Proposal Scottie Lee Thesis

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1 Introduction

In the dynamic and ever-evolving landscape of modern technology, consumer habits have markedly shifted, altering the perception of Personal Computers (PCs) from luxury items to indispensable tools in everyday life (Ho & Tsai, 2011; Umeda, Daimon & Kondoh, 2005). This transformation has not only revolutionized how we interact with technology but has also ushered in a wave of challenges, especially in the context of environmental sustainability. The escalation of electronic waste (Perkins, Drisse, Nxele & Sly, 2014), fueled by the disposal of still-functional devices, coupled with the rise in hardware costs driven by increased demand from sectors such as cryptocurrency mining, underscores the urgent need for the adoption of sustainable practices in PC usage and consumer decision-making.

The surge in electronic waste represents a significant environmental challenge, with millions of tons of unused or discarded electronics contributing to global pollution each year (Perkins et al., 2014). This situation is exacerbated by the rapid pace of technological advancements, which shortens the perceived lifespan of PCs and encourages consumers to frequently upgrade their devices. Furthermore, the increased demand for powerful hardware, partly due to the rise of digital currencies and their mining requirements, has led to inflated prices, making access to technology more costly for the average consumer. These issues highlight a critical need for strategies that can reconcile the demands of technological progression with environmental stewardship and economic accessibility. Given this context, the question arises, how can individual consumers contribute to reducing the environmental impact of personal computers through their purchasing decisions, usage habits, and disposal practices?

Enter the concept of Product Lifetime Extension (PLE), a strategy designed to confront these challenges head-on (Den Hollander & Bakker, 2012). PLE advocates for upgrading individual components of PCs such as the processor, memory, or storage rather than replacing entire systems. This approach capitalizes on the inherent modularity of PC design, allowing for the extension of the devices' usable life. Such a practice not only has the potential to significantly reduce the volume of e-waste generated but also offers a cost-effective alternative for consumers. By promoting the reuse and upgrading of PC components, PLE contributes to slowing down the rapid turnover rate of electronic devices. This, in turn, aligns with the broader goal of reducing the demand for raw materials, which is crucial for the sustainability of our planet's resources. But the question is, what is the most optimal strategy to implement PLE?

However, implementing (PLE) raises a pivotal question: What are the most effective strategies for its execution, especially in determining which components to upgrade and when? This challenge is crucial to optimize PLE's benefits, balancing technological advancements with environmental and economic considerations.

Therefore, this research seeks to answer the research question: What are the most effective strategies for implementing Product Lifetime Extension in personal computers, specifically regarding the selection and timing of component upgrades, to balance technological advancement, environmental sustainability, and economic viability?

This research question will be supported by the following sub-questions:

- Which components of the personal computers have the biggest carbon footprint?
- Which personal computer component deteriorates the fastest?
- Which computer component determines the computer performance the most?
- How does the upgrade frequency of specific PC components influence the overall lifecycle carbon footprint of personal computers?

This study will undertake several methodological steps to address the stated research questions, as outlined in this proposal.

Initially, data will be collected using web scraping techniques, employing programming languages such as R and Python. This collected data will serve as the foundation for the subsequent analysis phase, where trends within the component data will be examined to predict future technological developments.

Following this analysis, the study will assess the deterioration rate of different PC components, specifically focusing on their lifespan under normal usage conditions.

Finally, a model will be developed to guide consumers toward the most effective upgrade strategies. This model aims to balance cost efficiency while also considering the environmental impact of such upgrades.

Additionally, this proposal includes a literature review that examines existing research within this field. Subsequently, the research objectives will be elaborated upon, providing a comprehensive overview of the study's aims. A detailed description of the aforementioned methodological steps will follow. The proposal concludes with a timetable, outlining the projected timeline for the research activities.

2 Literature Review

The relentless evolution of technology, coupled with escalating environmental concerns and the growing imperative for sustainable practices, underscores the significance of researching Product

Lifetime Extension (PLE) strategies within the personal computing domain. This Literature Review embarks on a critical examination of works and recent studies that form the bedrock of understanding the environmental impact of electronic waste, the potential of design and consumer behavior in prolonging product lifespans, the dynamics of the market and legislative influence on sustainability practices, and, most crucially, the role of component-level upgradability in fostering a more sustainable computing environment.

