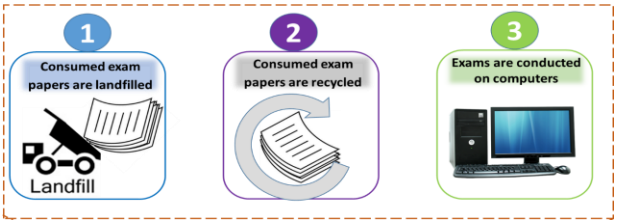

Figure 2. Three scenarios for modelling and comparison purpose

System boundaries for the three scenarios considered in this work are collectively shown in Figure 3. For the first scenario, trees (raw material in this case) are cut from the forest and are transported by trucks to the factory to begin the manufacturing process which includes pulp making, bleaching and paper making. Paper is then transported from the point of manufacturing in Indonesia to the consumers at UT in Saudi Arabia. Papers are consumed by students for exam purposes, subsequently marked by the instructors and afterwards landfilled. During this process, energy is consumed, and emissions are released in addition to the consumption of water and chemicals.

For the second scenario, recycled papers are mixed with virgin material, this is shown in Figure 3 through the connected flow between disposal and manufacturing. The rest of the process is the same as explained in scenario 1. For scenario 3, the process starts with the raw material preparation followed by fabrication, assembly and packing of computers. Computers are delivered to consumers. Student use computers for taking exams and finally computers are discarded after their appropriate life span.

2.1.2.3 Assumptions

To carry out LCA for this research work, various assumptions and considerations were made. This includes the study period for the research work, which extended for an academic year. The sample taken consists of one student studying at the College of Engineering who spent approximately 51.6 hours of exams per calendar year. The materials that were taken into consideration are only two types: the plain paper used in the exam in the case of conducting the exams in person (paper-based exam), and the computer used in the exam in the case of conducting the exams remotely (computer-based exam).

For simplicity of analysis, we consider only the controlled and provided materials by the faculty of engineering for both exams, the excluding materials includes packaging material, staples, and printing processes needed for paper exams. Furthermore, any other supplies needed and commonly used during paper-based exams are solely the responsibility of the students, and therefore excluded, this may include pencils, pens, erasers, sharpener, rulers, calculators. In future research work, the excluded materials during paper-based exam could be considered to understand if there are any changes in the results comparing to the obtained results from this study.

In both cases of paper and computer-based exam, one student spends around 4.3 hours to complete the quizzes, midterm and final exams required for assessment for one course. The average student will take 12 courses during the entire academic year including summer term. Therefore, the total hours considered for exams purposes for one student equal to 4.3 hours per course multiplied by 12 courses per year which sum up of 51.6 hours in a school year.

