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Analysis of Greenhouse Gas Emissions Related to Food: A Study of Two Cafeterias in the Danish Municipality of Lyngby-Taarbæk

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ANALYSIS OF GREENHOUSE GAS EMISSIONS RELATED TO FOOD: A STUDY OF TWO CAFETERIAS IN THE DANISH MUNICIPALITY OF LYNGBY-TAARBÆK

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Abstract

An important step in confronting climate change is assessing greenhouse gas emissions from everyday objects. Collaborating with the Science Shop, our team analyzed emissions associated with foods at the City Hall and Annex cafeterias in the Danish municipality of Lyngby-Taarbæk. Using life cycle assessment, we estimated emissions at 7.29 and 5.67 kgCO_2-eq/kg from the City Hall and Annex cafeterias, respectively. Analyzing ten recipes, we found an average 35.7% fewer emissions per unit mass from 'heart healthy' over traditional Danish recipes.

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Executive Summary

Many scientific sources have suggested that increasing levels of greenhouse gases in the Earth's atmosphere, caused by anthropogenic forcing factors, are leading to climatic warming trends all over the planet [1]. Continuance of these warming patterns could have devastating effects, including increased drought, food shortages, increasingly severe storm patterns, and mass coastal flooding as sea levels rise due to the melting of arctic ice [2]. Policies, such as the Kyoto Protocol, have been implemented to halt the impact of global climate change.

Every nation under the Kyoto Protocol has been given greenhouse gas (GHG) emission reduction goals to be met by 2012. Each country's reduction target is based on its emissions levels in the year 1990 [3]. Denmark, a country that was environmentally conscious long before the implementation of the Protocol, has been struggling to meet its objective. The nation has pledged to reduce emissions to 21% below the baseline, but current predictions assert that Denmark will still need to reduce by 18.8% of the baseline by 2010 [4]. To help meet this commitment, many community-based organizations have launched GHG reduction initiatives at the local level.

The Science Shop at the Technical University of Denmark is a non-government research group that has undertaken professional scientific analyses of GHG emissions, among many other civic projects, in communities across the globe. Our project stemmed from a comprehensive investigation of emissions in the municipality of Lyngby-Taarbæk initiated by the Science Shop. As associates of this organization for a seven-week period, we were tasked with examining GHG emissions connected with food served by the cafeterias in

the City Hall and Annex. The purpose of our research was to estimate the amount of food-related GHG emissions for each cafeteria and make recommendations as to how these emissions could be reduced.

To achieve our goals, we needed to determine applicable methods of GHG evaluation and reduction and employ them in our specific context. We discovered that, in general, reducing emissions could be achieved using various proven approaches, such as utilizing materials that require less energy during manufacture and use, conserving energy, restructuring transportation systems to be more eco-friendly, and switching to renewable energy sources. The most intriguing method of evaluation we found was life cycle assessment, where one considers all the energy inputs from every element of an item's production within the bounds of a defined system. These bounds are based on the scope of the analysis, and frequently include raw material production, manufacture, distribution, use, and disposal [5]. We realized that this type of assessment would allow us to calculate the GHG footprint of the food items served in the cafeterias, thus giving us a baseline from which to evaluate the effectiveness of our means of GHG reduction.

Based on this background research, we developed our own methodology to apply to the cafeterias. We outlined our approach by creating three goals to complete through our analysis. Our first goal was to determine the significant food products purchased at each cafeteria. Our second objective was to compute the associated greenhouse gas footprint of the significant food products. Our final objective was to compare the climatological impact of menu items prepared in differing manners.

Our first target was to determine which food products we wanted to consider in our analysis. We were given comprehensive lists of food purchases, spanning one year, for each cafeteria. Each inventory consisted of nearly one thousand items listed in Danish and included specifications for each item, such as stock number, count, count units (e.g., kilograms, cases, pieces, etc.), and cost. For our analysis, it was necessary to render each item in its mass equivalent. Since not all items were initially listed in kilograms, and because we would need to translate all the items we were considering into English, we chose to examine only sixty percent of the items, by mass and cost, from each inventory. By considering this percentage of items, we could focus on the intended analysis instead of spending valuable time translating and still obtain a reasonable approximation of the greenhouse gas footprint for the entirety of the inventories. We narrowed down the lists of food products to those 'significant' items for each cafeteria and moved on to the next stage of our analysis.

To evaluate the effectiveness of the GHG reduction methods we were to recommend, we first needed to establish an estimate of the amount of GHG emissions for each significant item and subsequently for the cafeterias overall. Due to time constraints, we could not possibly conduct our own life cycle assessment for all these items, so we chose to use the findings of a study that had already been conducted for a situation similar to ours. These findings came from a Swedish study conducted by Annika-Carlsson Kanyama, et al., in which the life cycle energy inputs were calculated for 150 food items consumed in Sweden [6]. We and our sponsor agreed that these data closely approximated that which we needed for the Danish foods we were considering, but because the study gave the energy consumed for each product, not the equivalent GHG emissions, we needed a way to convert the data to be useful to our GHG investigation.

We discovered a study completed by Carbon Neutral, an Australian based research group, in which the researcher, Brian Rose, determined an "embodied emissions factor for food" by calculating and weighing the average emissions associated with the life cycle energy inputs for food products, based on 90-95% of the energy being sourced from diesel fuel and 5-10% from Australian grid electricity [7]. We derived an emissions factor for Danish foods by calculating emissions per energy unit for diesel fuel and Danish grid electricity, using United States Environmental Agency figures and widely accepted thermodynamic properties for diesel fuel and Danish Energy Authority statistics for grid electricity. We found a value of 0.153 $^{kgCO_2\text{-eq}}/_{MJ}$ for diesel and 0.150 $^{kgCO_2\text{-eq}}/_{MJ}$ for Danish grid electricity. We were hesitant to use Rose's weighting since his study was conducted in an Australian context, but because the two values we calculated are nearly equal, we determined that little inaccuracy would be introduced by using his weighting in our investigation. Using 92.5% diesel and 7.5% Danish grid electricity, we determined our emissions factor to be 0.153 $^{kgCO_2\text{-eq}}/_{MJ}$. Finally, Rose gave values for food categories exhibiting a large amount of non-energy related emissions, such as methane and nitrous oxide associated with ruminant and some dairy products. With this information, we were able to adapt Carlsson-Kanyama's data to our estimate the GHG footprint of the food in each cafeteria.

We created spreadsheets of the cafeterias' inventories, our emissions factor, and the Carlsson-Kanyama figures to facilitate our analysis. Not all the food items we were examining were present in the Carlsson-Kanyama energy input data, so we took averages of each food category she considered and used these values to compute the emissions for those items. For each cafeteria, we calculated the net emissions of the significant items as well as emissions as measured by various metrics. We then made objective comparisons between the two eateries based on these findings as well as by comparison of the distributions of food types purchased. Sven Pedersen, the City Hall cafeteria manager, told us that on an average day, 225 people were served at the City Hall cafeteria and 270 people were served at the Annex. Although the Annex served 20% more people and thus had a 17.4% higher mass intake and 60.5% higher costs, its net emissions from significant items were 9.1% lower than those of the City Hall cafeteria. In emissions per cost, the Annex was 43.4% lower than the City Hall. Similarly, an average serving of food at the Annex had 23.4% less associated GHG emission than one served at the City Hall. Furthermore, the Annex had 22.6% lower emissions per kilogram of food.

Using the average percentage of mass and cost covered by our lists of significant items, we computed approximations for the total emissions of all foods purchased by each cafeteria. We estimated 7.29 $^{kgCO_2\text{-eq}}/_{kg}$ and 5.67 $^{kgCO_2\text{-eq}}/_{kg}$ for the amount of emissions associated with the entire food inventories for the City Hall and Annex, respectively. Based on all our methods of evaluation, it was evident that the Annex cafeteria had a smaller GHG footprint than the City Hall cafeteria.

To point out possible reasons for these differences in GHG emissions, we determined for each cafeteria the distribution of mass of significant foods between general food categories. The categories included fruits & vegetables; beef, pork, & chicken; breads & cereals; sugars, spices, oils, & fats; seafood; and eggs & dairy. We found that the City Hall cafeteria has a rather even distribution between major food categories with nearly a quarter of foods in the categories of sugars, spices, oils, & fats and eggs & dairy. On the other hand, these particular categories represented less than 10% of the Annex's intake, whereas fruit & vegetables and beef, pork, & chicken made up more than half of the cafeteria's foods. With the evaluation of each cafeteria's GHG footprint complete, we moved to possible GHG emission reduction methods.

We were given recipes for ten meals served at the cafeterias. However, each meal had two recipes, one for a traditional Danish preparation and one for a 'heart healthy' version which was served some weeks in lieu of the traditional offering. We wanted to determine if preparing a meal in a more 'heart healthy' way had an impact on the GHG emissions associated with it. Using the same methods as before, we calculated the emissions related to each ingredient and summed them for each meal prepared through the two different recipes. For every meal considered, the heart healthy offering had lower total emissions as well as emissions per kilogram than the same meal prepared traditionally. Overall, the ten traditional dishes totaled 428.85 kgCO_2-eq for 65.10 kg of food, while the heart healthy recipes summed to 262.49 kgCO2-eq for 62.82 kg of food. On average, the traditional recipes produced 6.71 $^{kgCO_2\text{-eq}}/_{kg}$ and the healthier recipes generated 4.32 kgCO2-eq/kg. This represents an average reduction in emissions of 35.6%. After inspecting the ingredients used in each recipe, it was clear that the source of this reduction was the 'heart healthy' recipes' inclusion of a smaller amount of high GHG emitting foods, such as red meat, dairy, and fats; and larger amount of low GHG emitting foods, such as fruits and vegetables. Thus, we were able to conclude that for the cafeterias to reduce their GHG footprint, they needed to serve less red meat, dairy, and fats; and more fruits and vegetables. The Annex cafeteria already had a smaller food-related GHG footprint than the City Hall cafeteria, but both could improve their emissions levels by making some adjustments in menu planning. Although it may take some persuasion and changing of attitudes to work, if they promoted the dual advantage of eating healthier as a means to improve one's own well-being as well as to help suppress the effects of climate change, perhaps more customers would show a preference toward these 'heart healthy' meals. As a result, the cafeterias could begin buying a smaller quantity of high GHG emitting foods and a larger quantity of low GHG emitting foods, thus leading each eatery to a smaller GHG footprint. We hope any economic strain caused by this transition will be supplemented with increased financial allowances made by policy makers after reviewing the environmental benefits we present through this project.

This study was conducted in the specific local context of a cafeteria, but the ideas and principles presented could easily be applied in any retail business setting. With the proper life cycle assessment and emissions data, the GHG footprint of the products making up any retailer's inventory could be determined. Then, with knowledge of how the retailer's products are used, different methods could be recommended to reduce these emissions, much like the way we were able to suggest the cafeterias to modify their menu plans to be more eco-friendly. Future research can be facilitated with the use of the Microsoft Excel workbook we created to assist our analysis and have included with this report. This tool can be dynamically updated to include any reference data found to be more suitable than that which we used in our investigation. We encourage any interested inquirers to view our workbook and continue to develop its validity and robustness, so that future studies may benefit from its use.

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Chapter 1

Introduction

The Earth's climate is changing across the globe. Fluctuations within a certain bound are natural and to be expected; however, a growing body of scientific evidence compiled by the Intergovernmental Panel on Climate Change (IPCC) indicates an undeniable warming trend in recent decades [1]. Should such warming trends persist, the impact to the climate could be dire. Drastic global climate change could devastate local ecosystems and pose a grave threat to humanity through increased drought, food shortages, increasingly severe storm patterns, and mass coastal flooding as melting arctic ice causes sea level to rise [2].

Trends in climate change are intrinsically linked with changes in the atmosphere. Concentrations of carbon dioxide (CO_2), methane (NH_4), and other greenhouse gases in the atmosphere now greatly exceed the natural range of the past 650,000 years [1]. Greenhouse gases (GHGs)[1] occur naturally in the atmosphere and, when at the appropriate concentration, play an integral role in maintaining a stable climate; however, when concentrations increase, the gases trap heat within the atmosphere, leading to warming beyond the desired norm [8]. This sharp rise in GHG concentrations in the atmosphere could be attributed to natural cycles. However, the current changes almost certainly derive from anthropogenic sources. Gases such as carbon dioxide are a byproduct of a staggering number of essential technologies, including everything relying upon energy from the burning of fossil fuels and natural gas [1].

[1] "Greenhouse gas" and "greenhouse gases" will henceforth be abbreviated as "GHG" and "GHGs" respectively.

The need to reduce GHG emissions is now receiving international attention, and policies such as the Kyoto Protocol are paving the way for meaningful change. The Kyoto Protocol establishes targets based on nations' baseline GHG emissions in the year 1990 [3]. In this way the protocol is focused on progress, not overall GHG production, putting already environmentally active countries, such as Denmark, in an especially difficult position. Since the country had already taken progressive steps to reduce GHG emissions prior to the protocol, the nation's targets are exceptionally low and Denmark is not projected to meet its emission requirements. Denmark is currently estimated to overshoot its target, resulting in an emissions level that is above the nation's Kyoto obligation by 18.8% of the 1990 baseline[4]. In addition to the obvious environmental concerns, this overshoot will likely have substantial economic consequences due to Kyoto Protocol enforcement. Therefore, it is imperative that Denmark work to reduce its GHG output as much as possible to minimize these ecological and consequent financial impacts.

