One Tonne Life?

Greenhouse gas mitigation in a household perspective - a system approach

Master of Science Thesis in the Master Degree Program; Industrial Ecology – For a sustainable society

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Abstract

The concentration of greenhouse gases (GHG) in the atmosphere has increased due to anthropogenic activities and as a result the global mean temperature has risen. To mitigate the impact on the Earth the United Nations Framework Convention on Climate Change has agreed that the global mean temperature should not increase more than by two degrees Celsius. Taken into account the anticipated population increase this gives the average people a CO_2-eq “budget” of one ton per capita per year. The emissions from the average Swedish consumer are at present 8-10 ton CO_2-eq per person per year.

To examine if it is possible to live in present society only emitting one ton of GHGs per person per year, the Swedish companies Vattenfall, Volvo and A-hus started the project *One Tonne Life* (OTL). The project was performed by letting a Swedish family live in an energy efficient house for 20 weeks using the energy efficient technology. This thesis has used data from the OTL project to analyze the measures connected to the mitigation of GHGs from a household perspective. One part of the emissions from the household consumption is difficult for the consumer to influence because they depend on the energy system. To consider these aspects the study has extended the scope to illustrate the GHG emissions caused by the family in the future by a transformed energy and food system. The purpose of the study is to describe the GHG emissions caused by the family’s consumption for the present and a future system.

During the 20 project weeks the family reduced their GHG emissions from 8.1 ton to 3.1 ton CO_2-eq per person per year, with both private and public consumption included. The largest reduction was reached within the transportation category, which was reduced by 95 percent. The mitigated emissions from the family’s consumption were a result of using energy efficient technology as well as changed lifestyle. In the future scenario the emissions caused by the family could be reduced to 0.6 ton CO_2-eq per person per year. In order to reach a one ton lifestyle the results from this study indicates that an energy system based on low carbon emitting energy sources as well as technical and lifestyle changes will be necessary.

Preface

This report has been carried out as a thesis for the Degree of Master of Science in Industrial Ecology at the division of Physical Resource Theory at Chalmers University of Technology. The thesis has followed the project One Tonne Life initiated by the Swedish companies Vattenfall, Volvo and A-hus.

The main goal of the thesis is to describe the progress of a Swedish family's mitigation of greenhouse gases. The master thesis also aimed at describing the family's emissions in a future energy system based on low carbon emitting energy sources.

I would like to give a special thank to my supervisors Fredrik Hedenus and David Andersson for the support and help during this thesis. My gratitude also goes to my examiner Christian Azar, professor at Physical Resource Theory at Chalmers University of Technology.

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1 Introduction

Many human activities, mainly burning of fossil fuels, cause greenhouse gas (GHG) emissions which contribute to the climate change by accumulating in the atmosphere. In Sweden 2009; 79 percent of the GHG emissions came from carbon dioxide, 12 percent nitrous oxide and 9 percent methane. (Naturvårdsverket, 2011c).The concentration of GHG in the atmosphere has since the start of the industrialisation in 1750 increased substantially which has led to an increased global mean temperature (IPCC, 2007). Since 1880 the global surface mean temperature has increased with 0.83ºC (NASA, 2011). The Intergovernmental Panel on Climate Change (IPCC) has concluded that the temperature increase most likely depend on anthropogenic activities.

The United Nations Framework Convention on Climate Change (UNFCCC) requests a stabilization of GHG on a level they define as "a level that would prevent dangerous anthropogenic interference with the climate system" (UN, 1992). On the UNFFCC conference in Cancun, Mexico 2010 an agreement was reached which involve a strategy to reduce anthropogenic caused emissions to avoid the global temperature to rise more than two degrees compared to pre-industrial levels (The Cancun Agreements, 2010).

The average Swede's consumption causes emissions corresponding to about ten ton of GHG each year (Naturvårdsverket, 2008). Out of these, eight tons are related to the private consumer and two tons to the public consumption. The projection for the future is that the global population will continue to increase, and by that the GHG emissions. Until year 2050 the world population is estimated to reach 9 billion or more (Garnett, 2010), which imply an increase with more than a third from today's level. Given this estimated population increase, in order to reach the two degrees target result in a CO_2-eq "budget" of one ton per capita per year. The reduction of GHG emissions is dependent on the climate sensitivity and the estimated amount in the OTL project is based on that the two degrees target should be reached with high probability (Vattenfall, 2010c).

In order to examine if it is possible to live in present society only emitting one ton of GHG per person per year the Swedish companies Vattenfall, Volvo and A-hus started the project "One Tonne Life" (OTL). The project was performed by letting a Swedish family live in an energy efficient house for 20 weeks and using energy efficient technology. To succeed with the task the family also got an electric car and advisors to guide them through their journey towards a less climate intensive lifestyle. The data from the OTL- project has been used in this master thesis to analyse the areas of potential mitigation. The OTL-project only considers the private consumption when stating the one ton goal, whereas this study also regards the public consumption.