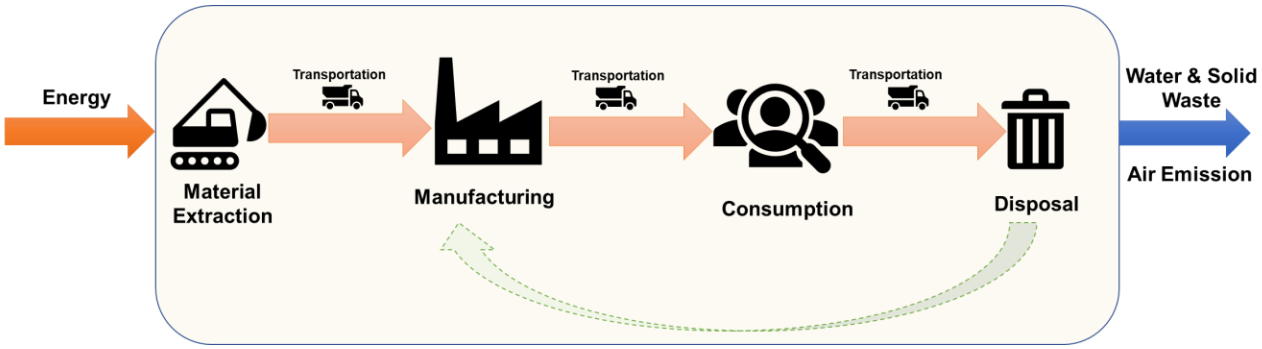

Figure 3. System boundaries of the three scenarios

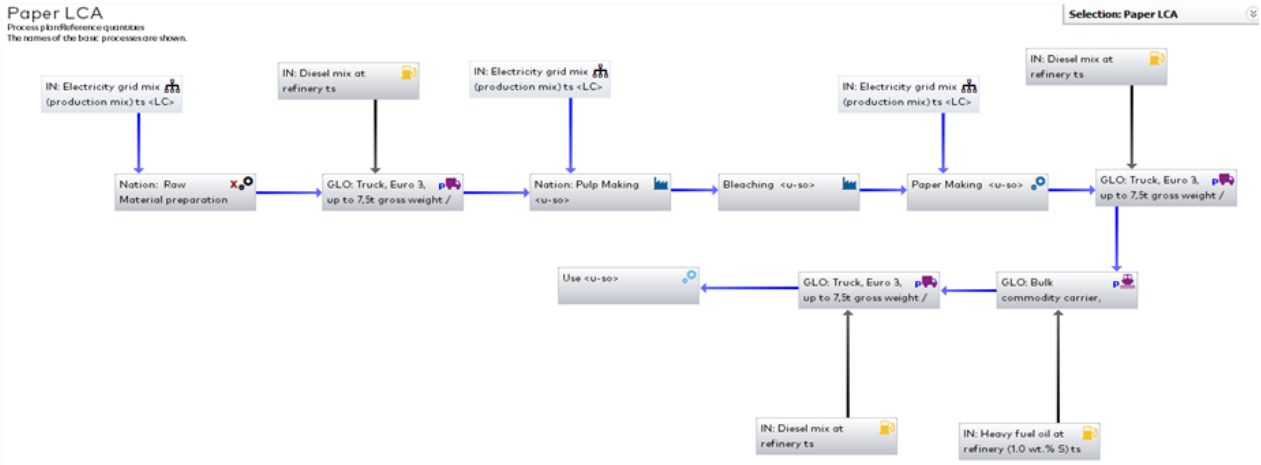

Figure 4. The GaBi model for first scenario

It depends on multiple factors to determine the lifespan and power consumption of desktop computer. For instance, the useful service life of a desktop computer depends on company policy and its requirements regarding the use of computers. We take an average of five years as the computer lifespan. This assumption is based on our observation at the UT as well as is backed by the result of a survey conducted by [14] in which the researchers found that the average service life of a desktop computer wase five years.

The exact energy consumption of a typical desktop computer is difficult to determine because of different hardware configurations including video cards which have a great impact on energy consumption [15]. The minimum consumption of a desktop is reported as 60 watts [16] therefore, we assume 80 watts per hour for the computer-based exam scenario.

2.2. Life Cycle Inventory (LCI)

According to ISO 14040 standard, the Life Cycle Inventory (LCI) step involves compilation and quantification of product system inputs and outputs throughout its life cycle. In relation to this research work, we considered inputs and outputs of each scenario and used them in creating models in GaBi software tool. Some examples of input and output data include raw materials, energy, products, wastes, and emission to air, water, and soil.

The first scenario assumes that papers used for exam purposes are made of virgin material and they go to landfill after use. Paper goes through a series of manufacturing and transportation processes before they are used at the university for exam purposes. The process of manufacturing paper starts with raw material extraction. The raw material is then transported by trucks to the manufacturing facility. The paper is then manufactured in four major steps: (1) pulp making, (2) bleaching, (3) stock preparation, (4) paper making or sheet formation.

The transportation distances considered for this scenario include (1) 50.5 km from forest to paper manufacturing facility, (2) 20 km from paper manufacturing facility to Jakarta port, (3) 7977 km from Jakarta port to Dammam port, (4) 1650 km from Damam port to the University of Tabuk.

After compilation of the required inputs, the first scenario was modelled in GaBi software. As presented in GaBi model of the first scenario depicted in Figure 4, the first process is the raw material preparation, which requires energy input, followed by transportation to the paper making facility. In this facility, other processes such as bleaching and paper making are also performed. The next process is the transportation of papers from manufacturing facility to Jakarta port, transportation by ships to Dammam port, and finally the paper is transported from Dammam to Tabuk. The last process is the use of papers during the exam purpose.

The second scenario assumes that the used paper will be recycled. In the recycling process, paper is collected after their first use. The used paper is then mixed with virgin raw materials for paper manufacturing. The rest of the paper manufacturing processes is similar to scenario 1. After computations of the required inputs, the second scenario was modelled in GaBi software.

The third scenario assumes that exams will be conducted using computers. For this scenario, we assume that computers are being manufactured in Beijing China. In this study, we considered desktop computers. Major components of desktop computers include motherboard, Central Processing Unit (CPU), hard drive and monitor. The average life of university computers is estimated to be 5 years. However, these computers are used for other purposes such as lab demonstrations and experiments. Therefore, it is estimated that 10% of the utilization is allocated for exam purpose. For transportation, the products are shipped from Beijing via naval route and received at Dammam port. The distance between Beijing and Dammam is estimated 6194 km. From Dammam, computers are transported to Tabuk which is 1650 km apart. After compilation of the required inputs, the third scenario was modelled in GaBi software tool.