Over the past few years, many Danish communities have begun a variety of 'green', or environmentally-minded, initiatives in hopes of reducing their collective GHG footprint through measures taken at the local level. The framework for these local efforts have been derived from national "energy action" plans, such as "Energy21," which have set targets of as high as fifty percent CO_2 emission reduction by 2030 [9]. However, years of studies have shown even the best-laid energy action proposals to be ineffective without organizations working to encourage individuals to take measures to reduce their personal mark on the environment [10]. For an issue as widespread as this, many local areas have turned to public organizations for assistance. These groups serve as a voice for the community and work to address civic concerns, like local greenhouse gas emissions, typically free of charge. Some are subsidized by the government, but many are non-government organizations.

The Science Shop at the Technical University of Denmark (DTU) is an influential non-governmental organization in Denmark. This organization aims to link concerns of the public with the expertise of university backed scientific research [11]. While the Shop does not directly solve problems, it does offer inquiring parties the privilege of access to scientists and researchers from the university, for no profit [12]. This group has established a major environmental initiative in the municipality of Lyngby-Taarbæk, the town where the Science Shop at DTU is located. The central inquiry is what local industries, homeowners and public institutions can do to help reduce the GHG footprint of the municipality. The initiative has taken into consideration many aspects of 'green' development in the community, including building codes, traffic planning, and renewable energy sources. Although the Science Shop has been working within this municipality for years, opportunities for reducing GHG emissions remain.

Our study represented a small component of the municipality's initiative to reduce GHG emissions. Particularly, we considered the GHG related to the operation of two cafeterias in the municipality of Lyngby-Taarbæk: those at the Lyngby City Hall and Annex. We focused upon the GHG emissions associated with the food served by the cafeterias. Using life cycle assessment data, which considers emissions from production, storage, and transport of products, we calculated the GHG footprints of each of the significant food items. Significant items were chosen from each cafeteria based upon a percentage of either cost or mass. We compared the two cafeterias based upon net emissions, emissions per capita, and emissions per kilogram of food purchased. The climatological impact of various menu items prepared through different recipes were also considered. Specifically, these comparisons considered whether foods prepared in a 'healthier' manner using more vegetables and less meat and fat would have a smaller environmental impact than a traditional preparation. Based upon these analyses, we made recommendations to the cafeterias indicating potential avenues for GHG reduction. Although our investigation focused on cafeterias, our methods and conclusions have implications beyond this specific local context.

Chapter 2

Background

When approaching the matter of reducing GHG emissions in Lyngby-Taarbæk's City Hall and Annex cafeterias, certain background information is needed to fully elucidate the importance of the task, as well as the challenges specific to this project. This chapter briefly reviews the historical and scientific context of climate change, the local issues that are pertinent to this project, the greenhouse gas reduction methods applicable to the cafeterias, and the concept of life cycle assessment which is a central feature of our research methods.

2.1 Climate Change

The Earth's climate represents "the average state of the atmosphere and the underlying land or water, on time scales of seasons and longer" [13]. This average state is determined by a number of factors such as temperature, humidity, winds, and precipitation and may be considered with respect to both a local and global scale [13]. Climate change describes a period in which these factors are in flux; when the energy balance of the Earth is shifted due to the influences of various perturbations which may derive from external forces such as "changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties" [1] as well as internal feedback loops spurred by these external changes [13].

These external forcing factors do not solely regulate the Earth's climate; natural fluctuations in climate occur "in the absence of any change in forcing, just as weather fluctuates from day to day" [13]. It is therefore important to distinguish such oscillations from those arising from external forcing such as anthropogenic, or human-related, stimuli. It is impossible to precisely determine the extent of natural climate fluctuation due to an incomplete history of the Earth's climate. However, a variety of sources do still suggest with high certainty that temperatures over the past half-century have been higher than "any other 50-year period in the last 500 years and likely the highest in at least the past 1,300 years" [1]. This evidence leads to the conclusion that the current warming trend is not indicative of normal climate fluctuations, but rather due to some external forcing factor.

As described previously, a number of forcing factors could lead to current climate trends. However, the Intergovernmental Panel on Climate Change (IPCC), a committee created by the United Nations and World Meteorological Organization to assess scientific data on climate change [8], has reached consensus that current fluctuations are a derivative of human actions: "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" [1]. Greenhouse gases, which include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor (H_2O), ozone (O_3), and the chlorofluorocarbons, are characterized primarily by their ability to absorb infrared radiation and their presence in the Earth's atmosphere [13]. Carbon dioxide is considered "the most important anthropogenic greenhouse gas" [1] and is produced by burning of fossil fuels, wood, and natural gas [13]. The extensive reliance on such energy sources has led to a sharp and continuous rise in carbon dioxide concentrations in the atmosphere since the Industrial Revolution, with levels rising 17% (from 315 ppmv[1] to 370 ppmv) between 1958 and 2000 [13]. Both this concentration of carbon dioxide, along with the concentrations

[1]Parts per million by volume

of methane (1774 ppb[2] in 2005) and other GHGs far exceed the natural range of the last 650,000 years (which ranged from 180-300 ppm for carbon dioxide and 320-790 ppb for methane) [1]. Concentrations of carbon dioxide over the past thirty years are illustrated in Figure 2.1. The excess concentration of these GHGs is a clear climate forcing element just as inescapable as the evidence that climate change is a very real concern [1].

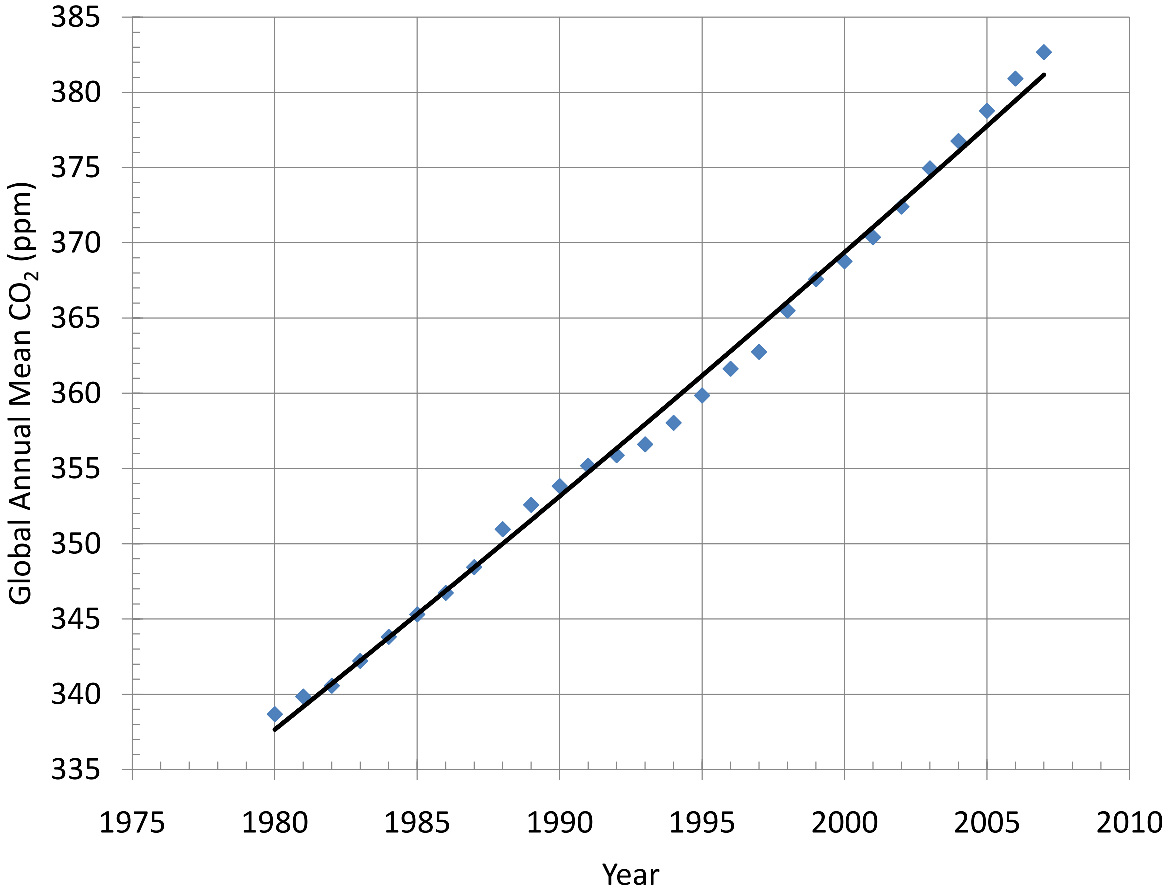


Figure 2.1: Plot of globally averaged marine surface annual mean concentrations of CO_2 from Dr. Pieter Tans, NOAA/ESRL [14].

2.1.1 Kyoto Protocol

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" [1]. The effects of global climate change are

[2]Parts per million (ppm) and parts per billion (ppb)

equally undeniable, with the IPCC compiling a number of demonstrable impacts that include the increase in glacial lakes, earlier occurrence of leafing, migrations, egg-laying, and other spring events, increased drought in certain regions, and rising sea levels [2]. Evidence such as this, put forth by the First Assessment Report of the IPCC, spurred the development of the initial treaties intended to counter climate change on an international level. These early efforts culminated in the adoption of the United Nations Framework Convention on Climate Change on 9 May 1992 [8]. Those nations that have agreed to the treaty, known as Parties to the Convention, hold annual conferences "to foster and monitor [the Convention's] implementation and continue negotiations on how best to tackle climate change" [8]. At the first conference, the Parties recognized that a more rigid set of commitments for industrialized nations would be necessary to have any recognizable impact on curbing GHG emissions and the effects climate change. This realization led to the adoption of the Kyoto Protocol in December of 1997 as an "extension to the Convention that outlined legally binding commitments to emissions cuts" [8].

The Kyoto Protocol pledges industrialized nations, known through the Protocol as Annex I, to overall reduction of GHGs by "at least 5 per cent below 1990 levels in the commitment period 2008 to 2012" [3]. The Protocol makes a number of provisions to ease the economic burden of emission reduction and encourage Non-Annex I nations, developing countries that have ratified the Protocol, to take steps toward developing sustainable infrastructure. Reduction goals may be met through any of three methods including direct emission cuts, trading of emission assigned amount units (AAUs), and development of carbon sinks such as changes in land use practice and reforestation [3]. The Protocol also establishes a clean development mechanism (CDM) to encourage sustainable development of non-industrialized developing countries. Through the CDM, Annex I nations may fund renewable infrastructure development, forestation projects, and other initiatives that result in a net GHG emission reduction in Non-Annex I nations and, upon approval of the program, receive carbon emission credits equivalent to the reduction in the developing country [3]. In this manner, an Annex I nation receives assistance in meeting its own pledged emission rates, and a Non-Annex I nation is encouraged to develop in a manner that shall have a more positive long-term environmental impact.

In addition to programs such as the CDM and emissions trading schema, the Kyoto Protocol also makes allowances for nations to act jointly in the pursuit of their collective emission goals [3]. The fifteen states forming the European Union at the adoption of the Protocol have pledged to meet their emission goals under such a joint agreement [8]. The European Community as a whole has pledged to reduce emissions to 92% of 1990 rates (an 8% reduction compared to the 5% standard reduction) by 2012 [3]. However, as a joint entity, the European Union is free to internally distribute emission reductions goals between member states to produce a net reduction of 8% below 1990 levels across the entire community. Denmark has pledged to reduce emissions to 21% below 1990 levels. Based upon 2007 estimates, this represents a reduction of 14.5 $MtCO_2$-eq[3] from 1990 baseline values to a goal of 54.8 $MtCO_2$-eq [4]. As of 2005, Denmark has achieved a reduction of GHG emissions to 7% below 1990 levels (9.8% below 1990 levels when the effects of land-use, land-use change, and forestry are considered) [15]. However, Denmark's emissions as projected for 2010 will still be above the Kyoto target by 18.8% of the 1990 baseline (i.e., 2.2% below the 1990 baseline) [4]. Denmark has clearly taken an active role in GHG reduction for the European Union; however, extensive reductions are still necessary to achieve the 2012 goals.

2.2 A Local Response to Greenhouse Gas Reduction

As previously described, the main cause of excess greenhouse gas emissions is the increased reliance of the citizens of developed countries on technologies that cause the release of emissions into the atmosphere. With emission reduction targets established for

[3]Megatonne of CO_2-equivalent gas—which represents the concentration of CO_2 required to cause the same radiative forcing as a given concentration of another GHG.

Denmark under the Kyoto Protocol, the nation has focused on reducing emissions at the community level. However, the expenses associated with scientifically related research endeavors of this magnitude often exceed local budgetary constraints [11]. To alleviate this potentially significant financial burden, many local communities and businesses, such as the City Hall and Annex cafeterias in Lyngby-Taarbæk, have turned to community-based, non-profit organizations for help evaluating methods to reduce their GHG footprint.

One group that has been acclaimed for its success in solving practical problems such as this is the International Science Shop Network (ISSNET). This network of university and private research groups has been providing communities across Europe cost-effective ways to address problems of science and society for nearly four decades [11]. Currently, the Science Shop at the Technical University of Denmark is implementing a series of 'green,' or environmentally-minded, initiatives in the community of Lyngby-Taarbæk, the municipality in which the university is located. We will be working within this initiative to develop a green solution for the City Hall and Annex cafeterias.