Initial studies by (Williams & Sasaki, 2003; Griese, Poetter, Schischke, Ness & Reichl, 2004) laid the groundwork by analyzing the lifecycle energy use of personal computers, making a compelling case for the reuse and upgrading of PCs as opposed to recycling. Their pioneering work underscores the substantial energy costs involved in manufacturing computers and highlights the significant environmental benefits of extending their lifespan through strategic management practices.

Further exploration into design strategies and consumer behavior was provided by (Park, 2009; Van Nes & Cramer, 2006; Bakker, Wang, Huisman & Den Hollander, 2014), who investigated how product design and user interactions contribute to extending the lifespans of electronics. These studies collectively suggest that both design innovation and consumer awareness are pivotal in fostering sustainable consumption patterns.

(Kuehr & Williams, 2007; Crafoord, Dalhammar & Milios, 2018) explored the secondary market for computers and the influence of public procurement policies on promoting remanufacturing and reuse. Their research indicates the significance of legislative frameworks and market mechanisms in supporting sustainability goals.

(Khan, Mittal, West & Wuest, 2018) focused on upgradability as a viable strategy for product life extension, noting a gap in empirical research regarding upgradable Product-Service Systems (PSS). This gap signals a promising area for further exploration, particularly in the empirical validation of theoretical models.

(Den Hollander & Bakker, 2012) contributed an economic-balance hybrid Life Cycle Assessment (LCA) extended with uncertainty analysis, specifically addressing the case of laptop computers. Their work emphasizes the complexity of assessing environmental impacts within the IT sector's intricate supply chains.

The studies by (Yan, 2023; Luo, 2023) bring critical insights into the discussion of sustainable computing practices, focusing on the specifics of component-level optimization for personal computers. Yan's research reveals significant differences in performance improvement rates among various computer components, with GPUs showing faster improvement rates than CPUs and hard drives. This study advocates for targeted component upgrades as a cost-effective and environmentally friendly alternative to complete PC replacements, aligning with broader sustainability goals. Those researches focussed more on upgrading computers more cost-efficient and on the three main components. In my research, we extend the research by adding extra perspective in computer variables and also looking more into the carbon footprint of certain components

Despite the comprehensive exploration of sustainability practices in the computing industry, a notable gap persists in the empirical study of component-level upgradability and its economic, performance, and environmental implications. Most existing literature either focuses on broader sustainability strategies without delving into the specifics of component upgradability or lacks empirical data to support theoretical frameworks.

My research aims to bridge this gap by developing a model that evaluates computer components based on performance, price, and sustainability, to inform life extension decisions. By leveraging data on component performance and using PassMark data, my study provides a novel approach to understanding the most cost-effective and environmentally friendly strategies for computer component upgrades. We will extend the previous research with the carbon footprint of certain parts, and besides that also work with ram and multi-component upgrades instead of only one.

3 Objective

The primary objective of my research is to develop a comprehensive Product Lifetime Extension (PLE) strategy for personal computers (PCs) that addresses the critical challenges of electronic waste and environmental sustainability. This strategy aims to achieve the following specific goals:

- **Timing**: Find the optimal timing for switching certain components of personal computers, when should a component be switched?
- **Component**: Find the components which should be switched.
- **Improve Economic Accessibility**: Lower the financial barriers to technology access for consumers by offering cost-effective upgrade paths that extend the lifespan of existing PCs, making high-performance computing more affordable.
- **Reduce the lifecycle CO2 Emissions of Personal Computers**: The CO2 emissions produced by personal computers should be minimized; this aspect should be incorporated into the model.

To achieve these objectives, the proposal outlines a series of actionable steps that include detailed data collection on PC components, the use of models to forecast technological trends and component deterioration, and the development of a model to guide consumers in making sustainable upgrade decisions. By integrating sustainability measures at each step, this proposal aims to provide a practical and impactful framework for extending the lifetimes of PCs in a way that benefits consumers, the environment, and the global technology landscape.

