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Modelling the environmental benefit of a lifetime extension on a laptop to facilitate pro-environmental behaviour

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MASTER THESIS

for

Student Lars Michael Stockhausen Hektoen

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Consumer awareness towards redesign and repair of household products
- Using LCA as a tool to influence consumer behaviour

Background and objective

Much of our belongings today end up as waste too soon or are used inefficiently, partly because we have more "things" than we need on a regular basis and partly because there is a lack of alternatives for reuse and repair. However, both the EU and the Norwegian Government wish to see a shift away from the linear economy and towards a circular economy, where our belongings can find alternative routes through their lifecycles. Reuse and waste prevention are placed high on the waste hierarchy, meaning they generally are preferred alternatives to recycling and energy recovery. This however must be justified for different product groups, as long lifetime also can preserve ineffective products. Much research has been done to estimate the environmental aspects of different waste treatment solutions as well as recycling, but little research has been made in Norway to estimate the environmental benefits of redesign and repair in such a perspective.

Ostfold Research and Fretex have recently commenced a research project where the main goal is to provide the consumer with information of the environmental and social impacts of the redesign products of Fretex. In connection to this research project, the aim of this master thesis is split into two parts. The first is to conduct a consumer survey to investigate the awareness among the inhabitants of Ås municipality in general, and students of NMBU more specifically, of the environmental and social impacts of redesign and repair of household products, with main emphasize on clothes and textiles. The second part is to apply the life cycle assessment (LCA) methodology on a relevant type of household products to examine the environmental benefit of redesign and repair compared to current waste treatment methods. Finally, an evaluation be done of how the LCA results can be presented to the consumer with the intention of influencing consumer actions.

The following tasks are to be considered:

1. Carry out a literature study relevant to the topic of this project
2. Specify the scope and research questions for the study
3. Decide upon and describe the proper methodology for conducting the consumer survey and the relevant study objects
4. Construct and distribute the consumer survey aiming to answer questions such as:
    a. What interest is there among the inhabitants of Ås municipality and the students of NMBU to redesign/repair consumer products such as clothes, household appliances and furniture?
    b. What is the motivation for the consumer to repair products themselves or to buy products that are redesigned or repaired by others?
        i. Environmental concerns?
        ii. Economic concerns?
        iii. Social value?
    c. How would this motivation be influenced by increased information regarding the environmental benefit of redesign or repair?
    d. To what degree is redesign and repair already taking place?
5. Analyse the results of the consumer survey
6. Provide a systems definition (incl. goal and scope, system boundaries, processes and flows) of the current waste handling system for clothes, aiming at studying the environmental value of redesign and repair, compared to the current waste treatment methods.
7. Collect information and data needed to define and describe the given system.
8. Apply the LCA or Social-LCA methodology on a relevant garment or product group to quantify the environmental impact of redesigning or repairing that specific garment instead of it ending up as waste.
9. Calculate the potential life cycle environmental impacts of the system, and perform a sensitivity analysis of the results from the scenarios.
10. Evaluate how this information could be presented to the consumer
11. Discuss the overall findings of my work, agreement with literature, what are critical variables and assumption, strengths and weaknesses of your methods, and recommendations for further work.
12. Write the master thesis report

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In

the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 26. January 2016

Olav Bolland
Department Head

Helge Brattebø
Academic Supervisor

Ole Jørgen Hanssen, NMBU
Academic co-supervisor

PREFACE

This thesis is the final work of my master's degree in Industrial Ecology at the Norwegian University of Science and Technology. It was completed in the spring of 2016 and comprises 30 ECTS.

Based on a discussion with Ostfold Research and the approval of my two supervisors, the decision was made to decouple my research from the ongoing project at Ostfold Research, which focused on the environmental and social impacts of redesigned products sold by Fretex. The differences in the research plan for the two projects led to that I would not get access to the necessary data to perform an LCA on textiles. Instead, it was decided to use already available LCA-based data to model the environmental impact of lifetime extension on a household good. A laptop was chosen as a study object, based on a personal experience I had refurbishing my five year old MacBook Pro in the fall of 2015. My main motivation for this refurbishment was to save the money of not investing in a new laptop, but as an environmentally concerned individual, I started to wonder what the environmental benefit was of extending the lifetime of my laptop was, and whether this information could be of interest to other consumers. Could it create awareness and encourage to pro-environmental behaviour?

I am very grateful to my two supervisors, Ole Jørgen Hanssen and Helge Brattebø, for steering and pushing me in the right direction until the very end. Special thanks also to my partner in life, Jenny Benum Lorange, for all her love and support.

Oslo, July 14 2016

Lars Michael Stockhausen Hektoen

ABSTRACT

English

Consumption of household goods is one of the main drivers behind several environmental impacts, including emission of greenhouse gases. Lifetime extension has been proposed as a strategy to mitigate emissions. Keeping products in use through service and repairs can replace the need for new purchase and thereby reduce the overall impacts associated with material extraction, manufacturing, recycling and transport. In this thesis, a scenario model is developed to compare the environmental impacts of a base-scenario where a laptop s replaced after 4 years, which is the current average lifetime of laptops, with a lifetime extension scenario where an overhaul is performed after 4 years, giving the laptop 2 additional years. In addition, a consumer survey is performed on inhabitants of Ås municipality and students at the Norwegian University of Life Sciences to identify: a. whether consumers are aware of the environmental impacts associated with household goods, focusing on the greenhouse gas emissions from the production phase; and b. whether more information of the environmental impacts potentially can encourage consumers to pro-environmental behaviour. Results show a clear environmental benefit in the lifetime extension scenario, with a 20 percent difference in cumulative GHG-emissions over a 12 year period. Results from the survey indicate a low level of awareness among consumers of the environmental impacts associated with household goods, but at the same time the expressed belief that such information should be more available and that it can in fact influence behaviour in a pro-environmental direction. Building on the results, the development of a tool is proposed which can visualize the environmental and economic benefits of lifetime extension on a wider range of products in order to create awareness among consumers and stimulate to pro-environmental behaviour. Further research on lifetime extension of household goods is suggested.