2.2.1 The Concept of Science Shops

Science shops are originally European-based institutions, set up to bring scientific resources to communities looking for answers to problems of all kinds. Officially, a science shop is classified as "a unit that provides independent, participatory research support in response to concerns experienced by civil society" [11]. The main objectives of these shops, as outlined by ISSNET, are to "help improve people's quality of life through research; provide an affordable service; promote and support public access to [and] influence on science and technology; [and] enhance understanding of civil society among policy-makers and the scientific community" [11]. Science shops are distinguished by certain features. Some are linked to universities, while others serve as independent non-government organizations [11]. Many shops offer original, expert research themselves, and some operate simply as liaisons between public and scientific communities. Typical subjects of research include social science, physics, engineering, chemistry, and biology [11].

The idea started in the 1970s when a few Dutch chemistry students began helping those with little financial background to seek solutions to scientific problems [11]. Their goal was to have schools, students, and faculty more involved in municipal affairs and to provide public interest groups access to scientific resources [11]. Soon, Science Shops were created at every university in the Netherlands; and by 1990, nearly 40 shops had been set up in the country [11]. The idea caught on, and today there are science shops in more than a dozen countries, including Austria, Belgium, Denmark, France, Germany, Romania, Spain, and the United Kingdom [11]. The idea has also spread to countries outside of Europe, such as Canada, Israel, and the United States [11].

As new shops are established, the original concept has been modified to suit "local conditions and needs," in order to customize services based on the specific characteristics of the community in which the Shop is located [11]. This is important for the issue of local GHG emissions because every municipality is structured differently. Having local access to expert research pertaining to the topics we are investigating will be helpful because similar projects will provide us with relevant data for our project. As part of our investigation, we are examining past and present projects related to GHGs and food, including research carried out by the Science Shop at the Technical University of Denmark.

The increased emergence of science shops indicates that they have established a distinct means by which to fulfill the public demand for science-based information. Moreover, since the issues tasked to science shops will likely affect the lives of many, if not all, members of a community, the solutions arrived at "cut across social, disciplinary and gender divides" [11]. This will be especially true in the City Hall cafeteria setting because this is a place where people of many different backgrounds come together. Municipal officials, city hall employees, and local residents are all common patrons of the cafeterias, so our solution will need to cater to the preferences of all these people. Overall, science shops have provided a “very cost-effective method of giving society access to research” [11]. Understanding the overall mission of this organization gives a broad sense of what we can expect of the Science Shop in Lyngby-Taarbæk and what to strive for as associates of this group.

Even though science shops have adapted to the locations wherein they operate, they all work to serve the community for no financial gain. Their services are typically free, although some shops charge small fees to help cover expenses [11]. Costs are reduced by relying heavily on volunteer work. Students make up a majority of the researchers, particularly at science shops associated with colleges. In fact, students participate in nearly 70 percent of all science shop research [11]. At many schools, students can receive course credits for their work with science shops [11]. Beyond course credits, however, science shops provide “an invaluable stepping stone from unskilled student to someone who can design, manage and complete a piece of research,” according to Andy Kirkcaldy of Interchange, a Liverpool-based research affiliation [11].

A unique aspect of science shops is their “bottom-up approach” for conveying information [11]. This means that their answers are constructed using the distinct characteristics of the problem as a foundation. The solutions they provide are rooted in community involvement. When a societal issue is presented, they help the inquirer develop what research will be needed, and then work with the inquirer to effectively fill that gap in knowledge. When a research request is initiated, the shop first attempts to find what information already exists on the subject. If there is a need for more information, research will then be performed either directly by the science shop or through other organizations linked to it. The ISSNET provides a way of transferring “information and expertise between science shops” [11]. The results of an inquiry are presented as a culmination of new discoveries and relevant material from past studies, from which the shop will then help the inquirer use in the most effective ways [11]. In our project, the inquirer is the City Hall cafeteria system.

Through their continued efforts to bring knowledge to society, science shops have gained support from local, regional, and national governments. Maria van der Hoeven, Dutch Minister of Education, Culture and Science believes that science shops have aided in the development of democracy, claiming that "by supporting citizens in their quest for knowledge, people are given more possibilities to take responsibility for shaping their own life and their living environment" [11]. Local authorities have increasingly supported the shops, as many see them as useful tools for developing solutions to problems under their jurisdiction [11]. Moreover, many believe organizations like science shops encourage the integration of science into everyday life [11].

2.2.2 The Science Shop at the Technical University of Denmark

The Science Shop at the Technical University of Denmark (DTU) was established in 1985 and was the first science shop set up in the country [12]. Since then, two other Danish shops have been created, one at Roskilde University and another at the University of Copenhagen [11]. Echoing the overall mission of the ISSNET, the Science Shop at DTU was formed with the purpose of connecting citizens and community groups with university research resources that would not otherwise be available to the public. Through these connections, the shop creates interdisciplinary courses and research opportunities for students to investigate so that at the end of the project they can report useful information back to the client.

Topics addressed by this Shop typically relate to the intertwining realms of environment and society. As director of the DTU shop and supervisor of our project, Professor Michael Jørgensen points out, "the knowledge needs of the clients fall typically within the analyses of social and environmental problems experienced by citizens, and analyses and further development of citizens' initiatives for better social welfare and a more sustainable development" [11]. This is directly related to our project in that we were working to fulfill the informational requests of Lyngby-Taarbæk's City Hall cafeteria in hopes of advancing the local GHG reduction initiative, thus working toward environmental sustainability.

Some specific subjects addressed by the Science Shop at DTU have included urban ecology, handicap equipment, organic food production, city and traffic planning, sustainable energy, outdoor environment, and working environment. Requests for information regarding these topics come from "non-profit organizations, organizations concerned with external environment and energy, housing movements, consumer organizations, handicap organizations, and local trade unions" [12]. During its first ten years of operation, over two hundred projects were completed [12]. Currently, the Science Shop at DTU is in the process of implementing a variety of green initiatives in Lyngby-Taarbæk involving building codes, traffic planning, renewable energy sources, and other related areas. Our cafeteria project is just one section of this overarching research initiative that has been going on in the municipality for a few years.

One example of a successful endeavor undertaken by the shop was a collaborative effort with the Copenhagen Energy and Environment Centre (CEEC). Since the year 2000, three research projects have been initiated to examine local waste separation [11]. The CEEC's waste management consultant, Jørgen Martinus, was very pleased with the results, particularly with the "valuable feedback about how the waste separation works in practice and how it can be improved" [11]. This example illustrates the organization's concept of bringing science to the community to help solve civic issues. By using the DTU shop to its full advantage, the team hopes the cafeteria investigation will be met with the same level of success that the waste management project achieved.

As with many science shops across Europe, a majority of the research at the DTU shop is completed by students for course credits. The shop is funded by the university, but it is not financial support that is most cherished at this facility. According to Professor Jørgensen, the shop's most important quality is the "time which the students and their supervisors contribute" [11]. This statement evinces the altruistic component of science shops in general, perhaps suggesting why this organization has been regarded so highly. It also further validates that science shops are a community-oriented group that provides advice citizens can trust. This has great implications for our GHG inquiry because working within an already respected institution helps encourage our client to endorse the research and recommendations we make.

2.2.3 The Municipality of Lyngby-Taarbæk

Our project is part of a larger program being undertaken in the municipality where the Science Shop is located. We now turn to a discussion of the physical composition and societal structure of Lyngby-Taarbæk.

The municipality is located just north of Copenhagen on the island of Zealand. The mayor of Lyngby-Taarbæk, Rolf Aagaard-Svendsen, describes the community as "privileged," with "commercial, industrial, university, green residential, cultural and recreational" aspects [16]. The town is a major retail center of the region in which its shopping center and department stores meld with its quaint surroundings to form a unique commercial setting for a variety of large and small businesses [16]. As previously described, the presence of the Technical University of Denmark within the community has made the area a hub for technical research and education. Housing for the 51,000 residents of Lyngby is provided in 'green' communal areas which consist of single-family homes, terraced houses, and apartment buildings [16]. Aside from commercial and residential areas, more than half of the municipality is made up of fields, wooded areas, lakes, and a river. This description illustrates that the community is already environmentally-minded.

The political culture and local government of Lyngby-Taarbæk is characterized by the promotion of social welfare and sustainability in the community [16]. The City Council consists of 21 members, who are responsible for the election of the mayor and vice-mayor, as well as the appointment of members of the town's political committees. Both the council and the committees hold monthly meetings that are always open to the public. The structure of Lyngby's government consists of 11 committees and 4 town departments. The groups that are important to this project are the Local Planning Committee, Town Planning Committee, Environment Committee and Technical Committee, as well as the Technical and Environmental Department [16]. These are the authorities that would most closely deal with the effects of climate change in the community and local business, such as the City Hall cafeteria.

Among other duties, these particular committees and departments are responsible for environmental considerations for the town [16]. An overall town plan is revised every four years, with other community initiatives being established when necessary. Regulations are set in place to keep the relative number of single houses, flats, offices, and other types of buildings in balance [16]. Moreover, the Environment Committee develops environmental laws and makes certain that companies abide by them. Cooperation between businesses and the committee encourage ecological improvements for commercial establishments, which in turn helps Lyngby stay environmentally sound [16]. It is apparent that the environment is an important focus of the municipality's administration. The town government is inherently aware of environmental issues and is set up to address these problems when they arise.

We have described climate change and how the Science Shop can provide resources to address this issue in the cafeterias of Lyngby-Taarbæk's City Hall. Next, we will present GHG reduction strategies to be implemented in a local context, with particular focus on methods applicable to our project.

2.3 Greenhouse Gas Reduction Methods

The problem of GHG emissions is incontrovertibly coupled to humanity's need for energy and the reliance on GHG emitting solutions for its acquisition. It follows that any viable plan for reducing GHG emissions must address this fundamental need for energy. Thus, reduction methods can be broken down into energy conservation, increased use of renewable energy sources, and carbon offsetting. Taking generally accepted reduction methods and relating them specifically to the case of the Lyngby-Taarbæk City Hall cafeteria system was the main challenge of the project. The following sections outline primary sectors of GHG emission and applicable reduction methods in the context of a public cafeteria.

2.3.1 Energy Conservation

Energy conservation is one of the main focuses of our study, as it is both cost effective and practical. The primary goal of energy conservation is clear and simple; by using less energy, the current infrastructure can provide for more people. In the long term, this reduces the need to build additional GHG-emitting infrastructure. Energy conservation covers a wide variety of specific reduction methods that range from community level education to wide scale policy changes. Energy conservation can be as simple as teaching people to turn off lights or lower their heat, but compounded over an entire population it can make an enormous difference in energy use, and subsequently, GHG emissions. In the context of the City Hall and Annex cafeterias, energy conservation methods and public education will play a pivotal role in making 'green' dining halls.

Identifying the primary areas for GHG reduction in the eateries makes up the basis of this project; however, there are many general areas to consider for energy conservation prior to any substantial analysis. Cafeterias use energy in the form of electricity, water, and food so any conservation policies will emphasize these resources. Electricity is wasted in lighting, kitchen appliances, and food heating apparatus. Water is wasted both in food preparation and dish washing. The efficiency of food can be improved both by using foods with a lower GHG footprint and reducing wasted food. A thorough analysis of current dining hall operations and practices is important for developing a clear policy.

2.3.2 Transportation

Automobile traffic makes up a large portion of GHG emissions in most developed countries of the world. In Denmark CO_2 emissions from traffic in 2006 accounted for more than 30% of Denmark's overall CO_2 emissions for that year (this is comparable to the US with transportation making up 32% of overall emissions [17]). Emissions of CO_2 due to traffic rose over 27% between 1990 and 2006 while most other emission sources were falling [18]. From the data it is clear that GHG emissions from transportation remain an important area for Denmark to address. Emissions come from both commuters and the transportation of goods so both facets of the problem will be addressed when looking at the City Hall cafeteria.

2.3.3 Renewable Energy

Obtaining a reliable source of energy is absolutely vital to any developed nation; unfortunately, economics and availability lead many nations to non-renewable GHG emitting energy sources such as coal and oil. Denmark has been very progressive in this regard, investing heavily in wind energy. As of 2006, over 15.8% of Denmark's total energy consumption was derived from renewable energy sources [18]. Denmark has taken a place as a world leader in renewable energy and set itself up as a viable example for other nations to follow.

2.3.4 Carbon Offsetting and Emissions Trading

Due to practical and technological constraints it is often impossible for individuals or businesses to attain true carbon neutrality. Even with aggressive environmental policies

GHG emissions cannot always be eliminated; however, the growing industry of carbon offsetting is helping to alleviate this problem. A company or individual that desires to become carbon neutral can pay a carbon offsetting company to reduce GHG emissions in some other way essentially offsetting their own GHG output. Carbon offsetting companies invest in a variety of projects such as renewable energies, increasing energy efficiency, reforestation, and waste management depending largely on geographic area [19]. Carbon offsetting has become increasingly popular with both businesses and consumers alike. Even some events have opted to offset their carbon emissions; some notable examples include the FIFA World Cup and the Oscars Ceremony [19]. "In 2005, the international market [of carbon offsetting] was on the order of US$10bn - tripling in 2006 to US$30bn" [20]. Carbon offsetting is a potential factor in a plan for GHG reduction at the Lyngby-Taarbæk cafeteria. Even after a complete analysis it may still be impossible or impractical for the cafeteria to become completely carbon neutral. The growing industry of carbon offsetting represents a viable component to carbon reduction and should not be overlooked when considering an effective GHG reduction plan.