4 Approach

4.1 Data Collection

We will collect comprehensive data on the CPU, GPU, RAM, and Hard Drive. This data will include various types of features, such as:

- PassMark Benchmark score
- Current price
- Release Price
- Release data

In addition to this data, we will also attempt to collect information indicating each component's carbon footprint.

4.1.1 PassMark score

The formulas used to calculate the scores for each component can be found in the following list:

- **CPU score:** $1.791798549 \times \frac{\sum W_i}{\sum \frac{W_i}{X_i}}$
- **3D Graphics score (GPU):** $9.712167917 \times \frac{\sum W_i}{\sum \frac{W_i}{X_i}}$
- **Memory score:** $0.215741845 \times \frac{\sum W_i}{\sum \frac{W_i}{X_i}}$
- **Disk score:** $10.84951297 \times \text{Average}(X_i)$

The formulas use weights (W_i) and scores (X_i) from different tests that belong to the different components. Such as encryption for CPU, image rendering for GPU, and read speed for memory and hard disk speed. Using the weights together with the scores for each test, the PassMark score for the component can be made.

4.2 Forecasting

In the forecasting section, we delve into an analytical review, focusing on the evolution of prices and performance metrics of the various components over time. This comprehensive examination is designed to provide insights into the trends and patterns that emerge within the market. By carefully analyzing these elements, we enable ourselves to make educated predictions about future developments in component technology.

To perform forecasting, we will make use of various statistical methods, such as (quantile) regression and time series analysis (e.g., ARIMA).

4.3 Deterioration

Using the results from forecasting, we will determine the deterioration rate of the different components. This will help in accurately predicting the lifespan and performance decline of components over time.

4.4 Model

We will begin with a model designed to identify the most optimal way to upgrade a computer, aiming to maintain consistent performance while reducing the average cost. This will involve the use of time-series data on the performance and price of computer components. Subsequently, we will develop another model to assess whether the identified upgrade schedule also results in a reduced average carbon footprint for the computer.

In summary, our approach will include a price-performance model for economic analysis, followed by a carbon footprint-performance model for environmental analysis. The environmental analysis will be used to perform more of a validation of the outcome of the economic analysis.

5 Timeline

We plan to work on my thesis until the end of July. Below, you can find a Gantt chart that roughly outlines the planning I have in mind. Each deliverable must be completed within the specified period.