Norwegian

Forbruk av husholdningsvarer er en av hoveddrivkreftene bak flere miljøpåvirkninger, deriblant utslipp utslipp av klimagasser. En forlengelse av levetid har vært foreslått som en strategi for å redusere utslippene. Det å holde produkter i bruk gjennom service og reparasjoner kan erstatte behovet for nye kjøp, og dermed redusere de samlede påvirkningene forbundet med materialutvinning, produksjon, gjenvinning og transport. I denne avhandlingen er en scenariomodell utviklet for å sammenligne miljøpåvirkningene et grunn-scenario der en bærbar datamaskin blir erstattet etter 4 år, som er den nåværende gjennomsnittlige levetiden for bærbare datamaskiner, med et forlenget levetid scenario der en overhaling blir utført etter 4 år som gir den bærbare datamaskinen 2 ekstra leveår. I tillegg blir en forbrukerundersøkelse utført på innbyggerne i Ås kommune og studenter ved Norges miljø- og biovitenskapelige universitet for å identifisere: a. om forbrukerne er klar over de miljømessige konsekvensene forbundet med husholdningsvarer, med spesielt fokus på klimagassutslippene fra produksjon; og b. om mer informasjon om miljøkonsekvensene potensielt kan oppmuntre forbrukere til miljøvennlig atferd. Resultatene viser en klar miljøgevinst i et levetidsforlengelse scenario, med en 20 prosent differanse i kumulative klimagassutslipp over en 12 års periode. Resultater fra undersøkelsen indikerer et lavt nivå av bevissthet blant forbrukere om de miljømessige konsekvensene forbundet med husholdningsvarer men samtidig et ønske om mer informasjon og en tro på at mer informasjon kan påvirke atferd i en miljøvennlig retning. Som følge av resultatene blir det forslått å utvikle et verktøy som kan visualisere de miljømessige og økonomiske fordelene av en forlenget levetid på et bredere spekter av varer, som igjen kan bidra til å skape bevissthet blant forbrukere og stimulere til miljøvennlig atferd. Videre forskning på levetidsforlengelse av husholdningsvarer blir foreslått.

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1 INTRODUCTION

Household consumption contribute with more than 60% of the global greenhouse gas emissions (GHG-emissions) and between 50% to 80% of total land land, material and water use (Ivanova et al., 2015). Focusing on how to mitigate GHG-emissions, a first natural step is to analyse the life cycle of different household goods from cradle to grave with the Life Cycle Assessment (LCA) methodology, in order to develop an overview of the cumulative GHG-emissions from the products life cycle and in which life phase the largest emissions occur.

Every product bought carry an invisible carbon footprint which often is mandatory for companies to report. For consumers, this information may need to become more available. A consumer has the possibility to reduce the personal carbon footprint from household goods, but not consciously without the information of how much GHG-emissions that are associated with the various goods and which decisions in the everyday life that will affect this impact. Conscious decisions can be made during all three phases of owning a product: in the purchase phase by choosing products with a lower carbon footprint, in the use phase by taking action to extend the lifetime and thereby avoiding unnecessary new purchases, and finally in the disposal phase by securing that the product is properly recycled to secure valuable resources. However, whether we choose to repair and extend the lifetime of a product or to deliver it to a recycling facility will usually be based on evaluations of replacement cost and the convenience of repair (Scott & Weaver, 2014), and not based on our knowledge of the GHG-emissions "saved" by extending the lifetime of the product.

For this thesis, a laptop was chosen as the study object, partly because laptops have relatively high environmental impacts compared to other household goods. According to Desautels & Berthon (2011), the environmental costs of laptops are amongst the highest of any product on the planet when measured relative to its weight. The environmental impacts can be measured in several ways, one of which is material use.

Other calculations, by Anderson (1998) show that the production and distribution of a 4.5 kg laptop requires approximately 18,000 kg of material to be processed and distilled. For this thesis however, the focus will not be on material use but GHG-emissions associated with the lifecycle of laptops.

The largest percentage of the GHG-emissions from a laptops life cycle occur in the production phase, which includes material extraction, production and transportation of raw materials, as well as the manufacture, transport and assembly of all parts and product packaging. The figures range from 57-93% of the total GHG-emissions (Prakash et al. 2012; Apple 2012; Deng et al. 2011). The second largest percentage usually occurs in the use phase depending on the intensity of use, and thereafter the end-of-life phase and the transport associated with shipment from the manufacturing site to distribution points (Apple, 2012). Given the high impact from the production phase and the fact that laptops currently have an average lifetime of 4 years (Bakker, Wang, Huisman, & Den Hollander, 2014; Prakash et al., 2012), a lifetime extension strategy has been recommended to reduce the life cycle impacts (Deng et al. 2011; Bakker et al. 2014; ERM 2011). Several strategies can be implemented to extend the lifetime, including directives for more durable design and developing more effective closed-loop systems in society, such as those illustrated by the circular economy diagram on the next page in Figure 1. As described by the International Waste Association, the general aim of the circular economy is to utilise the maximum value of resources and keep them in use for as long as possible (Williams-Gaul, 2015).

However, it is the consumer who ultimately decides the lifetime of a product, no matter how the durable it is. A consumer can choose to throw something away and replace it with a new one. This is especially the case for electronic devices such as laptops, TV´s and cell phones, as we tend to get dissatisfied with the model currently in our possession. Perhaps it has started misbehaving in some way, and we figure it is best to replace it with a new one. In 2015, every Norwegian produced on average 28 kg electric and electronic-waste (EE-waste). 97,5% of this was recycled, giving Norway an unofficial world record in recycling of EE-waste (Elretur, 2016). Recycling is important because

EE-waste is diverted from landfills and some of the valuable metals are recovered. However, to reduce the overall GHG-emissions of laptops, avoiding unnecessary replacement of devices through encouragement of lifetime extension is most likely more effective.

LCA data is sometimes used to guide consumers to environmental purchasing decisions through environmental labelling, but so far, little research has focused on using LCA data showing the environmental benefit of a lifetime extension to encourage consumers towards pro-environmental behaviour in the use phase. Information on the environmental impacts of laptops are to some degree available for consumers through environmental reports, but not in a format which can readily visualize the benefits of choosing a lifetime extension vs. replacement.

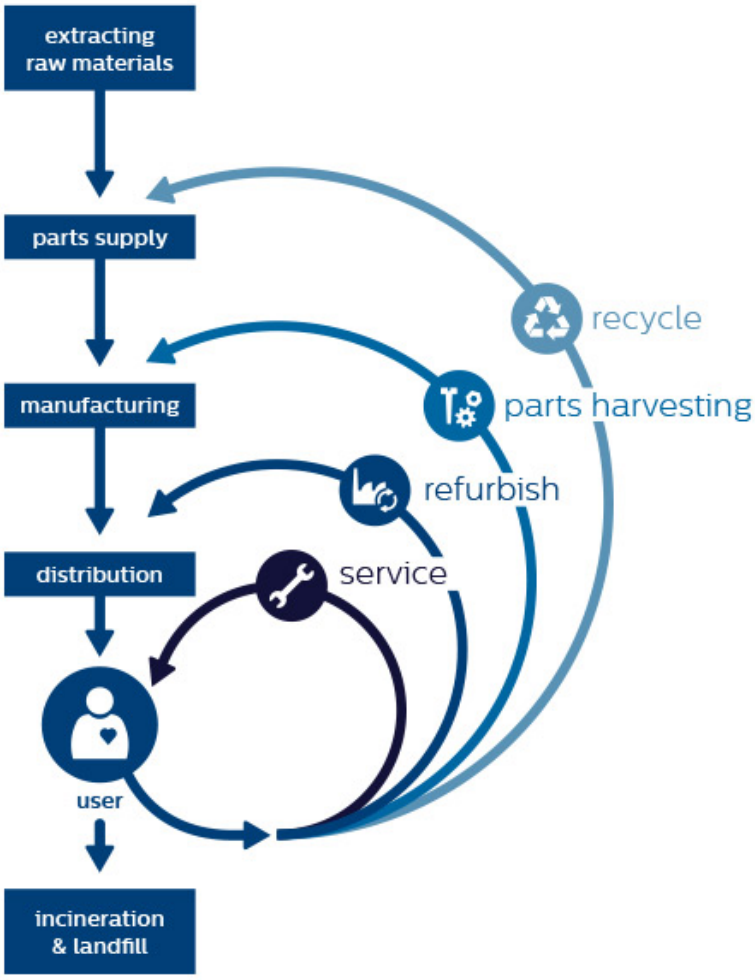

Figure 1 – Circular economys closed loop system (Philps, 2016)