2.4 Life Cycle Assessment

In order to formulate a policy of GHG emission reduction in Lyngby-Taarbæk's City Hall cafeteria it is first important to acquire a clear understanding of the cafeteria's possible environmental impacts. By analyzing the complete GHG emissions of an item a common means of comparison can be established, allowing for a more informed decision to be made. Such an analysis is known as a life cycle assessment (LCA), which acts as "a holistic yardstick of the environmental performance of products and services" [5]. A complete LCA takes into account energy inputs from every element of an item's production within the bounds of a defined system. The boundaries of this system are usually defined based upon the scope of the assessment, and often include raw material production, manufacture, distribution, use, and disposal. Figure 2.2 depicts an elementary example of an LCA system through the stages of ‘cradle’ to ‘table’.

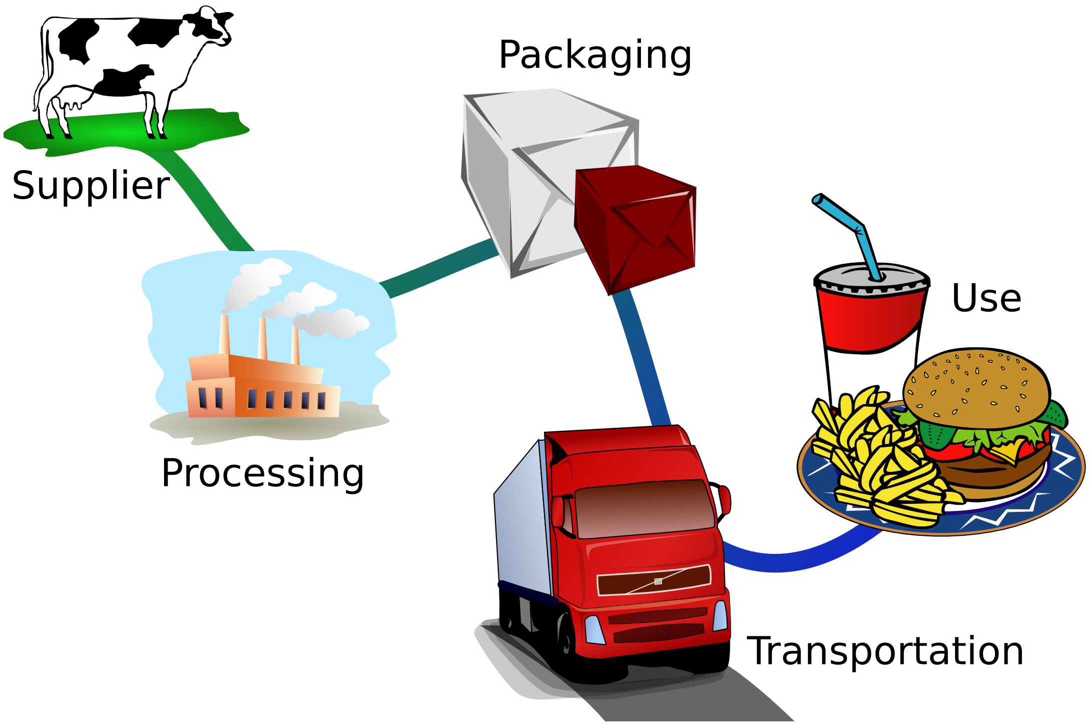


Figure 2.2: Illustration of cradle to table life cycle assessment system. (Image created by Derek Eggiman using open source images.)

When considering the results of an LCA study with regards to a product’s impact on climate change, it is usually desirable to measure this impact in GHG emissions, not energy input. These emissions are customarily measured in CO_2 equivalent gases (CO_2-eq), which represent the concentration of carbon dioxide required to cause the same amount of radiative forcing as a given concentration of another greenhouse gas (e.g., methane, fluorocarbons, and nitrous oxide). Energy data is rendered in comparable emissions through use of a conversion factor representing local energy use practices. In the background for his comprehensive GHG calculator, Rose described this conversion term as an “embodied emissions factor for food”. Rose defined embodied emissions as “the sum of the greenhouse gasses emitted in the combustion of fossil fuels in all aspects of production, including electricity, upstream fuel emissions and machinery depreciation, together with other GHG emissions such as methane and nitrous oxides that may be emitted as a result of production processes." Embodied emissions are divided between energy from combustion engines (e.g., during transit) and from grid electricity (e.g., during storage and processing). For Rose's study, which considered Australian foods, the emissions factor was "consistent with 90-95% of the energy being sourced from diesel [fuel] (0.08 [kgCO_2-eq/MJ]) and about 5-10% from Australian grid electricity (0.0308 [kgCO_2-eq/MJ])" [7]. This factor has units of concentration of CO_2 equivalent gas per unit energy (e.g., kgCO_2-eq/MJ).

The GHG emissions associated with the production of various food products will be important in analyzing the cafeteria and a thorough LCA is particularly important for such cases. Many LCA of food products consider only the energy consumption throughout the life cycle. However, a study by Annika Carlsson-Kanyama in 1998 of various foods consumed in Sweden determined that the non-energy related GHGs can in fact represent a significant proportion of a food's GHG emissions. Furthermore, reduction methods aimed at such other GHGs can be considerably more effective than methods that only consider improvement of energy usage in transportation [21]. When precise LCA data are not available, these non-energy related emissions can be generalized for the food categories having significant emissions of this form. These categories are milks (dairy and soy), red meats (lamb and other ruminants, except beef), dairy (cheese, butter, cream and milk powders) and beef [7]. These emissions can be substantial, thus it is important to ensure that the LCA system is sufficient in scope and detail to include all such factors.

2.5 Background Summary

Climate change is a mounting global issue. A wealth of scientific data indicates that worldwide temperatures are indeed rising, and that the cause is almost certainly rapidly increasing levels of anthropogenic greenhouse gases in the atmosphere. Global initiatives such as the Kyoto Protocol have spurred developed nations to work towards reducing their emissions while such global initiatives have encouraged organizations, such as the

Science Shops, to take action on a local level. There exist a number of different methods that can be utilized to reduce GHG emissions, ranging from switching to renewable energy sources, to restructuring transportation and considering the life cycle emissions of foods to adopt more eco-friendly diets. This plethora of reduction methods, combined with a very real need to consider the issue, has resulted in a challenging situation for local organizations and businesses that are seeking to reduce their GHG footprint. We will now introduce the methods we used to address this issue in the specific context of a cafeteria.

Chapter 3

Methodology

This project investigates the relations between GHG emissions and trends in food consumption and menu planning for a cafeteria. Particularly, we considered two cafeterias in the Danish municipality of Lyngby-Taarbæk: those at the Lyngby City Hall and the nearby Annex. Three objectives were outlined to conduct this analysis:

1. To determine the significant food products purchased at each cafeteria.

2. To compute the associated greenhouse gas footprint of the significant food products.

3. To compare the climatological impact of menu items prepared in differing manners.

The methods implemented in completing these objectives are detailed in the following sections.

3.1 Significant Food Products

We collected lists of food purchases over a period of roughly one year from both the Lyngby City Hall and Annex cafeterias. Each cafeteria's list consisted of approximately one thousand individual products and contained information such as item count, item units, and total cost in Danish kroner. Additionally, all items were labeled in Danish, necessitating that we translate them for effective analysis. We compiled data from these lists into spreadsheets for ease of management.

Because of time constraints, it would be impractical for us to consider the entirety of the aggregated lists; therefore, the data were sorted to consider only the significant food products from each list. However, as units of counting were not consistent over all food items (e.g., many items being recorded per 'piece' or 'crate' rather than kilogram) and price data were also unavailable for others, we approximated the most significant items through considering both price and mass. We determined that a number of items not listed by mass were labeled with a description of mass, and thus these items were converted to kilograms prior to sorting. For each cafeteria, we compiled lists of items that made up the sum-total of 60% of the cafeteria's total expenditures on food and lists of items that constituted the sum-total of 60% of the cafeteria's total mass intake. These two lists were then merged to produce a single list of significant items for each cafeteria. As a result of this process, the list of significant items represented the sum-totals of at least 60% of cost and mass. We and Professor Jørgensen of the Science Shop felt this percentage would yield a reasonable number of items from which to approximate the overall emissions of all the items listed. Moreover, this percentage allowed us to complete our analysis more efficiently as it limited the number of items we needed to translate. Items having neither price nor mass data were disregarded at this stage of analysis.

With lists of the food products purchased by each cafeteria narrowed down to only those items forming a majority of each cafeteria's consumption, more detailed analysis of greenhouse gas (GHG) footprints for each item and both cafeterias in total could be conducted.

3.2 Greenhouse Gas Footprints of Food Products

The GHG impact of each of the significant food products used by either cafeteria was determined through the principles of Life Cycle Assessment (see Section 2.4). Due to constraints upon both our resources and time we could not conduct our own assessment of these items and thus used existing data. Our data were based on the research of Annika

Carlsson-Kanyama into the life cycle energy inputs of 150 foods consumed in Sweden [6]. Although this study considered a Swedish perspective, we and Professor Jørgensen of the Science Shop determined that the results could be used to approximate a Danish context. Denmark and Sweden are very close geographically, thus locally produced foods have similar energy inputs from farming practices (which vary by climate) and imported foods have comparable transportation distances. Furthermore, the Carlsson-Kanyama considered only life cycle energy inputs for foods, not the GHG emissions associated with this energy use. Therefore, we were able to calculate an embodied emissions factor (see Section 2.4) specific to Denmark and apply this conversion factor to the Carlsson-Kanyama data.

As a model for calculating a Danish embodied emission factor, we used the methods suggested by Rose's GHG-Energy Calculator [7]. Although Rose's study applied to Australian foods, we determined that his overall distribution of energy sources were applicable to Denmark and our cafeteria study because these values would not be significantly dependent on location. Our embodied emissions factor was calculated with an energy distribution of 92.5% diesel fuel and 7.5% Danish grid electricity. For diesel fuel we calculated an emissions factor of 0.153 $^{kgCO_2\text{-}eq}/_{MJ}$ while for Danish grid electricity, we determined an emissions factor of 0.150 $^{kgCO_2\text{-}eq}/_{MJ}$. We calculated our total embodied emissions factor as 0.153 $^{kgCO_2\text{-}eq}/_{MJ}$. Refer to Appendix A for a complete consideration of these calculations.

When conducting a thorough LCA of food products, it is important to also consider non-energy related sources of emissions (e.g., natural greenhouse gas emissions from livestock). Employing methods suggested by Rose's study, we approximated for these emissions with a constant factor added to food groups associated with such emissions. Specifically, we added 0.700 $kgCO_2$-eq/kg for milks (dairy and soy), 6.4 $kgCO_2$-eq/kg for red meats (lamb and other ruminants, except beef) and dairy (cheese, butter, cream and milk powders), and 9 $kgCO_2$-eq/kg beef [7]. These last adjustments put the Carlsson-Kanyama data in a form which we were readily able to apply to our research.

To facilitate the application of our LCA data, we translated all significant items to English and rendered them in a standardized form. We standardized the units for each food product to kilograms. As previously noted, many items were measured in a non-standard fashion (e.g., 'items' of fruit) and thus approximations were necessary. The conversion factors for these units were determined through calculation of average mass per unit (e.g., the average mass of an 'item' of banana) and estimation of masses by cafeteria staff for products without a clear indicator of size (e.g., 'cases' of tomatoes). With all food products labeled in an understandable fashion and measured in a consistent manner, LCA data could be applied to the lists of significant items.

To determine the GHG footprint associated with each food product, we grouped significant items into categories that could be cross-referenced with LCA data indicating the number of kilograms of CO_2-equivalent gases (kgCO_2-eq) emitted per kilogram of food during production, storage, and transport. Categories were dictated by available LCA data (refer to Appendix B for a complete list). To account for items for which data was not present, we calculated averages of each broad food group (e.g., 'beef', 'dairy, cheese', 'cereals'). These averages are preceded by an asterisk (*) to denote that they are our own entries. We matched food items as closely as possible, making generalizations on specific details where necessary (e.g., 'pickled shrimp' is categorized 'shrimp, without shells, Sweden'). Food items which could not be categorized, but clearly belonged to a broad food group were categorized by the average of that group (e.g., 'asparagus' is categorized '*vegetable, average'). Items which could not be categorized by either of these methods were disregarded from further consideration. When multiple source locations were present for LCA categories, food items were assumed to originate in Sweden (and thus by our initial assumptions, Denmark) unless another source location was apparent.

Emission rates per kilogram, as determined from LCA categories, were multiplied by the number of kilograms of the given food purchased by the cafeteria to determine the total GHG footprint of that product for the year in consideration. We then summed over the entire list of significant food products to determine an estimate of each cafeteria's total GHG footprint from food usage for the given year. To accurately compare the GHG footprint of the two cafeterias, it was necessary to adjust for usage, as the Lyngby City Hall and Annex each have different levels of patronage. We divided each cafeteria's yearly GHG footprint by an estimate of the average number of patrons served daily at each cafeteria to determine a relative value describing the kilograms of CO_2-equivalent gases emitted per person served at each cafeteria over the duration of one year. A similar value was determined based upon the total mass of all significant items, giving the kilograms of CO_2-equivalent gases emitted per kilogram of food used.