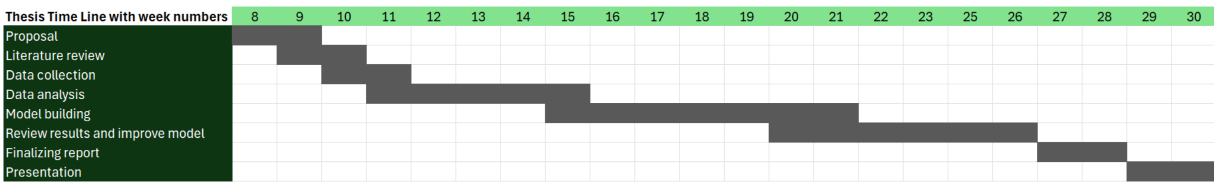

Figure 1: Gantt chart

Literature Table

Study	Reference	Key Findings
Energy analysis of end-of-life options for personal computers: resell, upgrade, recycle	(Williams & Sasaki, 2003)	Reselling or upgrading end-of-life computers can significantly reduce life cycle energy use compared to recycling. The energy investment in producing the complex form of a computer plays a significant role in the environmental impact. Management strategies should focus on extending the lifespan of electronics.
Reuse and lifetime extension strategies in the context of technology innovations, global markets, and environmental legislation [electronics]	(Griese et al., 2004)	The paper emphasizes the importance of sophisticated reuse strategies to enhance eco-efficiency, discusses the analysis of three product categories in terms of reuse strategies, and highlights weaknesses in the European WEEE directive regarding reuse and environmental impacts.
Product life: designing for longer lifespans	(Park, 2009)	The main findings include investigating design strategies to prolong product lifespans, the role of user behavior in determining product life, and the contribution of the study to new knowledge about product lifespans and design practice.
Product lifetime optimization: a challenging strategy towards more sustainable consumption patterns	(Van Nes & Cramer, 2006)	The paper discusses the importance of longer-lasting products from an environmental perspective, introduces the ecological payback period as a decision-making tool, and categorizes consumer replacement motives into four types.
Products that go round: exploring product life extension through design	(Bakker et al., 2014)	The preferred strategy for reducing environmental impacts of refrigerators and laptops is product life extension, designers lack expertise in this area, and tailored approaches are necessary
Computers and the environment: understanding and managing their impacts	(Kuehr & Williams, 2007)	Secondary markets for used computers in the US and Japan are significant and growing, involving various entities. Consumer awareness about the availability of the secondary market for unwanted computers is low. Legislation like takeback systems can increase awareness and incentivize consumers to participate in reselling computers
The use of public procurement to incentivize longer lifetime and remanufacturing of computers	(Crafoord et al., 2018)	Some Swedish municipalities procure remanufactured computers with positive experiences; Public sector support for circular Economy trough recycled materials in new computers
Review on upgradability – A product lifetime extension strategy in the context of product service systems	(Khan et al., 2018)	Growing interest and promising potential of upgradability as a product lifetime extension strategy. Research on upgradable Product-Service Systems (PSS) is dominated by theoretical work, indicating a need for more empirical research
Products that go round: exploring product life extension through design	(Bakker et al., 2014)	The preferred strategy for reducing environmental impacts of refrigerators and laptops is product life extension, designers lack expertise in this area, and tailored approaches are necessary
Extending PC lifespan through secondary markets	(Williams, 2003)	Secondary markets for used computers in the US and Japan are significant and growing, involving various entities. Consumer awareness about the availability of the secondary market for unwanted computers is low. Legislation like takeback systems can increase awareness and incentivize consumers to participate in reselling computers
The use of public procurement to incentivize longer lifetime and remanufacturing of computers	(Crafoord et al., 2018)	Some Swedish municipalities procure remanufactured computers with positive experiences; Public sector support for circular Economy trough recycled materials in new computers
Economic-balance hybrid LCA extended with uncertainty analysis: case study of a laptop computer	(Den Hollander & Bakker, 2012)	Manufacturing a laptop computer requires significantly less energy compared to manufacturing a desktop computer. The manufacturing phase accounts for a substantial portion of the total energy used in both manufacturing and operation. Truncation error from excluded processes in the bottom-up process model is significant, especially in complex supply chains of information technology products
Data Collection and Optimization of Component Upgrading Plans for Personal Computers	(Yan, 2023)	Significant differences in performance improvement rates among components, with GPUs showing faster rates of performance improvement compared to CPUs and hard drives. Targeted component upgrades could serve as a cost-effective and environmentally friendly alternative to full PC replacements.
Study on Product Lifetime extension: case study of personal computers	(Luo, 2023)	Using data from PassMark for CPU, GPU, HDD, and RAM performance, the study develops a model to determine the most cost-effective timing for component replacement, generally around the 6-year mark. It highlights the economic and environmental benefits of product lifetime extension (PLE), suggesting that consumer decisions on upgrades are influenced by performance requirements and other factors. The thesis underscores the importance of PLE strategies in achieving sustainable consumption and recommends further research on optimization and consumer behavior.

Table 1: Literature Overview Table

Conclusion

By integrating these sustainability measures, our proposal aims to provide a comprehensive framework for extending the product lifetimes of PCs in a manner that is not only economically beneficial for consumers but also aligns with critical environmental sustainability goals which is an addition in comparison with old literature. The adoption of Product Lifetime Extension practices, supported by detailed data collection, advanced forecasting, and a robust model for making informed upgrade decisions, represents a pivotal step towards reducing electronic waste and promoting a more sustainable future in the technology sector.

URLS used for data

The following URLs have been used to compute the data:

- CPUs: A list containing all the CPUs with their scores made by PassMark.
- GPUs: A list containing all the GPUs with their scores made by PassMark.

- Hard Drives: A list containing all the Hard drives (SSD and HDD) with their scores made by PassMark.
- Memories: A list containing all the Memory sticks (single) with their scores made by PassMark.

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