In order to potentially assist decision making for the consumer, a model is developed which can quantify the environmental benefit of a lifetime extension scenario on laptop compared to a replacement scenario. In addition, a consumer survey (n=114) is carried out on inhabitants of Ås municipality and students at the Norwegian University of Life Sciences, addressing the level of awareness among consumers of environmental impacts from household goods whether more information potentially can encourage pro-environmental behaviour. The following chapter outlines the goals, research questions and scope of the thesis.

2 GOALS, RESEARCH QUESTIONS AND SCOPE

2.1 Goals

The following two goals were set for this thesis:

- Develop and test a scenario model to quantify the environmental benefit of a lifetime extension on a laptop, which potentially can give consumers an encouragement to avoid unnecessary replacement.
- Conduct a survey to investigate the level of awareness among consumers of the environmental impacts from household goods and whether more information can encourage pro-environmental behaviour, focusing on the GHG-emissions from production.

2.2 Research questions

Matching the goals, the following four research questions were developed and tested through the scenario model and the consumer survey:

- What is the environmental impacts of extending the lifetime of a laptop with two years above the current average of four years?
- What are critical factors influencing the results of the model?
- What is the level of awareness among consumers of the environmental impacts associated with household goods?
- Is there a belief that more information can encourage pro-environmental behaviour?

In addition, two hypotheses were chosen to test possible age-related differences within the collected sample of respondents:

- Hypothesis 1: Older people think of repairing as more important for the environment.
- Hypothesis 2: Younger people have a higher level of environmental awareness.

2.3 Scope

The consumer survey was limited to to inhabitants of Ås Municipality and students at the University of Life Sciences. The environmental impacts modelled only include GHG-emissions. A lifetime extension is in this thesis defined as an action extending the lifetime of a product, and comprises the terms re-use, refurbishment and repair. Redesign is excluded since this term is not suitable for laptops, but rather for textiles. The literature study performed on consumer awareness of environmental impacts and whether more information can influence behaviour in a pro-environmental direction was minimized since the scenario model was the main focus of this thesis.

3 METHODS AND DATA GATHERING

3.1 Scenario model

The functional unit for the scenario model is: domestic use of a laptop over a 12 year period. The following two scenarios was created to analyse the environmental impact of a lifetime extension on a laptop:

Scenario 1 – base-scenario: Purchase and subsequent use of laptop for 4 years, after which it gets recycled and replaced it with a new one. This cycle is repeated 3 times (see Figure 2)

Scenario 2 – lifetime-extension scenario: Purchase and subsequent use of laptop for 4 years, after which it gets refurbished and used for another 2 years. This cycle is repeated 2 times (see Figure 3).

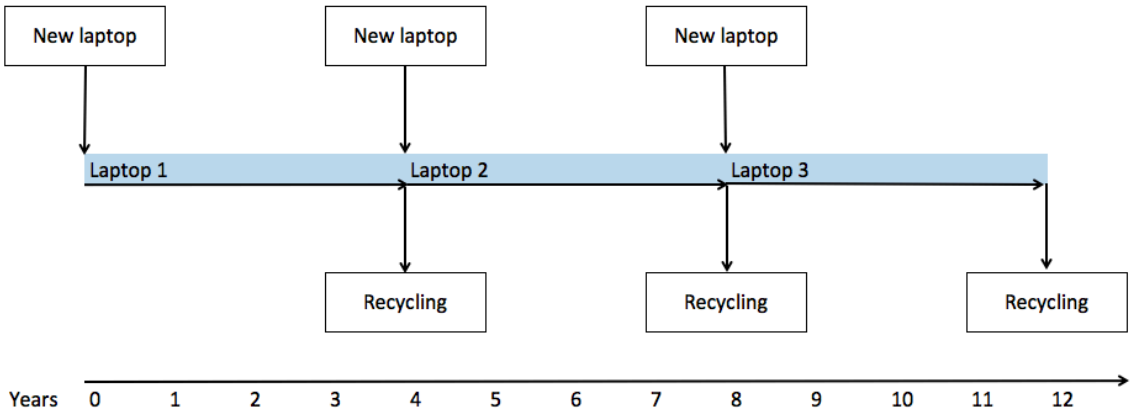

Figure 2 - Base Scenario

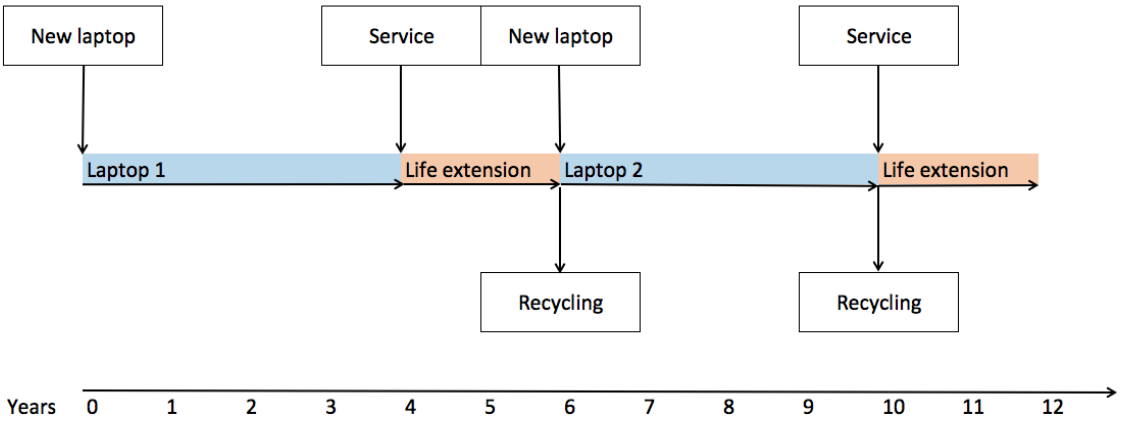

Figure 3 – Lifetime-extension scenario

The environmental report of a 13-inch MacBook Pro was used as a foundation for data gathering. Specifically, the information on the GHG-emissions from the lifecycle was extracted from the report, as seen in Figure 1below.