3.3 Climatological Impact of Menu Planning

Having calculated the approximate GHG footprint associated with the food products purchased by the cafeterias, it was then necessary to consider methods through which these GHG emissions could be reduced. When considering food products, these reductions originate primarily through menu planning and the types of foods served. Making such reductions requires using lower quantities of food with a high GHG footprint and greater quantities of those with a smaller footprint. Naturally this change results in an alteration in menu, and such a change must be palatable to the patrons if the reduction is to have a minimal socio-economic impact. With this in mind, we considered the difference in GHG footprint for similar menu items prepared through different recipes.

The cafeterias we studied occasionally had weeks with altered menus where food was prepared to incorporate more vegetables or to be 'heart-healthy' by using less meat and fat. As the cafeteria already had alternative recipes prepared for these occasions, we compared the GHG footprint associated with the alternative meals as compared to a similar dish prepared in a traditional Danish fashion. We collected pairs of recipes for ten different dishes for comparison. The various recipes listed quantities of ingredients, many of which we had already determined corresponding values of CO_2-equivalent gas emitted per kilogram of food. For the few items that had not been previously considered significant enough to calculate GHG footprints, we determined an associated footprint using the same methods described in Section 3.2. With these values calculated, we determined the total GHG footprint for each recipe by summing the contributions from each ingredient. GHG footprints associated with these differing preparations of menu items could then be directly compared based upon these calculated values.

Chapter 4

Results and Analysis

4.1 Analysis of Greenhouse Gas Footprint

In this section we present the results of our GHG footprint calculations for both the City Hall and Annex cafeterias. For each cafeteria, net emissions of the significant items as well as emissions as measured by various metrics are considered. We then make objective comparisons between the two eateries based upon these figures as well as by comparison of the distributions of food types purchased.

Based upon our methods outlined in Chapter 3, we calculated the net emissions of all significant items from each cafeteria. Additionally, we determined the net mass and cost of these items. The results of these calculations are summarized in Table 4.1, which compares the results from both the City Hall and Annex cafeterias. Based upon an estimate by Sven Pedersen, the City Hall cafeteria manager, we also determined an average number of patrons served daily at each cafeteria, with the City Hall cafeteria serving roughly 225 people while the Annex served roughly 270 people daily. Although the Annex cafeteria served 20% more people and thus had a 17.4% higher mass intake and 60.5% higher costs, its net emissions from significant items were 9.1% lower than those of the City Hall cafeteria.

To allow for better comparison between the two cafeterias, we calculated the emissions from each as measured against various metrics. We determined emissions per mass and cost based upon our calculated net totals for these values. Emissions per serving were

Table 4.1: Summary of net sums of significant items for emissions ($kgCO_2$-eq), mass (kg), and cost (DKK) for the City Hall and Annex cafeterias.

	City Hall	Annex	Units
Net Emissions	74148.23	67381.39	$kgCO_2$-eq
Net Mass	11153.87	13089.42	kg
Net Cost	229,678.32	368,700.60	DKK

based upon average daily patronage. We assumed that each patron would consume a single 'serving' and multiplied the average daily patronage by the number of weekdays in a year (260) to approximate the number of servings sold each year. These results are summarized by Table 4.2. The Annex cafeteria had lower emissions than the City Hall cafeteria across all three metrics. Due to its high operating costs, the Annex was very efficient in emissions per cost with a value 43.4% lower than that of the City Hall. Likewise, the average serving of food at the Annex had an associated GHG emission 23.4% lower than the average serving at the City Hall cafeteria. The average GHG emission per kilogram of food used by the Annex was similarly 22.6% lower than that used by the City Hall.

Table 4.2: Summary of emissions data per unit mass ($kgCO_2\text{-eq}/kg$), cost ($kgCO_2\text{-eq}/DKK$), and serving ($kgCO_2\text{-eq}/meal$) for the City Hall and Annex cafeterias. Data are based upon the net totals from significant items. Servings based upon average patronage over one year.

Emissions	City Hall	Annex	Units
per Mass	6.65	5.15	$kgCO_2$-eq/kg
per Cost	0.323	0.183	$kgCO_2$-eq/DKK
per Serving	1.27	0.96	$kgCO_2$-eq/serving

The majority of our analysis has considered only those significant items that were considered by our study. However, we can estimate values for the total emissions from both cafeterias by adjusting for the percentage of items considered. This percentage was determined as the average percentage of mass and cost covered by our list of significant items. In this manner, we estimated the total emissions to be 120175.87 $kgCO_2$-eq and

103827.74 $kgCO_2$-eq for the City Hall and Annex respectively. Likewise, estimated values for total emissions per mass were 7.29 $^{kgCO_2\text{-eq}}/_{kg}$ and 5.67 $^{kgCO_2\text{-eq}}/_{kg}$ for the City Hall and Annex respectively. These values for emissions per mass are illustrated by Fig. 4.1, which compares the results from these estimated totals to the original values calculated from lists of significant items. The emissions per mass calculated from estimated totals increased by 9.6% for the City Hall cafeteria and 10.2% for the Annex from the original values.

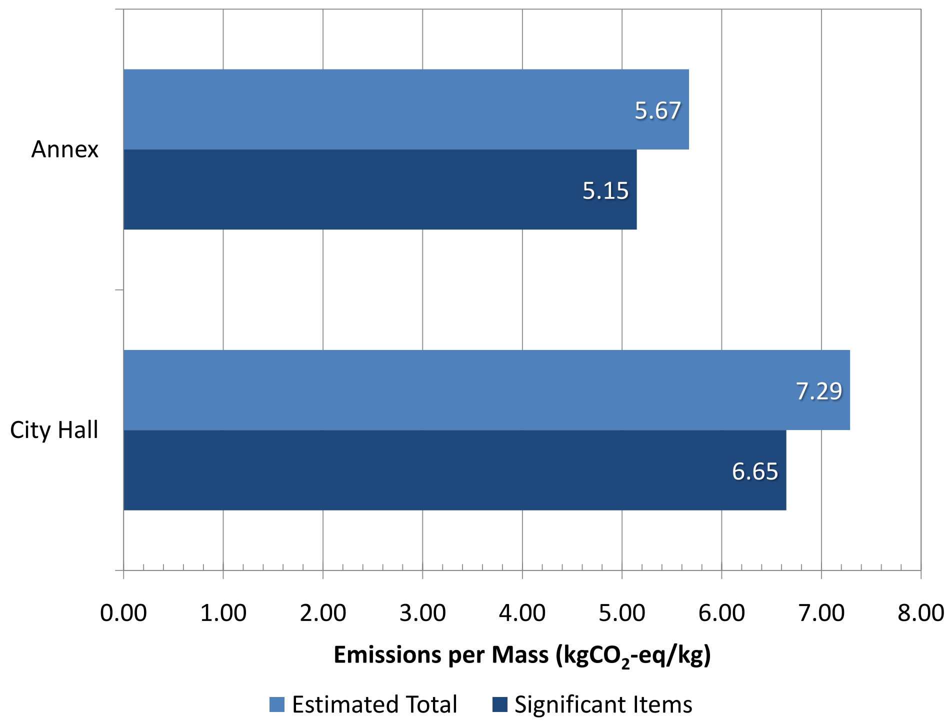
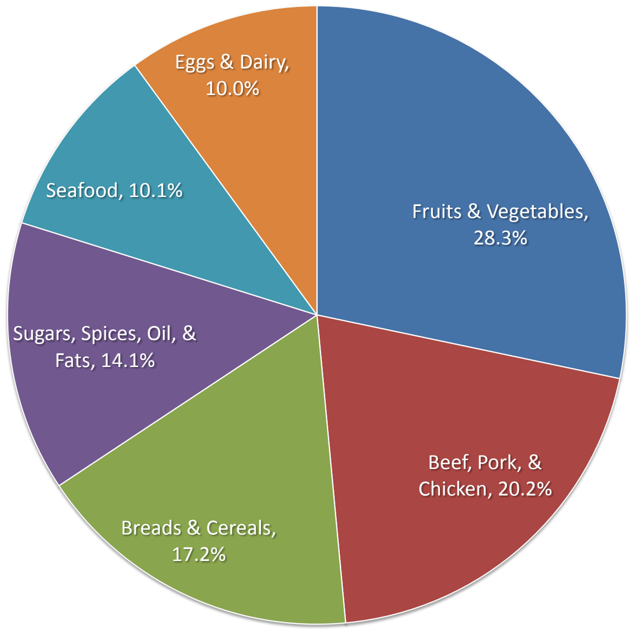
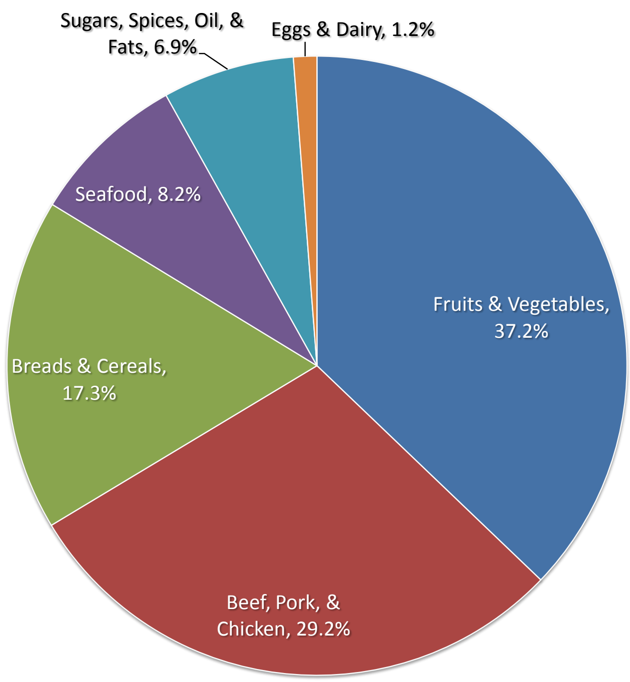


Figure 4.1: Plot comparing emissions per mass ($^{kgCO_2\text{-eq}}/_{kg}$) measured over all significant food products and as estimated over the entire inventory from the City Hall and Annex cafeterias.

To highlight causes for the difference in emissions rates between the City Hall and Annex cafeterias, we determined the distribution of mass of significant foods purchased by each cafeteria between general food categories. The results of this breakdown are illustrated in Fig. 4.2, which divides foods into the categories of fruit & vegetables; beef, pork, & chicken; breads & cereals; sugars, spices, oil, & fats; seafood; and eggs & dairy. The City Hall cafeteria has a fairly homogeneous distribution of foods with



(a) City Hall



(b) Annex

Figure 4.2: Chart displaying the relative distribution of purchases between food categories at the City Hall and Annex cafeterias. Calculations are based upon the significant food products considered.

almost a quarter of foods in the categories of sugars, spices, oils, & fats and eggs & dairy. In contrast, these groups represent a minority of the Annex's intake (less than 10%), while fruit & vegetables and beef, pork, & chicken combined make up more than half the cafeteria's foods. For a complete breakdown into individual categories refer to Appendix C.

4.2 Recipe Comparison

To explore possible ways to reduce the greenhouse gas footprint of the City Hall and Annex cafeterias, we considered the impact of alterations in menu planning and types of food served. We did this by comparing the GHG emissions produced by preparing similar menu selections through different recipes. Specifically, we wanted to determine whether the 'heart healthy' recipes had a lower GHG footprint than the same meals prepared in a traditional Danish manner. The results of our calculations are shown in Fig. 4.3. The bar chart shows comparisons of the GHG emissions (in kilograms of CO_2-equivalent gas per kilogram of food used in each recipe) produced by preparing each meal with either the traditional or 'heart healthy' recipe.

The traditionally prepared stew used 5.72 kg of ingredients and produced 45.86 kgCO_2-eq (8.02 $^{kgCO_2\text{-eq}}/_{kg}$), while the healthier version used 2.92 kg and generated 22.37 kgCO_2-eq (7.66 $^{kgCO_2\text{-eq}}/_{kg}$). The heart healthy recipe used 1 kg of beef and no margarine, whereas the traditional version used double the beef and 200 g of margarine. These ingredients were the highest GHG contributors present in either recipe, and as a result of preparing the stew more healthily, there was a 4.49% reduction in emissions per mass.

A larger reduction, 41.7%, was found for veal, chiefly because the traditional recipe called for 3 kg of beef and 200 ml of cream while the heart healthy recipe used only 1 kg beef and no cream. The traditional veal used 7.10 kg and produced 55.71 kgCO_2-eq (7.85 $^{kgCO_2\text{-eq}}/_{kg}$). The healthy veal used 8.05 kg and emitted 36.86 kgCO2-eq (4.58 $^{kgCO_2\text{-eq}}/_{kg}$).