Some of the emissions caused by a person's consumption are difficult to reduce because the emissions are connected to the surrounding energy system. To illustrate the effects the energy system has on the family's household consumption one future situation for around 2050 will be described. This implies that the GHG emissions caused by the family's household consumption are going to be estimated for both the present and a future system. For each of the cases the consumption during three different weeks will be described; baseline; which corresponds to the time before the family entered the project, mid time; which corresponds to the first time in the OTL-house and low level; which corresponds to the last project weeks of the project.

1.1 Purpose

The purpose of this study is to describe the GHG emissions caused by a Swedish family's private household consumption. The emissions are going to be described both for the present energy system and for the future energy system around 2050.

The objective of this study is to answer to the following research questions:

- Which of the studied areas, accommodation, transportation, food and other consumption, were most affected by the changes made by the family to reduce their emissions of GHG?
- How would the family's emissions be affected if the energy system was changed to be based on low carbon emitting energy sources?
- How does the result from the OTL-project correspond to the measures presented in literature?

1.2 Limitations

This thesis will only consider the impact of greenhouse gas emissions affecting climate change. The study covers the GHGs carbon dioxide, nitrous oxide and methane, which are the GHGs emitted in largest amounts by anthropogenic sources. The exclusions of some GHG would not influence the main result since they only constitute a minor part of the emissions caused by the family's household consumption (Naturvårdsverket, 2011c). Also, this study does not consider CO_2 emissions caused by land use changes and deforestation, which may influence the result to a greater extent.

1.3 Structure of the thesis

The report is structured as follows: The first chapter gives a short introduction to the thesis and the underlying environmental issue. This chapter also states the purpose of the thesis and its limitations. In Chapter 2, I discuss the theory behind household consumption related to climate change. In chapter 3, are the method and the system boundaries for the study presented. In chapter 4 the modeled scenarios will be described for the future situation in 2050. In chapter 5, the results and analysis are presented. First in this chapter are the main findings from the One Tonne Life project presented, then the results for each studied category for the cases; baseline, mid time and low level, and it ends with the results for the future scenario. The report continues with chapter 6 holding a discussion and ends with chapter 7, including conclusions from the study.

2 Background

This chapter includes background about sources affecting the global warming as well as how these emissions have the potential to be mitigated. The chapter also holds a discussion about consumption connected to climate change and background to the One Tonne Life project.

2.1 Greenhouse gas emissions

The three GHGs, carbon dioxide, nitrous oxide and methane, affect the global warming to various extents. Carbon dioxide is the GHG emitted in the largest amount since the start of the industrialization and is mainly a result of burning of fossil fuels (McMichael and Butler, 2010 and IPCC, 2007).

The Global Warming Potential (GWP) is a way of measuring and comparing the climate impact of different GHGs. This expression considers how effective the gas is in absorbing infrared radiation considering the life length related to different time periods and thereby how they contribute to the global warming. All GHG are compared on a mass basis of one kilo to the reference one kilo of carbon dioxide and expressed as carbon dioxide equivalence. Both nitrous oxide and methane have a higher GWP than carbon dioxide, 25 respective 298, on a 100 year time span (IPCC, 2007).

2.1.1 Anthropogenic sources

The largest source of carbon dioxide emitted to the atmosphere originates from burning of fossil fuels (Naturvårdsverket, 2011). One of the largest anthropogenic sources of carbon dioxide emissions is the electricity sector, where a substantial share is produced by fossil fuel based sources. The global electricity sector consists of 38 percent coal, 20 percent renewable, 17 percent nuclear power, 16 percent natural gas, and 9 percent oil (Sims et al, 2003). Large amount of carbon dioxide is also emitted from the transportation sector and larger industries like steel, cement and refineries (Rootzén et al, 2009). Within the agricultural and food sector carbon dioxide is caused by among others energy use for synthetic fertilizer production, energy use at farms, fuel for harvesting, and from transportations (Wirsenius and Hedenus, 2010). Deforestation is another problem contributing to increased levels of CO_2 in the atmosphere. The forest takes up large amounts of CO_2 during the growing process through the photosynthesis, while mature forest is in equilibrium and only storing the CO_2. By clearing the forest the sink for CO_2 disappears and at the same time burning the trees free earlier stored CO_2. Examples of causes of deforestation are shifting agriculture, cattle ranching, mineral extraction and building of roads (Jackson and Jackson, 2000).