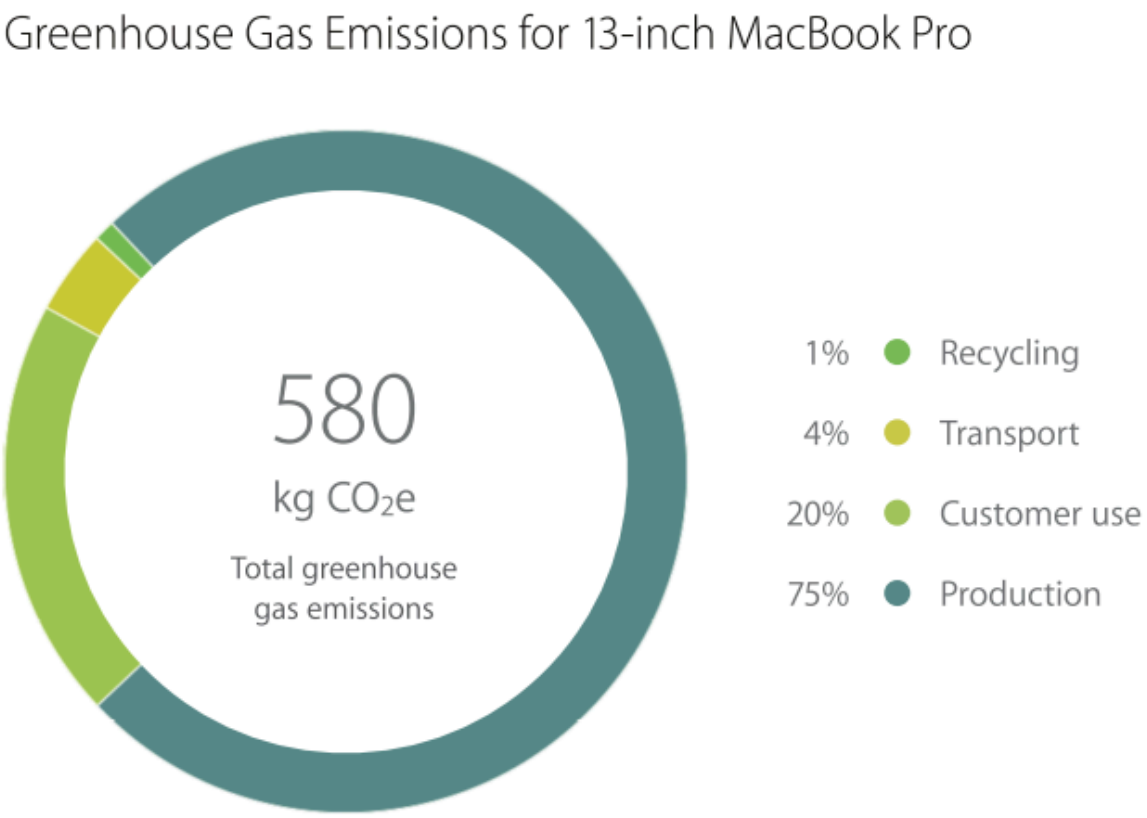

Figure 4 - GHG-emissions for 13-inch MacBook Pro (Apple, 2012)

Using the total GHG-emissions (580kg CO_2e) as a starting point, representing the emission from lifecycle of 4 years, and the given allocation percentages from the different life phases, Table 1 was created and used for calculating the cumulative GHG-emissions of the two scenarios. The input necessary for a refurbishment was set to 12% of total lifecycle impacts (Downes, Thomas, Dunkerley, & Bridge, 2011a).

Table 1 - Data table used for calculation of cumulative GHG-emissions

Total emissions for one lifecycle impacts (4 years)	580 kg CO_2e
Production (P) - 75% of lifecycle impacts	435 kg CO_2e
Recycling (R) - 1 % of lifecycle impacts	5,8 kg CO_2e
Energy use per year (E) - 20 % of lifecycle impacts	116 kg CO_2e
Input for refurbishment (I) - 12% of lifecycle impacts	69,6 kg CO_2e
Transport (T) – 4% of lifecycle impacts	11,6 kg CO_2e

For both scenarios, the emissions from transport was allocated equally between the purchase (2%) and recycling (2%). The emissions from energy use was distributed equally between the 4 years of use. Table 2 was created to show year by year how the emissions were allocated to model the scenarios.

Table 2 - Allocation of emissions over 12 years

Year	Scenario 1	Scenario 2
0	T+P	T+P
1	E	E
2	E	E
3	E	E
4	P+E+T+R	E+I+T
5	E	E
6	E	P+E+T+R
7	E	E
8	P+E+T+R	E
9	E	E
10	E	E+I+T
11	E	E
12	T+R+E	T+R

The emissions from production refurbishment was identified as the most critical factors, and a sensitivity analysis was performed to test the following two changes:

I. A 10% increase or decrease in the emissions from refurbishment.
II. A 20% increase or decrease in emissions from production. This could for example be caused changes in the energy efficiency of the manufacturing process or a change in the energy mix used, with either an increase or decrease in the percentage of renewable energy in the mix, which has lower emission intensity per kWh.

3.2 Consumer survey

The research questions regarding awareness of environmental impacts of household goods was tested with the consumer survey. The survey was conducted from 11-14 April 2016. mostly in the daytime, when people were more easily accessible on the street. I placed myself on several different locations in the municipality of Ås and at the campus of the Norwegian University of Life Sciences (NMBU). Figure 5 shows the set-up.

Figure 5 – Set-up for consumer survey, Hektoen, Michael 2016. JPG.

An in-person format was chosen to collect respondents instead of the more commonly used online format. This was first suggested by my supervisor Ole Jørgen Hanssen who had previous experience with such a form of data collection. The pros and cons of an online survey vs an in-person survey was considered, and the essential arguments can be found in the discussion.

As an incentive for respondents to answer the survey, a prize was used which everyone could participate in winning. The respondents could leave behind their email if they were interested. A toolset chosen was used as the prize, as a symbol of lifetime extension. Two different ways of collecting respondents was tested, asking directly as people were passing or letting people approach me out of curiosity. The latter seemed most effective, as people I approached directly possibly thought that I was trying to sell something.

In the collection process, I aimed to obtain a mix of respondents between different age classes and between male/female. In the final sample with n=114, the distribution between male/female was very even with 51% male and 49% female. The age distribution however, seen in Figure 6, was skewed towards younger respondents (those below 39). Most likely, this was due to the fact that the majority of respondents (55%)

were students, as seen in Figure 7. The population of Ås municipality is generally dominated by the students from NMBU. The younger respondents were perhaps also more eager to answer the survey.