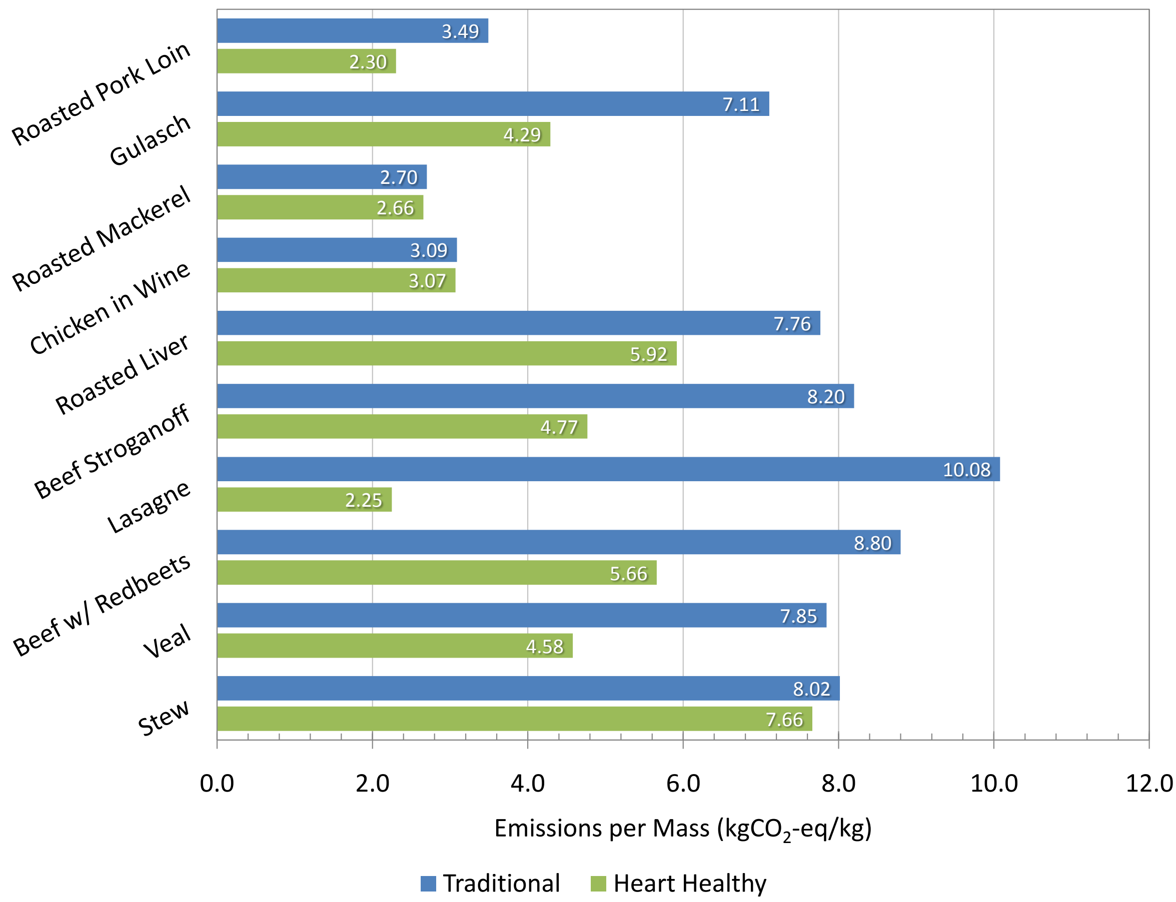


Figure 4.3: Plot comparing emissions per mass, measured in $^{kgCO_2\text{-eq}}/_{kg}$, between meals prepared with traditional Danish and heart healthy recipes.

A reduction of 35.7% was found by preparing beef with red beets more healthily, mainly because it included 1.2 kg less beef products and 2 kg more vegetables. Traditional beef with red beets produced 60.10 kgCO_2-eq for 6.83 kg of food (8.80 $^{kgCO_2\text{-eq}}/_{kg}$), whereas the healthier recipe generated 42.67 kgCO_2-eq for 7.54 kg (5.66 $^{kgCO_2\text{-eq}}/_{kg}$).

Lasagne offered the largest reduction of all the meals we considered, as the emissions went from 10.08 $^{kgCO_2\text{-eq}}/_{kg}$ for the traditional recipe to 2.25 $^{kgCO_2\text{-eq}}/_{kg}$ for the healthier recipe, a 77.7% reduction in emissions per mass. This was a result of completely leaving out meat products and using 2.6 kg more vegetables in the healthy preparation. The total emissions were 49.13 kgCO_2-eq for the traditional lasagne, which called for 4.88 kg of ingredients, and 14.24 kgCO2-eq for the healthier offering, which used 6.33 kg of food.

It is clear that the ingredients used in the healthy recipe had a remarkable effect on the amount of emissions the meal produced.

The traditional and heart healthy recipes for beef stroganoff were comparable in weight (6.2 kg for traditional and 6.6 kg for healthy), but the healthy version used 1.8 kg of red meat, dairy, and fats and 4.8 kg of vegetables and other low GHG contributing ingredients, whereas the traditional recipe used 3.3 kg and 2.9 kg, respectively. The emissions per mass were reduced 41.8% by using the healthy recipe. Overall, the traditional option produced 50.84 kgCO_2-eq (8.20 kgCO_2-eq/kg), while the healthier version made only 31.46 kgCO_2-eq (4.77 kgCO_2-eq/kg).

Similarly, roasted liver contributed 23.7% less emissions per mass by preparing it more healthily. This was a result of using 1.14 kg less of high GHG producing ingredients and 900 g more of low GHG producing ingredients. In total, the traditional roasted liver gave off 56.33 kgCO_2-eq using 7.26 kg of food (7.76 kgCO_2-eq/kg), whereas the healthier alternative emitted 41.53 kgCO_2-eq using 7.02 kg of food (5.92 kgCO_2-eq/kg).

There was not a noticeable reduction in emissions per mass between the traditional and healthy recipes for both chicken in wine and roasted mackerel (less than 1.5% each). However, these meals were exceptionally low in emissions per mass. This was because both meals' traditional recipes already contained low GHG contributors (chicken and mackerel, respectively) as main ingredients. Chicken in wine varied from 24.56 kgCO_2-eq for 7.95 kg (3.09 kgCO_2-eq/kg) for the traditional recipe to 16.02 kgCO_2-eq for 5.22 kg (3.07 kgCO_2-eq/kg) for the healthier version. Traditional roasted mackerel gave off 14.23 kgCO_2-eq for 5.27 kg (2.70 kgCO_2-eq/kg) while healthy roasted mackerel generated 9.94 kgCO_2-eq for 3.75 kg (2.66 kgCO_2-eq/kg).

Using half the amount of beef in the healthy goulash preparation was the overwhelming cause of the 39.7% reduction in emissions per mass for that meal. Although the recipes were similar in mass, 6.40 kg for traditional and 6.00 kg for healthy, their emissions varied from 45.49 $kgCO_2$-eq (7.11 $^{kgCO_2\text{-}eq}/_{kg}$) to 25.74 $kgCO_2$-eq (4.29 $^{kgCO_2\text{-}eq}/_{kg}$), respectively.

The higher amount of fruits and vegetables and lower amount of meat present in the healthy recipe for roasted pork loin the lead to a 34.1% reduction in emissions per mass. The traditional recipe produced a total of 26.20 $kgCO_2$-eq using 7.5 kg of ingredients (3.49 $^{kgCO_2\text{-}eq}/_{kg}$), while the healthier alternative generated 21.65 $kgCO_2$-eq using 9.40 kg of ingredients (2.30 $^{kgCO_2\text{-}eq}/_{kg}$). We found pork produces relatively low GHG emissions in general, which explains why both recipes exhibited low overall emissions.

A summary of this recipe comparison is shown in Appendix D. In terms of overall emissions, the ten traditional recipes totaled 428.85 $kgCO_2$-eq for 65.10 kg of food, and the healthy ones summed to 262.49 $kgCO_2$-eq for 62.82 kg of food. On average, the traditional recipes produced 6.71 $^{kgCO_2\text{-}eq}/_{kg}$, while the healthy recipes produced 4.32 $^{kgCO_2\text{-}eq}/_{kg}$. This is an average emissions reduction of 35.6%.

4.3 Sources of Error

We are confident that our analysis was performed in the most accurate way possible, given the data provided. Still we were forced to make many approximations and several assumptions over the course of this analysis. Therefore, it is important to note that our results are susceptible to several potential sources of error that occur throughout the process.

4.3.1 Procurement Data

Because of the incompleteness of the procurement data provided from the cafeterias and our time constraints, which were due in large part to the language barrier, we were unable to take into account all the approximately two thousand items purchased by both cafeterias. As a result, we truncated the lists as described in our methodology, thus allowing us to focus our analysis on the most significant items from each cafeteria.Great efforts were made to ensure that sufficiently significant portions of items were analyzed; however, this truncation is still a notable source of potential error. Fortunately, the error introduced by the truncation should have minimal impact on our comparison of the City Hall and Annex cafeterias, since any error introduced would be reflected in both lists.

4.3.2 Limited Life Cycle Assessment Data

The success and accuracy of any GHG analysis relies heavily on the on the accuracy and consistency of the initial LCA data used. Life Cycle Assessment data is highly dependent on relative location, climate, and numerous other factors; thus, the importance of using data from the Scandinavian region was paramount. Unfortunately, we were unable to locate a reliable and comprehensive source of data including analysis of Danish food products by associated emissions of CO_2-equivalent gases. We settled on a Swedish LCA study by Annika Carlsson-Kanyama [6]. Due to Sweden's geographical proximity to Denmark, we determined that this study could closely approximate a Danish LCA of food products. However, this assumption introduces a potential source for error. The study does not differentiate between energy usage from transportation and other sources, thus we could not compensate for expected differences in transportation distance. However, we determined these deviations to be minor and inconsequential given our objective to make general approximations of GHG footprints.

The Carlsson-Kanyama study presented a relatively comprehensive list of fundamental foods in terms of energy per mass. To effectively make use of the data, we needed to convert the data to units of $kgCO_2$-eq per mass, as described in the methodology. This conversion introduces a relatively significant source of potential error as the process required several critical assumptions. In the calculation of our emissions factor we made use of the mass of CO_2-eq emissions per energy production for Danish grid electricity and diesel fuel usage. These values were calculated directly from established figures and any associated error is minimal and made inconsequential by our other approximations. Our final embodied emissions factor is constructed from a weighted sum of these two values taking 7.5% and 92.5% of electricity and diesel respectively. These weights were taken from an Australian GHG emission study [7]. The weights used in this calculation are of questionable accuracy and are a potential source of error in our analysis. However, any error introduced from these weights will influence only the magnitude of our emission totals, and will have limited effect on relative comparisons within our data. Furthermore, as our calculated emission factors for diesel and grid electricity differ by a factor of $\simeq 3\ {}^{\mathrm{gCO_2\text{-}eq}}/_{\mathrm{MJ}}$, this represents the maximum variance in our total embodied emission factor.

The task of pairing the LCA data with the cafeterias procurement lists presented a new source of error. Despite the relative comprehensiveness of the Carlsson-Kanyama study there were many items on the cafeteria procurement list that could not be paired with LCA data. To correct this problem we calculated average values for food categories from the LCA data (e.g., average vegetables) and paired those with the remaining items on the procurement lists. This step was unavoidable given the limited LCA data, but it does present a clear source of error. The error should have a limited effect on relative comparisons since the same methodology was used throughout the analysis.

Chapter 5

Conclusions and Recommendations

In our initial investigations, we were informed by Sven Pedersen, manager of the City Hall cafeteria, that the Annex consumed more fruits and vegetables and less traditional Danish foods (which are heavy in red meat, dairy, and fats) than the City Hall. Based upon this information, we expected to find lower emissions from the Annex than from the City Hall cafeteria. Our analysis confirmed this expectation, showing lower total emissions, as well as lower emissions as measured against mass, cost, and average serving from the Annex as compared to the City Hall cafeteria. This is in spite of the fact that the Annex had higher mass intake, costs, and patronage. Analysis of food distributions for each cafeteria likewise confirmed our initial expectations. The City Hall cafeteria had higher proportions of dairy and fats, while the Annex purchased more vegetables and chicken.

We based our hypothesis for the menu planning investigation on the results of our food inventory analysis. We theorized that the 'heart healthy' recipes would have a lower GHG footprint than the same meals prepared in a traditional manner because the healthier recipes included more fruits and vegetables and less red meat, dairy, and fats. After calculating the GHG emissions for each of the ten recipes prepared both ways, we were pleased to find that our initial supposition was valid. For every meal we considered, the emissions for the healthy recipe were lower than the traditional preparation.

Since different types of foods emit varying amounts of CO_2-equivalent gas per kilogram, it is clear that the results we obtained were explicitly due to differences in amounts and types of ingredients used in either recipe for each meal. Specifically, we confirmed that altering a recipe to use a smaller amount of high GHG emitting ingredients, such as red meat, dairy, and fats, and a larger amount of low GHG emitting ingredients, such as fruits and vegetables can considerably reduce a meal's greenhouse gas footprint.

Based on this conclusion, we can recommend to the cafeterias a viable means to reduce their GHG footprint. To achieve noticeable GHG emission reductions, the cafeterias should consider modifying their menu plans to incorporate more 'heart healthy' meals. Thus far, these meals have only been served on an occasional basis. We realize that serving these healthier meals more frequently may be unappealing, at least initially, because many people are not attracted to the idea of eating meals with less red meat, dairy, and fats and more fruits and vegetables. However, our conclusions may give customers a new reason to endorse our recommendations. By eating healthier, they will not only help their own well-being, they will also aid in the struggle to quell the effects of climate change. This is an especially interesting notion in an environmentally-minded country like Denmark, whose citizens generally support ideas relating to GHG emissions reduction.