2.3. Life Cycle Impact Assessment

In this phase, the three scenarios are compared with each other based on the results of the LCA study. Global Warming

Potential (GWP) is selected as the impact category for assessment and comparison purpose. GWP is a measure of how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to carbon dioxide (CO_2). The results of the three models based on GWP are depicted in Figure 5. The first scenario has the highest impact on the environment than the other two scenarios resulting in emission of 1.8 kg of CO_2.

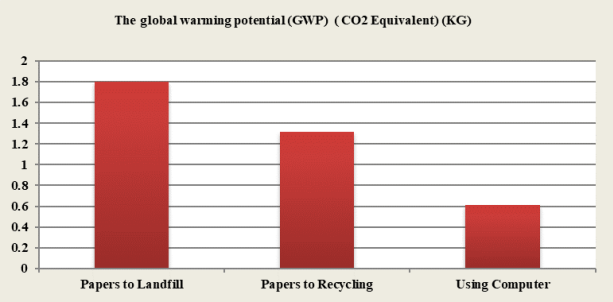

Figure 5. The results of the three scenarios based on GWP

2.4. Interpretation

Results based on the impact category GWP show that both alternatives (scenarios 2 & 3) have less impact on the environment than the current practice (scenario 1). Furthermore, switching to computer-based exams (scenario 3) has the least impact on the environment. Results of the three scenarios based on GWP show that the first scenario results in 1.8 kg of CO_2 emission which is almost equal to the sum of the other two scenarios (1.9 kg of CO_2). Furthermore, it also shows that the first scenario emits 1.8 kg of CO_2 in one year which is almost equal to the CO_2 emitted by the third scenario (1.83 kg) in three years.

3. Effect of Exam Mode on Student Performance

The LCA results favor the use of digital exams. However, it is equally important to investigate student performance in both

modes of exam i.e., paper and computer-based exams. A test or a written examination, whether conducted using papers or computers, is a method to evaluate student performance in terms of knowledge, skills, or abilities [17]. The use of such assessment techniques for student performance evaluation has a long historical record probably dating back to 2357 B.C. [18]. However, the use of computers for conducting exams is a recent phenomenon as IBM's model 805 was used in 1935 as the first application of computers for scoring of objective type questions [19].

Several student performance comparative studies between paper and computer-based exams have been found in the literature. For instance, in a study conducted by [20], the findings suggest that there is no significant difference of participants 'performance in paper and computer-based exams. In a most recent study, [21] investigated the performance of students in China for English majors using computer and paper-based exams. Their research revealed comparable performance levels for both modes of exams. [22] reviewed fifteen years literature and argue that the full equivalence of paper and computer-based exams is not possible. However, they concluded that the level of equivalence was increasing with the advancement in computing technology.

Other studies explored the effect of technology familiarization on student performance in the exam. For example, [23] analyzed student performance in both paper and computer-based exams. Their research reveals that after initial familiarization session, the student performance in both exams is equivalent. In another study from [24] suggest that the knowledge of internet and communication technologies has no effect on student performance level in computer-based exams. The research also supports the idea that the use of technology is growing and offers significant opportunities in the form of real time scoring, immediate feedback, and low cost.

Other researchers investigated miscellaneous factors when exploring implementation of paper and computer-based exams. For example, [25] compared paper and computer-based exams based on validity and reliability of administered test for English teacher education program. They found that the test delivery had no effect on reliability and validity of administered exam. Furthermore, their findings also indicate that there was no significant difference of student scores between the groups who participated in paper-based exams and computer-based exams. [26] found that computer-based exam approach can be implemented in educational institutions without additional cognitive load. [27] concludes findings of digital based assessment from teachers, students, and administrators' perspectives. They found that both teachers and students had a positive experience of technology-based assessment because teachers were required less time to grade written examinations and students were able to obtain their results quickly. Furthermore, students perceived their grades fairer.

All the above studies support the use of digital exams. However, some researchers have highlighted key issues with computer-based exams. For example, [28] specified key reasons of why digital exams are uncommon. They argue that digital assessment platforms do not provide enough capabilities. In another study, [29] compared paper and computer-based exams from students' working memory perspective. Their findings indicate that the students' working memory performance was better in paper based exams as compared to computer-based exam. [30] has highlighted key challenges in implementing computer-based assessments such as students and stakeholder resistance, technical issues, and student familiarity with basic computing skills.

With reference to the challenges and issues reported by researchers, the authors of this study believe that with increasing advancement in technology, the digital exam implementation issues will decrease in future. However, to further support our claim on student performance comparison, we analyzed data of 26 students in computer integrated manufacturing course at College of Engineering in UT, Saudi Arabia. Figure 6 shows a comparison of two midterm exam assessments.