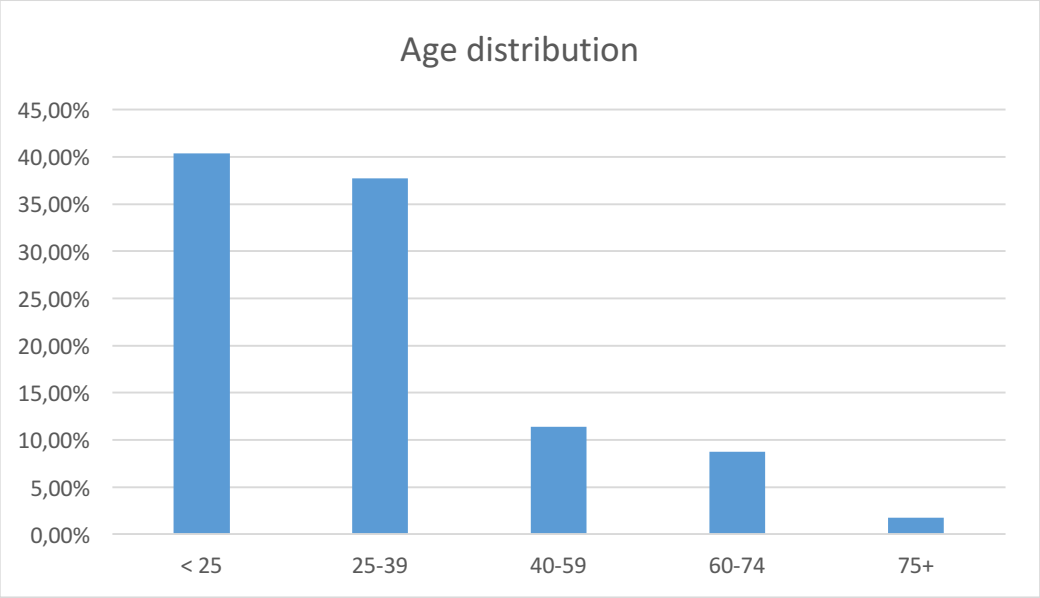

Figure 6 - Age distribution among respondents

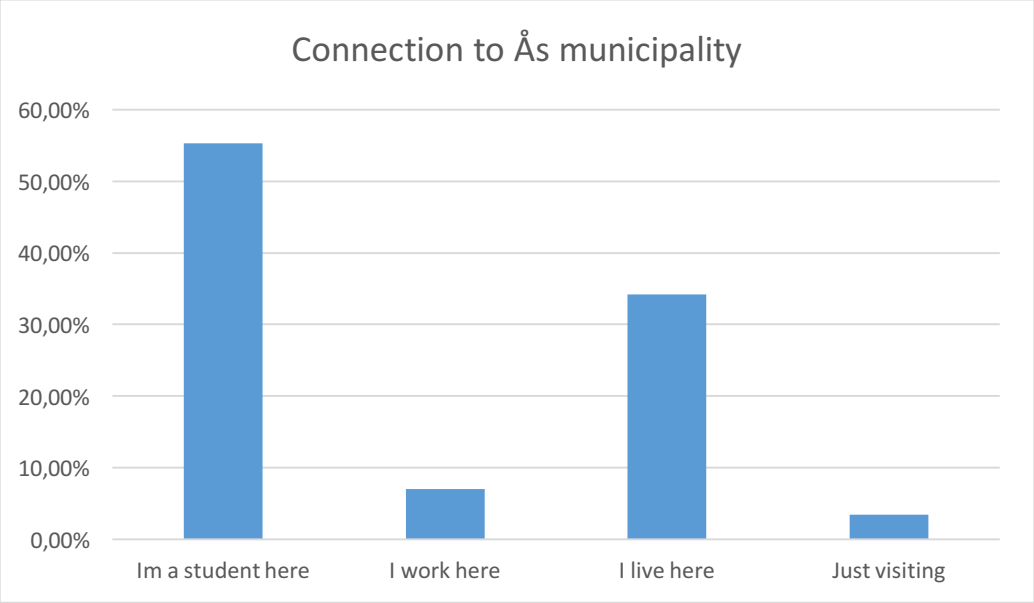

Figure 7 - Reported connection to Ås municipality

The survey consisted of 16 questions, in addition to 3 demographic questions. All questions used the Likert scale In the process of choosing the “right” set of questions which matches my research questions I made several revisions. I place the word right in acclamation points because it is hard to know when your questions are fully functional. It is often a matter of trial and error, and the first versions of the survey was tested on family, friends and also a class at NMBU. The first versions the questions were much more focused on laptops and peoples reuse habits of laptops, but a major revision was made when I chose to have a broader scope for the consumer survey. In the final version the of the survey, which is found in Appendix 1, the majority of questions focused not specifically one laptops, but on people’s general opinions on the environmental impacts of household goods and the value of repair. With a sample of n=114 and a population of approximately 20,000 the margin of error is 10% with a confidence level of 95%. Descriptive statistics of the data was done in Excel. SPSS was used for crosstabulation to test the two hypotheses regarding potential differences within between the older and younger respondents.

4 LITERATURE STUDY

4.1 The environmental benefit of lifetime extension

Within the research community, extending the lifetime of products through reuse or repair is commonly claimed as greener than replacement, as it avoids the resource consumption and waste generation associated with new products (Kwak, 2016a). In theory, a products lifetime should be extended until there is a new product available where the efficiency improvements in the use phase are bigger than the impact buying the new product. Recent research by Minjung Kwak was very relvant for my work. Her article “Assessing the greennesss of product lifetime extension” proposed to build an index which could reflect the nature of a products, including aspects such as technological trends and the intensity of remanufacturing.

The article “Building a library of consumer product LCA for enhancing sustainable consumer behaviour” by Kwak was also relevant for the the proposed application of the scenario model in chapter 6.3, namely to build an online database to store LCA-data on household goods for consumers to see. This area has not been much researched previously. The aim of the database is to help understand the environmental implications of consumer behaviour and identify ways to enhance its sustainability. See discussion for further explanation.

The environmental benefit of a lifetime extension strategy on laptops has been quite extensively researched in the work by Prakash et al. (2012), Bakker et al. (2014) and Downes, Thomas, Dunkerley, & Bridge (2011c). All three studies show that lifetime extension of laptops is the preferred strategy in an environmental perspective. A summary of the results from the three previous studies is shown in Table 3.

Table 3 - summary of literature review on lifetime extension of laptops

What and by who:	Main results:	Details:
Aim: compare the life cycle impacts of a typical laptop with a laptop with an upgrade resulting in an extended lifetime. *Peformed by:* Jackie Downes, Bernis Thomas, Carina Dunkerley and Howard Walker.	Laptop with extended lifetime had 20% lower environmental impact compared to a typical laptop.	The laptops were compared over a 50 year period. The lifetime of the typical laptop was 3 years and the extended lifetime was 2 years after an upgrade.
Aim: Estimate which life phase has the biggest environmental impact for a laptop. *Peformed by:* Siddharth Prakesh and Ran Liu, from the Öko-insitut e.V. – Institute for Applied Ecology, Freiburg & Karsten Schischke and Dr.Lutz Stobbe from Frauenhofer IZM, Berlin	Concludes that the production phase of a laptop makes a significant contribution to the overall GHG emissions, and suggest several aspects to be included in product policy measures which can lead to extended product lifetimes. Among these are possibilities of hardware upgrading and modular construction.	Based on results from three LCA studies from three different databases. Specifications for three laptops was defined and the Global Warming Potential (GWP) for the three laptops was calculated. The functional unit was 1 laptop over its lifetime, and lifetime was set to 5 years without the need for replacement parts or repairs.