We suggest the cafeterias begin offering a clear choice of either traditionally or healthily prepared meals every day instead of the current practice of intermittently serving only healthy meals. Along with promoting these meals as being not only greener in content but 'greener' in climatological impact, perhaps more and more customers will choose the healthier option. Eventually the meal plan could be set up to incorporate very few food choices that are known to produce high GHG emissions. Consequent with this transition in menu planning, the cafeteria food purchases would begin to have a lower climatological impact, thus leading the cafeterias to achieve their goal: a smaller GHG footprint. This movement to buying foods with lower related GHG emissions may cause economic strain due to varying food costs. However, we hope the environmental gains, which we have shown are possible by shifting to more eco-friendly food purchasing, will provide policy makers a reason to consider increasing financial allowances, if necessary, to facilitate this transition.

Our study, however, is not confined to the specific local context of a City Hall cafeteria. Our method of taking an inventory of goods and estimating the GHG emissions for the life cycle of each item in order to determine an overall level of GHG output can be applied to any retail business. Regardless of what the merchant sells, the principles would be the same. Our methodology proposes that given an inventory of products listing the masses of each, if one could find appropriate data for life cycle energy inputs and emissions conversion, one could then calculate the GHG footprint associated with these items. To determine ways of reducing this GHG footprint, one would have to investigate the context in which the goods are being used. In our project, we studied the effects of altering recipes to incorporate a larger quantity of ingredients with lower GHG emissions and a smaller quantity of ingredients with high emissions. This idea of exploring possible avenues for emissions reductions through modifying a business's retail strategy has a wide range of applications because every retail product we use has a life cycle associated with it, so no matter what product is being considered, there is always an opportunity to examine, and potentially improve, the GHG emissions associated with it.

An important outcome of this project was the creation of a Microsoft Excel workbook that can be used as a tool by the cafeteria managers, and researchers in general, to further analyze GHG footprints related to foods and other products. This workbook, which is described in Appendix E, was paramount to our analysis and contains all the data we used to arrive at our conclusions. It can be dynamically updated should any interested inquirer wish to further develop the analysis we have presented here. Due to limitations imposed by our reference data, there were several life cycle considerations we could not account for, such as the differences in emissions associated with buying foods locally or getting them imported and the effects of buying seasonal foods at various times of the year. The versatility of the workbook makes it easy for future researchers to update our findings based on more inclusive reference data. Through our study, we determined that the exact Danish food GHG emissions statistics we were looking for are either nonexistent or out of the reach of the everyday inquirer, so we encourage any interested party to use and develop the methods we have presented to further investigate this and any related subjects.

Finally, we would like to propose the inception of a new SI derivative unit for use in climate studies. As any researcher in the field undoubtedly knows, the kilogram of CO_2-equivalent gas ($kgCO_2$-eq) is an essential, yet cumbersome unit of measure. Therefore, we propose that this fundamental unit denoting the mass of gas having a radiative forcing factor equivalent to carbon dioxide be henceforth known as the Gore (G). The Gore shall be entirely equivalent to the kilogram of CO_2-equivalent gas (1 G = 1 $kgCO_2$-eq) and compatible with SI prefixes (e.g., 1,000,000 Gores = 1 mega-gore). We name it thusly in honor of Nobel laureate Albert Gore, Jr. for his contributions to the cause of halting global climate change.

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Appendix A

Embodied Emissions Factor

The embodied emission factor is a constant conversion factor to convert the life cycle analysis data from energy (MJ) to kilograms of CO_2-equivalent emissions (kgCO_2-eq). The conversion was made by summing the emissions from diesel fuel and the Danish energy grid with a weight given to each emissions factor, 92.5% and 7.5% respectively.

Our calculated emissions factor for diesel fuel was 0.153 $^{\text{kgCO}_2\text{-eq}}/_{\text{MJ}}$. This value is determined by dividing the emissions per volume of diesel by the energy density by volume of diesel. The energy density by volume is further multiplied by the thermal efficiency of an average commercial diesel engine to account for the inherent physical and theoretical inefficiency of the diesel cycle. For emissions per volume, we used a value determined by the United States Environmental Protection Agency of 10.1 $^{\text{kgCO}_2\text{-eq}}/_{\text{gal}}$ [22]. For energy density by volume, we used a widely accepted value of 38.833 $^{\text{MJ}}/_{\text{L}}$ [23]. Lastly, we used a value of 45% for the average thermal efficiency of heavy-duty commercial diesel engines [24]. This calculation is shown by Eq A.1 below.

$$\frac{\left(10.1\ ^{\text{kgCO}_2-\text{eq}}/_{\text{gal}}\right)\left(\frac{1}{3.79}\ ^{\text{gal}}/_{\text{L}}\right)}{\left(38.833\ ^{\text{MJ}}/_{\text{L}}\right)(0.45)} = 0.153\ ^{\text{kgCO}_2-\text{eq}}/_{\text{MJ}} \tag{A.1}$$

Our calculated emissions factor for Danish grid electricity was 0.150 $^{\text{kgCO}_2\text{-eq}}/_{\text{MJ}}$. This value was calculated based upon the emissions rate reported by the Danish Energy Authority in 2006 of 0.539 kgCO_2-eq per kilowatt-hour of electricity sold [18]. Unit conversion is shown by Eq A.2 below.

$$\left(0.539\ {}^{\mathrm{kgCO_2-eq}}\!/\!_{\mathrm{kWh}}\right)\left(\frac{1}{3.6}\ \frac{\mathrm{kWh}}{\mathrm{MJ}}\right) = 0.150\ {}^{\mathrm{kgCO_2-eq}}\!/\!_{\mathrm{MJ}} \tag{A.2}$$

As previously described, the total embodied emissions factor was calculated as the weighted sum of diesel fuel and grid electricity emission factors. Eq A.3 below shows the details of this calculation.

$$(0.925)\left(0.153\ {}^{\mathrm{kgCO_2}}\!/\!_{\mathrm{MJ}}\right) + (0.075)\left(0.150\ {}^{\mathrm{kgCO_2}}\!/\!_{\mathrm{MJ}}\right) = 0.153\ {}^{\mathrm{kgCO_2}}\!/\!_{\mathrm{MJ}} \tag{A.3}$$

The final emissions factor, calculated in Eq A.3, was 0.153 ${}^{\mathrm{kgCO_2\text{-}eq}}\!/\!_{\mathrm{MJ}}$.

Appendix B

Life Cycle Assessment Data

Here is presented a complete list of the life cycle assessment data used in this project. This data is summarized by Table B.1, which includes the LCA categories we used for analysis of food products, the emissions values, measured in units of $^{kgCO_2\text{-}eq}/_{kg}$, associated with these categories, as well as the intermediate values used in the calculations of these emissions values.

Categories, food specifications, and life cycle input data (measured in units of $^{MJ}/_{kg}$) are taken from the research of Annika Carlsson-Kanyama [6] with the exception of averages for each category, which we calculated independently. These entries are marked with an asterisk (*) to mark that we have added them to the table. Averages were computed using a standard arithmetic mean of all entries in a given category.

The emissions factor, measured in $^{kgCO_2\text{-}eq}/_{MJ}$, is used to convert the Carlsson-Kanyama data from megajoules to kilograms of CO_2-equivalent gas. This factor was calculated based upon GHG emissions rates from diesel fuel and Danish grid electricity. Refer to Appendix A for a complete description of the calculation used.

Finally, the Carlsson-Kanyama data was augmented by additional imputs, measured in $^{kgCO_2\text{-}eq}/_{kg}$, to approximate the effects of non-energy related GHG emissions associated with the production of food goods. These inputs, 0.7 for milks, 6.4 for red meat (except beef) and dairy, and 9 for beef, were obtained from Rose's GHG-Calculator [7].

Table B.1: List of life cycle assessment categories, their associated total emissions per unit mass, and the intermediate values used for calculation of totals. Life cycle inputs are measured in units of MJ/kg, the emission factor in units of $\mathrm{kgCO_2\text{-}eq}/\mathrm{MJ}$, both additional inputs and total emissions in units of $\mathrm{kgCO_2\text{-}eq}/\mathrm{kg}$.

Category	Food Specification	Life Cycle Input	Emission Factor	Additional Inputs	Total Emissions
Lamb	Lamb,fresh,Sweden,cooked	43	0.1525	6.4	12.96
	Lamb,frozen,Sweden,cooked	46	0.1525	6.4	13.41
	Lamb,frozen,overseas,cooked	52	0.1525	6.4	14.33
	Lamb sausage,fresh,Sweden,cooked	30	0.1525	6.4	10.97
	Lamb stew,Sweden,cooked	18	0.1525	6.4	9.14
	*lamb,average	-	-	-	12.16
Chicken	Chicken,fresh,Sweden,cooked	35	0.1525	0	5.34
	Chicken,frozen,Sweden,cooked	39	0.1525	0	5.95
	Chicken,frozen,Central Europe,cooked	41	0.1525	0	6.25
	Chicken sausage,fresh,Sweden,cooked	20	0.1525	0	3.05
	Chicken stew,cooked	13	0.1525	0	1.98
	*chicken,average	-	-	-	4.51
Pork	Pork,fresh,Sweden,cooked	40	0.1525	0	6.10
	Pork,frozen,Sweden,cooked	43	0.1525	0	6.56
	Pork,frozen,Central Europe,cooked	44	0.1525	0	6.71
	Pork sausage,fresh,Sweden,cooked	34	0.1525	0	5.18
	Pork stew,cooked	17	0.1525	0	2.59
	*pork,average	-	-	-	5.43
Beef	Beef,fresh,Sweden,cooked	70	0.1525	9	19.67
	Beef,frozen,Central Europe,cooked	75	0.1525	9	20.44
	Cow,fresh,Sweden,cooked	26	0.1525	9	12.96
	Beef stew,cooked	24	0.1525	9	12.66
	*beef,average	-	-	-	16.43

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Table B.1: (continued)

Category	Food Specification	Life Cycle Input	Emission Fact	Additional Inputs	Total Emissions
Fish & crustaceans	Cod,fresh,Sweden,cooked	105	0.1525	0	16.01
	Herring,fresh,Sweden,cooked	22	0.1525	0	3.35
	Mackerel,fresh,Sweden,cooked	37	0.1525	0	5.64
	Canned tuna,overseas	44	0.1525	0	6.71
	Salmon,farmed,Sweden,cooked	84	0.1525	0	12.81
	Clams,tinned,Sweden	19	0.1525	0	2.90
	Shrimps,without shells,Sweden	220	0.1525	0	33.54
	*seafood,average	-	-	-	11.57
Milk, cheese	Milk,Sweden,4% fat	5.9	0.1525	0.7	1.60
	Milk,Sweden,1.5% fat	5	0.1525	0.7	1.46
	Cream,Sweden,40% fat	19	0.1525	6.4	9.30
	Yoghurt,small pots,Sweden	11	0.1525	0	1.68
	Yoghurt,small pots,Central Europe	12	0.1525	0	1.83
	Cheese,Sweden	60	0.1525	6.4	15.55
	Cheese,Central Europe	64	0.1525	6.4	16.16
	Cheese,Southern Europe	65	0.1525	6.4	16.31
	Milk powder,Sweden	58	0.1525	6.4	15.24
	*dairy,average	-	-	-	8.79
Egg	Eggs,Sweden,cooked	18	0.1525	0	2.74
Legumes	Brown beans,Sweden,cooked	8.9	0.1525	0	1.36
	Yellow peas,Sweden,cooked	5	0.1525	0	0.76
	Soya beans,overseas,cooked	7.9	0.1525	0	1.20
	Brown beans,overseas,cooked	11	0.1525	0	1.68
	Beans,canned,overseas	20	0.1525	0	3.05
	Beans,canned,overseas	16	0.1525	0	2.44

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Table B.1: (continued)

Category	Food Specification	Life Cycle Input	Emission Fact	Additional Inputs	Total Emissions
	*legume,average	-	-	-	1.89
Sugar & candies	Sugar,Sweden	9.8	0.1525	0	1.49
	Honey,Sweden	1.3	0.1525	0	0.20
	Honey,overseas	5.6	0.1525	0	0.85
	Candies,Sweden	18	0.1525	0	2.74
	Chocolate,Central Europe	44	0.1525	0	6.71
	Chocolate,Sweden	43	0.1525	0	6.56
	Ice-cream,Central Europe	15	0.1525	0	2.29
	Ice-cream,Sweden	14	0.1525	0	2.13
	*sugars,average	-	-	-	2.87
Oil & fat	Rapeseed oil,Central Europe	15	0.1525	0	2.29
	Sun flower oil,overseas	20	0.1525	0	3.05
	Soya oil,overseas	14	0.1525	0	2.13
	Olive oil,Southern Europe	24	0.1525	0	3.66
	Butter,Sweden	40	0.1525	6.4	12.50
	Margarine,Sweden,80% fat	17	0.1525	0	2.59
	*oil/fat,average	-	-	-	4.37
Fruits	Apples,dried in the sun,overseas	18	0.1525	0	2.74
	Apples,dried with commercial energy,overseas	38	0.1525	0	5.79
	Apples,fresh,Central Europe	4.8	0.1525	0	0.73
	Apples,fresh,overseas	8.6	0.1525	0	1.31
	Apples,fresh,Sweden	3.5	0.1525	0	0.53
	Bananas,fresh,overseas	12	0.1525	0	1.83
	Cherries fresh,Central Europe	6.2	0.1525	0	0.95
	Cherries fresh,Sweden	5	0.1525	0	0.76

...