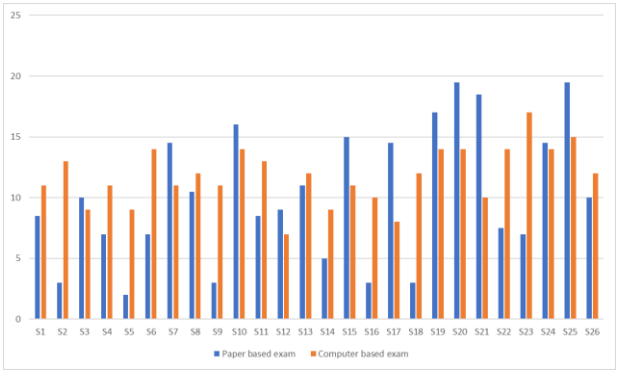

Figure 6. Student Performance Comparison in paper and computer-based exams

The midterm (1) exam was conducted using paper mode while midterm (2) exam was arranged on computers. The level of exam difficulty was comparable, however, the computer-based exam had comparatively short questions. The next paragraph shows comparison of average scores in both exams.

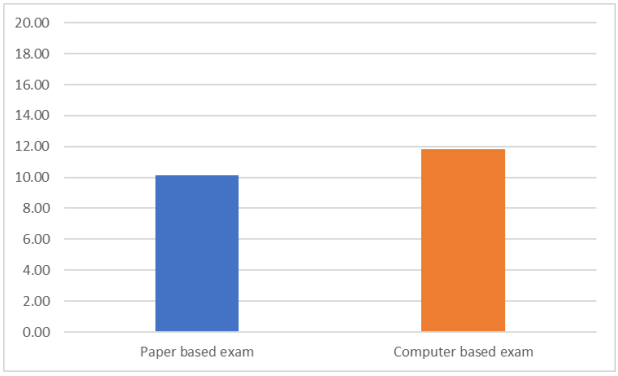

Figure 7. Average score comparison in paper and computer-based exams

As shown in Figure 7, the performance level in computer-based exam is slightly more than the paper-based exams. This is because of the enhanced use of short and multiple-choice questions in computer-based exam. However, the overall performance level is comparable. Hence, we contend that if exams are properly planned and arranged, the mode of exam will have a little impact on the assessment of student performance which is the core objective of written exams. Therefore, we believe that the decision based on LCA carries more weightage and should be considered as one of the key criteria when selecting the mode of exams.

4. Discussion and Recommendations

Based on the LCA results of the three scenarios, it is obvious that switching to digital-based exams causes less impact on the environment. This led us to propose the following recommendations to the administration and other stakeholders of the College of Engineering at UT:

- We propose to the UT administration to consider policy formation and working towards replacing paper-based exams with digital-based exams. Or consider selected courses that can be easily shifted to computer-based exams.
- We also propose that a similar approach should be applied to other areas in UT such as papers used for administration purposes, student handouts, books, and assignments which can be replaced with digital technologies.
- If a shift to digital exams is not possible, we propose to consider making policies and procedures for collection and recycling of paper consumed in the campus.
- We also propose that a policy should be made to use both sides of a paper. This can at least reduce the use of papers in the university campus and would result in having less impact on the environment.
- Efforts can also be made to look for a local paper manufacturer or from one of the neighboring countries of KSA, so that the environmental impact of paper can be reduced.

5. Conclusion and Future Work

The study has investigated environmental perspective of sustainability with key assumptions and Global warming potential (GWP) as the impact category for comparison purpose. The research has also explored the effect of exam mode on student performance. The issue of paper consumption in the College of Engineering at UT is considered. It has been found that the college consumes about 278,361 A4 size papers every year for exam purposes only. Three scenarios have been considered: (1) papers going to landfill, (2) papers are recycled and (3) computers are used for exam purpose. The LCA modeling of these scenarios have been carried out in GaBi Education software tool. The lifecycle inventory data has been computed from existing literature as well as using Gabi's built-in data and processes. The results show that digital-based exams have the least impact on the environment with reference to GWP impact category. Furthermore, the mode of exam has little impact on student performance.

A future decision of switching to digital-based exams will require further investigation from a more comprehensive set of impact categories as well as from social, and economic perspectives. The future study can also consider paper consumption for other purposes such as handouts, assignments and paper used for administration purposes. More specifically, LCA comparison studies can be conducted for scenarios such as printed books vs. electronic books, printed handouts vs. electronic handouts, paper-based assignments vs. electronic assignments and paper display boards vs. electronic display boards.

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