Aim: Find the optimal replacement time for a laptop. *Peformed by:* Conny Bakker, Feng Wang, Jaco Huisman and Marcel den Hollander.	Concludes that the product lifespan is the determining factor for the overall environmental impact of a laptop. The optimal lifetime for a laptop was found to be 7 years instead of the current average of 4.	The optimal replacement time for a laptop was calculated with life cycle optimization model based on Kim et al.(2006).

4.2 Awareness of environmental impacts

Encouraging pro-environmental behaviour is not a straightforward task, and several studies have indicated that simply providing information is not sufficient to changing behaviour. Lucas, Brooks, Darnton, & Jones (2008) suggest that policy makers adopt a holistic approach where initiatives are implemented both at the business level, household level and system level as a whole.

5 RESULTS

5.1 Scenario model

The main results for the scenario model is shown below in Figure 8. The cumulative GHG-emissions of scenario 1 was 1716 kg CO_2e and 1426,8 kg CO_2e for scenario 2. Extending the lifetime of the laptop by 2 years thereby had the benefit of a 20,3% reduction in GHG-emissions, or 290 kg CO_2e over a 12 year period. The year-by-year progression in emissions can be seen below in Figure 8. At one point, between year seven and eight, the cumulative emissions of scenario 2 is larger than those of scenario 1. However, since the production phase is accountable for 75% of the total GHG-emissions, scenario 2 will be environmentally beneficial in the long run since the number of laptops necessary to fill the functional unit is lowered.

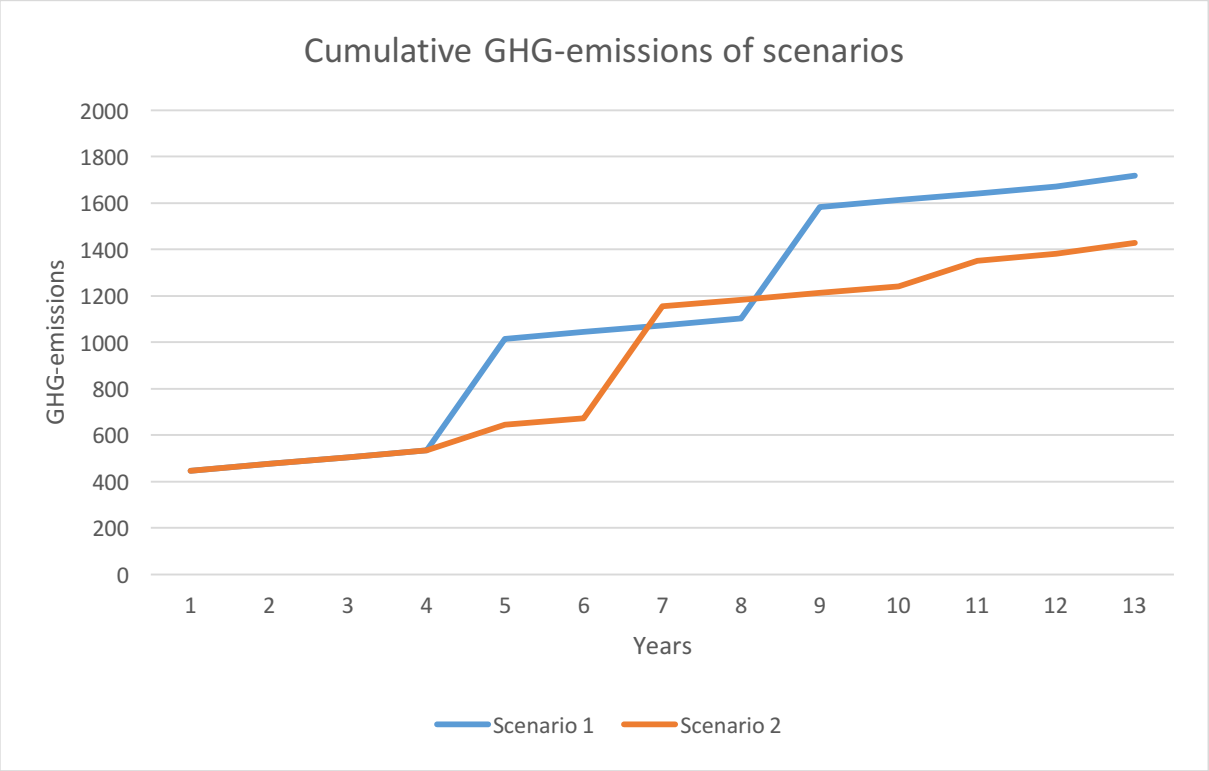

Figure 8 - Cumulative emissions of the two scenarios

Results for sensitivity analysis:

- The results were quite sensitive to changes in the estimated emissions from a refurbishment. A 10 % change resulted in an approximately equal change in the cumulative difference in emissions between scenario 1 and 2.
- A 20% reduction in emissions from production resulted in a small decrease in the benefit of scenario 2, but the GHG-emissions of base scenario was still 20% higher than those of scenario 2.

5.2 Consumer survey

The first question in the survey was related to awareness of the CO2-emissions associated with production of household goods. As seen in the survey in Appendix 1 the respondents were first shown three household goods with figures representing the GHG-emissions from production. The three goods were a laptop, a LCD-TV and a pair of jeans. Upon asked whether or not the figures were surprising, a total of 67% reported that they either 'agreed' or 'strongly agreed' in the statement. Following this question, a a total of 77% 'strongly agreed' when asked whether or not they thought such information should be more available.

Table 4: Results questions 1-2

To what extent do you agree or disagree with the following statements?

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know
The numbers above were surprising	25,4 %	42,1 %	10,5 %	10,5 %	9,6 %	1,8 %
Information regarding the CO2-emissions from production of household goods should be more easily available.	77,0 %	15,9 %	4,4 %	0,9 %	1,8 %	0,0 %

For questions 3-7, the questions focused on whether more information on the CO2-emissions associated with production of household goods would influence behavioural aspects. As seen in Table 5 between 67% and 75% of the respondents answered either quite likely or very likely upon asked asked whether the information would influence "choice of products", "motivation to repair household goods", "motivation to purchase second-hand goods instead of new ones", "motivation to look for products with lower greenhouse gas emissions" and "environmental awareness in general".

Table 5: Results questions 3-7

How likely or unlikely is it that more information regarding the CO2-emissions from production of household goods will influence the following?