Table B.1: (continued)

Category	Food Specification	Life Cycle Input	Emission Fact	Additional Inputs	Total Emissions
	Cherries,fresh,overseas	9.6	0.1525	0	1.46
	Grapes,fresh,overseas	9.7	0.1525	0	1.48
	Grapes,fresh,Southern Europe	7.8	0.1525	0	1.19
	Oranges,fresh,overseas	9.4	0.1525	0	1.43
	Oranges,fresh,Southern Europe	6.8	0.1525	0	1.04
	Raisins,dried in the sun,overseas	23	0.1525	0	3.51
	Tropical fruit,canned,overseas	13	0.1525	0	1.98
	Tropical fruit,fresh,overseas by plane	115	0.1525	0	17.53
	*fruit,average	-	-	-	2.77
Vegetables	Broccoli,frozen,Europe,cooked	18	0.1525	0	2.74
	Broccoli,frozen,overseas,cooked	20	0.1525	0	3.05
	Carrots,canned,Central Europe	11	0.1525	0	1.68
	Carrots,canned,Sweden	8.1	0.1525	0	1.24
	Carrots,fresh,Central Europe	4	0.1525	0	0.61
	Carrots,fresh,Sweden	2.7	0.1525	0	0.41
	French fries,Sweden,cooked as four portions	30	0.1525	0	4.57
	French fries,Sweden,cooked as one portion	60	0.1525	0	9.15
	Olives,canned,Southern Europe	15	0.1525	0	2.29
	Peas,frozen,Central Europe,cooked	12	0.1525	0	1.83
	Peas,frozen,Sweden,cooked	10	0.1525	0	1.52
	Potatoes mashed powder,Sweden,cooked	5.6	0.1525	0	0.85
	Potatoes,Sweden,baked	29	0.1525	0	4.42
	Potatoes,Sweden,cooked	4.6	0.1525	0	0.70
	Tomato,fresh,Southern Europe	5.4	0.1525	0	0.82
	Tomatoes,canned,Southern Europe	14	0.1525	0	2.13
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Table B.1: (continued)

Category	Food Specification	Life Cycle Input	Emission Fact	Additional Inputs	Total Emissions
	Tomatoes,fresh,greenhouse,Sweden	66	0.1525	0	10.06
	Vegetables,canned,overseas	18	0.1525	0	2.74
	White cabbage,Central Europe	5.1	0.1525	0	0.78
	White cabbage,Sweden	3.7	0.1525	0	0.56
	*vegetable,average	-	-	-	2.61
Jam	Wild berry jam,factory in South Sweden,55% fruit	11	0.1525	0	1.68
	Wild berry jam,factory in South Sweden,45% fruit	11	0.1525	0	1.68
	Raspberry jam,factory in Northern Sweden,55% fruit	16	0.1525	0	2.44
	Raspberry jam,factory in Northern Sweden,45% fruit	16	0.1525	0	2.44
	*jam,average	-	-	-	2.06
Breakfast Cereals	Müsli with sun dried apples,Sweden	15	0.1525	0	2.29
	Müsli with sun dried raisins,Sweden	17	0.1525	0	2.59
	Oat flakes,Sweden	11	0.1525	0	1.68
	Oat flake porridge,Sweden,cooked	2.5	0.1525	0	0.38
	Baked cereal,Sweden	37	0.1525	0	5.64
	Baked cereal,Central Europe	38	0.1525	0	5.79
	*breakfast cereal,average	-	-	-	3.06
Berries	Raspberries,frozen,Central Europe	16	0.1525	0	2.44
	Raspberries,fresh,Central Europe	7.5	0.1525	0	1.14
	Blueberries,frozen,Central Europe	9	0.1525	0	1.37
	Blueberries,frozen,Sweden	7.8	0.1525	0	1.19
	Strawberries,fresh,Sweden	6.2	0.1525	0	0.95
	Strawberries,fresh,Southern Europe	8.6	0.1525	0	1.31
	Strawberries,fresh,Middle East,by plane	29	0.1525	0	4.42
	Strawberries,frozen,Central Europe	16	0.1525	0	2.44

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Table B.1: (continued)

Category	Food Specification	Life Cycle Input	Emission Fact	Additional Inputs	Total Emissions
	*berry,average	-	-	-	1.91
Cereals	Whole wheat,Sweden,cooked as one portion	4.4	0.1525	0	0.67
	Whole wheat,Sweden,cooked as four portions	2.9	0.1525	0	0.44
	Rice,overseas,cooked as one portion	7.4	0.1525	0	1.13
	Rice,overseas,cooked as four portions	6.1	0.1525	0	0.93
	Pasta,Sweden,cooked	6.8	0.1525	0	1.04
	Pasta,Southern Europe,cooked	7.5	0.1525	0	1.14
	Fresh pasta,Sweden,cooked	8.9	0.1525	0	1.36
	Barley,Sweden,cooked	2	0.1525	0	0.30
	Couscous,Central Europe,cooked on a hot plate	5.3	0.1525	0	0.81
	Couscous,Central Europe,cooked with a kettle	5.1	0.1525	0	0.78
	Rye flour,Sweden	5.2	0.1525	0	0.79
	Wheat flour,Sweden	5	0.1525	0	0.76
	*cereal,average	-	-	-	0.85
Bread & Pastries	Bread,fresh,local bakery	8.9	0.1525	0	1.36
	Bread,frozen,local bakery,12	0.05	0.1525	0	0.01
	Bread,fresh,bakery far away	9.7	0.1525	0	1.48
	Bread,frozen,bakery far away	13	0.1525	0	1.98
	Crispbread,Sweden	14	0.1525	0	2.13
	Sponge cake,Sweden,with butter	16	0.1525	0	2.44
	Sponge cake,Central Europe,with butter	19	0.1525	0	2.90
	Sweet bread,Sweden with butter	19	0.1525	0	2.90
	Sweet bread,Central Europe,with butter	21	0.1525	0	3.20
	Sweet bread,Sweden,with margarine	15	0.1525	0	2.29
	Sweet bread,Central Europe,with margarine	18	0.1525	0	2.74

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Table B.1: (continued)

Category	Food Specification	Life Cycle Input	Emission Fact	Additional Inputs	Total Emissions
	Biscuits,Sweden,with butter	23	0.1525	0	3.51
	Biscuits,Central Europe,with butter	26	0.1525	0	3.96
	Cream cake,Sweden	16	0.1525	0	2.44
	Apple cake,Sweden,with butter	18	0.1525	0	2.74
	Apple cake,Sweden,with margarine	14	0.1525	0	2.13
	*breads,average	-	-	-	2.39
Drinks	Soft Drinks,Sweden	5.9	0.1525	0	0.90
	Soft drinks,Central Europe	7.1	0.1525	0	1.08
	Wine,Southern Europe	12	0.1525	0	1.83
	Wine,overseas	14	0.1525	0	2.13
	Beer,Sweden	12	0.1525	0	1.83
	Water from tap	0	0.1525	0	0.00
	Water from bottle,Central Europe	2	0.1525	0	0.30
	Orange juice,overseas	10	0.1525	0	1.52
	Apple juice,Central Europe	7.1	0.1525	0	1.08
	*drinks,average	-	-	-	0.97
Spices	Herbal spice,Southern Europe,commercially dried	36	0.1525	0	5.49
	Herbal spice,Southern Europe,sun dried	16	0.1525	0	2.44
	Herbal spice,overseas,sun dried	23	0.1525	0	3.51
	*spice,average	-	-	-	3.81

Appendix C

Food Type Distribution Data

Table C.1: Distribution of significant food items into life cycle assessment categories by mass for City Hall and Annex cafeterias. Net mass of each category (kg) and percentage of total mass of all categories is given for all categories from each cafeteria.

	City Hall		Annex	
Category	Mass (kg)	Percentage	Mass (kg)	Percentage
Lamb	0.0	0.00%	0.0	0.00%
Chicken	240.3	2.15%	1466.0	11.20%
Pork	1418.0	12.71%	1654.6	12.64%
Beef	597.1	5.35%	703.9	5.38%
Seafood	1131.9	10.15%	1072.0	8.19%
Dairy	1048.0	9.40%	89.0	0.68%
Egg	70.5	0.63%	70.5	0.54%
Legumes	0.0	0.00%	0.0	0.00%
Sugars	390.4	3.50%	238.3	1.82%
Oil/Fat	1185.4	10.63%	653.6	4.99%
Fruits	540.7	4.85%	573.0	4.38%
Vegetables	2572.9	23.07%	4291.2	32.78%
Jam	0.0	0.00%	0.0	0.00%
Breakfast Cereals	0.0	0.00%	0.0	0.00%
Berries	43.0	0.39%	0.0	0.00%
Cereals	1383.0	12.40%	1905.0	14.55%
Breads	532.2	4.77%	364.4	2.78%
Drinks	0.0	0.00%	0.0	0.00%
Spices	0.4	0.00%	8.0	0.06%
Total	**11153.9**	**100.00%**	**13089.4**	**100.00%**

Appendix D

Recipe Emissions Data

Here are presented the results from our analysis of ten recipes prepared in a traditional Danish and 'heart healthy' manner. The methods employed in this study are discussed in Section 3.3, while an analysis of these results is given in Section 4.2. A summary of results is shown in Table D.1, which lists the average emissions per unit mass, net sum of emissions, and net sum of mass over all ten recipes prepared in either manner. Tables D.2 & D.3 presents a breakdown of results for each recipe as prepared in a traditional and 'heart healthy' manner, respectively. Specifically, these tables list the total emissions, mass, and emissions per unit mass for each recipe.

Table D.1: Comparison of average emissions per unit mass ($kgCO_2\text{-eq}/kg$) and net sums of emissions ($kgCO_2$-eq) and mass (kg) over all ten traditional Danish and 'heart healthy' recipes.

	Traditional	Heart Healthy	Units
Avg. Emissions per Mass:	6.71	4.32	($kgCO_2$-eq/kg)
Net Emissions:	428.45	262.49	($kgCO_2$-eq)
Net Mass:	65.10	62.82	(kg)

Table D.2: Summary of results from life cycle assessment on ten recipes prepared in a traditional Danish manner. Results include total emissions (kgCO_2-eq), total mass (kg), and emissions per unit mass (kgCO_2-eq/kg) for each recipe.

Recipe	Emissions (kgCO_2-eq)	Mass (kg)	Emissions per Mass (kgCO_2-eq/kg)
Stew	45.86	5.72	8.02
Veal	55.71	7.10	7.85
Beef w/ redbeets	60.10	6.83	8.80
Lasagne	49.13	4.88	10.08
Beef stroganoff	50.84	6.20	8.20
Roasted liver	56.33	7.26	7.76
Chicken in wine	24.56	7.95	3.09
Roasted mackerel	14.23	5.27	2.70
Gulasch	45.49	6.40	7.11
Roasted pork loin	26.20	7.50	3.49

Table D.3: Summary of results from life cycle assessment on ten recipes prepared in a 'heart healthy' manner. Results include total emissions (kgCO_2-eq), total mass (kg), and emissions per unit mass (kgCO_2-eq/kg) for each recipe.

Recipe	Emissions (kgCO_2-eq)	Mass (kg)	Emissions per Mass (kgCO_2-eq/kg)
Stew	22.37	2.92	7.66
Veal	36.86	8.05	4.58
Beef w/ redbeets	42.67	7.54	5.66
Vegetable lasagne	14.24	6.33	2.25
Beef stroganoff	31.46	6.60	4.77
Roasted liver	41.53	7.02	5.92
Chicken in wine	16.02	5.22	3.07
Roasted mackerel	9.94	3.75	2.66
Gulasch	25.74	6.00	4.29
Roasted pork loin	21.65	9.40	2.30

Appendix E

Excel Workbook

A major element of our project was the creation of a comprehensive Microsoft Excel workbook detailing the GHG emissions from the cafeterias. This tool allowed us to make our analysis of the cafeteria emissions, but more importantly will allow for future researchers to advance upon our findings given future data.

The file ghg-workbook.xlsx included with this report contains all the data used in our analysis. The file includes seven worksheets titled: Summary, Energy Conversion, LCA Data, Rådhus Inventory, Anneks Inventory, "Traditional" Recipes, and "Healthy" Recipes.

'Summary' shows our final calculations based on data from all the other worksheets. This includes a summary of all relevant calculations including annual emissions for both cafeterias, distribution of mass between food categories, and a comparison of emissions between recipes.

'Energy Conversion' calculates our embodied emissions factor. The sheet takes energy-related values for diesel fuel and grid electricity in $^{kgCO_2\text{-}eq}/_{MJ}$ as well as their associated weights. In addition the sheet takes non-energy-related inputs for dairy and soy, beef, and other read meats in $^{kgCO_2\text{-}eq}/_{kg}$. These entries can be changed to dynamically update the values throughout the workbook.

‘LCA Data’ takes Carlsson-Kanyama’s data [6] and applies our emissions factors to calculate emissions in $kgCO_2\text{-eq}/kg$. The values are then referenced in the inventory and recipe sheets.

The inventory and recipe sheets take the cafeteria procurement data as well as the list of recipes provided and ties each item to an LCA food category.