	Very likely	Quite likely	Unsure	Unlikely	Very unlikely	Don't know
Your choice of products in the future	29,8 %	45,6 %	9,6 %	10,5 %	3,5 %	0,9 %
Your motivation to repair household goods	32,5 %	40,4 %	17,5 %	6,1 %	2,6 %	0,9 %
Your motivation to purchase second-hand goods instead of new ones	25,7 %	38,1 %	18,6 %	12,4 %	5,3 %	0,0 %
Your motivation to look for products with lower greenhouse gas emissions.	36,8 %	39,5 %	14,0 %	5,3 %	2,6 %	1,8 %
Your environmental awareness in general	32,5 %	35,1 %	23,7 %	4,4 %	2,6 %	1,8 %

Results for question 8-10 is seen in Table 6. Upon asked how often or seldom the environmental impacts of owned or bought products were considered, the largest proportion of the respondents answered either "often" or occasionally. A little surprisingly, when asked how often or seldom the lifecycle of a product was considered, 54% answered Often and 25% answered always. Upon asked how often or seldom the greenhouse gas emissions from producing household goods were considered, the

majority (65%) answered either occasionally or rarely. This matches the answers from question 1.

Table 6: Results questions 8-10

How often or seldom do you consider:

	Always	Often	Occasionally	Rarely	Never	Don't know
the environmental impact of products you buy or own?	1,8 %	33,6 %	32,7 %	21,2 %	8,8 %	1,8 %
the lifecycle of a product?	11,4 %	36,0 %	29,8 %	13,2 %	6,1 %	3,5 %
the greenhouse gas emissions from producing goods in the household?	2,6 %	10,5 %	34,2 %	30,7 %	19,3 %	2,6 %

Questions 11-13 fixated on the importance of different types of environmental information to influence environmental awareness. A total of 78% reported that data on "greenhouse gas emissions from producing household goods" would be either "fairly important" or very "important". This matches the answers for question 7, were 67% reported that it was either "very likely" or "quite likely" that information on CO2-emissions from production of household goods would influence their environmental awareness in general.

Table 7: Results questions 11-13

How important or unimportant do you think the following types of information will be to influence your environmental awareness of household goods?

	Very important	Fairly important	Neutral	Unimportant	Very unimporta	Don't know
Greenhouse gas emissions from producing the goods	23,0 %	55,8 %	10,6 %	5,3 %	3,5 %	1,8 %
Amount of resources necessary to produce the goods	29,2 %	46,9 %	14,2 %	4,4 %	2,7 %	2,7 %
Working conditions to those producing the goods	43,0 %	36,8 %	14,9 %	0,9 %	1,8 %	2,6 %

The last three questions asked about whether the actions of individuals were important for the environment as a whole and whether or not repairing was thought to be important to save the environment. As seen in, about 60% strongly agreed to all questions and about 30 percent agreed.

Table 8: Results questions 14-16

To what extent to you agree or disagree with the following statements?

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know
What the individual does for the environment is important for the whole	61,4 %	31,6 %	2,6 %	3,5 %	0,9 %	0,0 %
It's important to try to repair a product before you throw it away	65,8 %	28,1 %	3,5 %	2,6 %	0,0 %	0,0 %
The act of repairing goods in the household is important to save the environment	61,4 %	32,5 %	5,3 %	0,0 %	0,9 %	0,0 %

Crosstabulation:

Hypothesis 1: Older people think of repairing as more important for the environment.

To test this hypothesis, a crosstabulation of question 15 was run against age. The results showed that a slightly higher percentage of those above 40 years "strongly agreed" in that it was important to try to repair a product before it is thrown away.

Table 9 - Crosstabulation of question 15 and age

Question 15 * Age - Crosstabulation

			Age				
			>75	60-74	40-59	25-39	<25
It's important to try to repair a product before you throw it away	Disagree	Count	0	0	0	1	2
		% within Age	0.0%	0.0%	0.0%	2.3%	4.3%
	Neutral	Count	0	0	0	2	2
		% within Age	0.0%	0.0%	0.0%	4.7%	4.3%
	Agree	Count	0	2	3	13	14
		% within Age	0.0%	20.0%	23.1%	30.2%	30.4%
	Strongly agree	Count	2	8	10	27	28
		% within Age	100.0%	80.0%	76.9%	62.8%	60.9%
Total		Count	2	10	13	43	46
		% within Age	100.0%	100.0%	100.0%	100.0%	100.0%

Hypothesis 2: Younger people have a higher level of environmental awareness.

To test this hypothesis, a crosstabulation of Age was run against question 10, asking how often or seldom do you consider the greenhouse gas emissions from producing goods in the household. The results showed in a slightly higher percentage of answers

for the alternative “occasionally” for those ages between 60-74, and 50% of those above 75 reported that they “always” considered these impacts.

Table 10 - Crosstabulation of question 10 and age

Questions 10 * Age - Crosstabulation

			Age				
			>75	60-74	40-59	25-39	<25
How often or seldom do you consider the GHG-emissions from producing goods in the household?	Don't know	Count	0	0	0	1	0
		% within Age	0.0%	0.0%	0.0%	2.4%	0.0%
	Never	Count	0	2	6	7	7
		% within Age	0.0%	22.2%	46.2%	16.7%	15.6%
	Rarely	Count	1	1	2	9	21
		% within Age	50.0%	11.1%	15.4%	21.4%	46.7%
	Occasionally	Count	0	5	4	18	12
		% within Age	0.0%	55.6%	30.8%	42.9%	26.7%
	Often	Count	0	1	0	7	4
		% within Age	0.0%	11.1%	0.0%	16.7%	8.9%
	Always	Count	1	0	1	0	1
		% within Age	50.0%	0.0%	7.7%	0.0%	2.2%
Total		Count	2	9	13	42	45
		% within Age	100.0%	100.0%	100.0%	100.0%	100.0%

6 DISCUSSION AND CONCLUSION

6.1 Overall findings and agreement with literature

This study sought to estimate the environmental benefit of a lifetime extension operation on a laptop with the intention that the results can function as an incentive for consumers to avoid unnecessary replacements of products and thereby reduce GHG-emissions. As shown through the literature review, the general recommendation from previous studies has been to extend the lifetime of laptops to reduce the environmental impacts, and the GHG-emissions in particular. The results from this study can confirm this recommendation, given that the lifetime extension-scenario gave a 20% reduction in GHG-emissions over a time-period of 12 years compared to the base-scenario. This result was also found in the study by Downes, Thomas, Dunkerley, & Bridge (2011b). The scenario model was sensitive to changes in the emissions from refurbishments, which thereby is a critical factor to consider when making the decision of whether or not to extend the lifetime of the laptop in a GHG-perspective.

6.2 Strengths and weaknesses

and One weakness of the scenario model is that it only considers GHG-emissions and not a wider range of environmental impacts. The economic aspects of a lifetime extension could also have been included to review also the potential monetary benefits for consumers and the society as a whole of avoiding pre-mature replacements of household goods which still can be used. On the other hand, the strength of the model is that it is built on readily available data, which makes it relatively easy to apply it to a wider range of products. For example, all of the products from Apple could be compared to see the environmental benefit of lifetime extension. This is further discussed under potential applications and suggestions for further research. The pros and cons of the method used for the consumer survey will now be discussed.

Collecting data in person instead of online can have several benefits. First of all, if you wish to limit your respondents within a geographical location, it can be hard to retrieve such a selection of the population online. My survey was limited to the population of Ås municipality, but not because I necessarily wanted to describe some characteristics in this population. It was rather because I valued the other aspects of performing the survey in-person. I was curious to meet people and see their reaction, and on several occasions the survey led to a small conversation afterwards were people expressed their interest in the topic and wanted to know more. I got a better sense of people's opinions on the topic which was useful for my understanding and analysis of the results.

Another benefit of the in-person format is that respondents have the possibility to ask for questions or if something is unclear. Collecting respondents in-person can also be both easier and more time effective. There is direct access to asking people without having to go through emails or other forms of online communication. Online survey can often cause a delay in the data gathering process. When using the in-person format you receive an immediate response. On the other hand, if one wishes to collect a large sample from a wider geographical area, the online format can be preferred. With a relatively small sample size collected, the possibility of a comprehensive statistical analysis was limited. With higher number of respondents, a chi-square could for example have tested if there was significant differences in for example environmental awareness among older and younger people. Perhaps a qualitative survey combined with in-depth interviews would have been optimal to capture both qualities.

6.3 Areas of application and further research

The primary purpose of this study was not primarily to confirm the findings from previous studies on the benefits of the lifetime extension strategy, but to produce results in a form which could be of use for consumers to compare alternative actions in a decision making process, for example through a website. To do this, the model must be further developed and tested on different products categories. Afterwards, a set of

general recommendations can be made for how to reduce the environmental impact on different product groups. Similarly to the proposition by Kwak (2016b), I propose building an online database connected to a website where consumers can search and review environmental impacts of specific products and the environmental and economic benefits of alternative actions in the use phase. The conceptual idea for such a website is briefly outlined in Appendix 2.

This database/website could also be integrated with other existing tools, such as online repair manuals (iFixit) and carbon footprint calculators (for example Oroeco). This can create a better experience for the consumer and enable them to control their personal carbon footprint more extensively than through the currently available calculators which are based mostly on yearly spending's, travel patterns, energy use and eating habits. No online platform with a searchable library was found where the lifecycle footprint of products or the environmental benefits of actions such as lifetime extension of products was found. Due to this, the actual value of making such information available will remain uncertain until certain. Further research is therefore needed to develop robust calculation methodologies and to test whether information actually actually can increase awareness and to stimulate to pro-environmental behaviour.

Finally, there is a need for international policies which demand environmental footprint reports from all products in a unified format and using the same calculation methods. A clear difference was found between two of the major laptop producers globally, Apple and Lenovo. The report from a MacBook Pro 13" was compared with a ThinkPad T460s, which is a machine of similar quality. The environmental reports where both fairly easy to locate online, but the presentation format from Apple was much more easily readable. With the use of graphs, pictures and short explanations, the user receives an overview of the environmental impact of the product. The environmental reports from Lenovo seemed more directed to the business market instead of the consumer market. The specific GHG-emissions of the Lenovo laptop was also not found in the report. EU is currently working to improve this issue with the Single Market for Green Products

Initiative, which aims to create common methods of environmental footprinting, both for products and organisations (EU, 2016).

6.4 Conclusions

This thesis has highlighted two important aspects regarding the environmental impacts of consumption. The scenario model confirmed the results from previous studies, that extending the lifetime a laptop brings environmental benefits, in the form of a potential overall reduction in global CO2-emissions when production- and replacement rate is lowered and substituted with an increase in repair and refurbishment, keeping products in use instead of premature replacement. The consumer survey brought three important insights regarding the awareness of the CO2-emissions from production of household goods: 1.respondents reported that these figures were surprising; 2. there was a high level of agreement on the statement that information on the CO2-emissions from production of household goods should be more available; 3.respondents gave indications that such information could influence future decisions in a pro-environmental direction.

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APPENDIX

Appendix 1 - Survey

Consumer survey. Put a cross in one of the fields.

Below you can see the greenhouse gas emissions (CO_2e) from production of some common household hoods. As a reference, a diesel car emits an average of 2025 kg CO_2 per year (15000 km * 135gCO_2/km).

: 1 - MacBook Pro 13-inches 	435 kg CO_2e
: 2 - 32-inches LCD TV 	319 kg CO_2e
: 3 - Jeans 	55 kg CO_2e

1. *To what extent do you agree or disagree with the following statements:*
    a. *The numbers above were surprising*

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know

a. *Information regarding the CO2-emissions from production of household goods should be more easily available.*

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know

2. *How likely or unlikely is it that more information regarding the CO2-emissions from production of household goods will influence the following:*

a. *Your choice of products in the future*

Very likely	Quite likely	Unsure	Unlikely	Very unlikely	Don't know

b. *Your motivation to repair household goods*

Very likely	Quite likely	Unsure	Unlikely	Very unlikely	Don't know

c. *Your motivation to purchase second-hand goods instead of new ones*

Very likely	Quite likely	Unsure	Unlikely	Very unlikely	Don't know

d. *Your motivation to look for products with lower greenhouse gas emissions.*

Very likely	Quite likely	Unsure	Unlikely	Very unlikely	Don't know

a. *Your environmental awareness in general*

Very likely	Quite likely	Unsure	Unlikely	Very unlikely	Don't know

3. *How often or seldom do you consider the environmental impact of products you buy or own?*

Always	Often	Occasionally	Rarely	Never	Don't know

1. *How often or seldom do you consider the lifecycle of a product?*

Always	Often	Occasionally	Rarely	Never	Don't know

2. *How often or seldom do you consider the greenhouse gas emissions from producing goods in the household?*

Always	Often	Occasionally	Rarely	Never	Don't know

3. *How important or unimportant do you think the following types of information will be to influence your environmental awareness of household goods?*

    a. *Greenhouse gas emissions from producing the goods*

Very important	Fairly important	Neutral	Unimportant	Very unimportant	Don't know

    b. *Amount of resources necessary to produce the goods*

Very important	Fairly important	Neutral	Unimportant	Very unimportant	Don't know

    c. *Working conditions to those producing the goods*

Very important	Fairly important	Neutral	Unimportant	Very unimportant	Don't know

4. *To what extent to you agree or disagree with the following statements*

    a. *What the individual does for the environment is important for the whole*

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know

a. *It's important to try to repair a product before you throw it away*

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know

a. *The act of repairing goods in the household is important to save the environment*

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know

Gender

Woman	
Man	

Age

< 25	
25-39	
40-59	
60-74	
75+	

What is your connection to Ås?

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I work here	
I live here	
Just visiting	

Write you email below to have a chance to win the toolset worth 399,-

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Answer from the competition will be given as soon as the survey is finished.

Thank you for your attention!

Appendix 2 - Conceptual sketch of webbased tool