GHGs do not only derive from the energy and industry sectors but are also strongly connected with the food and agricultural sectors. Globally the agriculture sector is the largest anthropogenic source of N_2O emissions. Those emissions are mostly caused by the use of N-fertilizers to increase the crop yield. The emissions connected with the fertilizers are emitted through leakage from the soil and by conversion into air emissions through biological processes (DeAngelo et al, 2006). The global emissions of methane among others come from the enteric fermentation of ruminants, manure handling from animals and flooded rice fields (Naturvårdsverket, 2011b). Methane and nitrous oxide is also emitted from storage of manure. The manure stored in lagoons, tanks etcetera produce methane through anaerobic decomposition, which leak into the atmosphere (DeAngelo et al, 2006). Methane is also emitted into the atmosphere by leakage from the processing and storing of natural gas and from waste disposal sites (Naturvårdsverket, 2011b).

2.1.2 Mitigation measures

The largest part of the carbon dioxide emissions are emitted from burning of fossil fuels (Naturvårdsverket, 2011), this implies not using the source will reduce the emissions substantially. Alternative energy sources for the heat and power system are for example wind power, solar power, hydro power, bioenergy and nuclear power. The GHG emissions emitted during the electricity production with nuclear power are in the same range as renewable sources (Sims et al, 2003). From the Swedish energy company Vattenfall's production, nuclear power cause 3.7 g CO_2-eq per kWh compared to hydropower which cause emissions corresponding to 6 g CO_2-eq per kWh (Vattenfall 2010a and Vattenfall AB Generation Nordic, 2008). However, nuclear power also has some drawbacks, which among other are storing of the radioactive waste and the problem of ensuring the safety of the plants (Sims et al, 2003).

The transportation sector is another fossil fuel intensive sector and is a non-point source of GHG. There are available technologies on the market to reduce the GHG emissions, both alternative fuels and electrical and hybrid vehicles (Hedenus, 2008). Future technologies may also include fuel cells which do not emit any emissions as long as a non-carbon source is used for the production of the hydrogen. The same reasoning holds for the electrical vehicle which is dependent on the energy system generating the electricity (Hedenus, 2008).

Carbon dioxide emitted from larger industry sectors has the potential to be mitigated by carbon capture and storage (CCS). The emissions from the large point source are collected and then transported for storing in geological formations and by that avoiding the carbon dioxide being emitted into the atmosphere (Gibbins and Chalmers. 2008). Rootzén et al (2009) have studied the potential to reduce the emitted carbon dioxide from larger sectors which include oil refineries, cement as well as iron and steel production. There is a range of different ways to separate and store the carbon dioxide. The gas could be separated through post-combustion capture, pre-combustion capture and oxyfuel combustion. There are also different alternatives for storing the separated gas, for example storing in depleted oil reservoirs or gas fields, and deep saline aquifers (Gibbins and Chalmers, 2008).

The methane and nitrous oxide caused by the food and agricultural sector are more difficult to mitigate than the carbon dioxide because the emissions are interconnected to the animal livestock production. Due to this the technological improvement to reduce the GHGs is limited and other mitigation strategies need to be implemented (Wirsenius and Hedenus, 2010). One possible measure is to increase the efficiency of the livestock production, which means to get more meat or milk per kg of GHG emissions. This could be reached by optimizing the diet for the ruminants. The diet should preferably consist of grains rather than grass because it contains less cellulose, which is the substance changed into methane through the digestive system of the ruminants (McMichael and Butter, 2010). By giving the ruminants' optimal food they will use the energy and not release it as waste in form of methane.

The emissions of methane and nitrous oxide released into the atmosphere could also be reduced by improving the manure management (Garnett, 2010). This can for example be done by taking care of the manure and trough anaerobic digestion produce biogas. The produced biogas can be substituted for fossil fuel used at the farms, which further will decrease the GHG emissions. It is also important to cover the stored manure to prevent the emissions to escape into the atmosphere. The emissions related to the manure practices have the potential to be reduced by 25-80 percent depending on the effectiveness of today's system (Cole et al, 1997). The management and use of fertilizers in Europe are already today much more efficient compared to the rest of the world, which result in lower mitigation potential (De Angelo et al, 2006).

The run off of nitrogen from agriculture land is dependent on factors like harvesting methods and seasonal time for adding of fertilizers to the soil. By using the nitrogen fertilizers more efficient, through distributing during right seasons and not overuse, the release to the surroundings could be mitigated (McMichale and Butler, 2010). The soil carbon management can also be improved by no till farming which avoid the release of carbon sequestered in the soil (Garnett, 2010). Another option is to use less synthetic fertilizers and by that less energy is needed for the production, which will reduce the emissions of carbon dioxide (Garnett, 2010).

The methane emissions originated from flooded rice fields are formed through anaerobic decomposition of organic matter (DeAngelo et al, 2006). One way to mitigate the gas formation is to decrease the amount of fertilizers used. Another way is to improve the water management system to reduce the anaerobic conditions arising in the flooded rice fields (DeAngelo, 2006). Also methane from waste disposal and land filling sites has the potential to be mitigated. One mitigation measure is to reduce the amount of organic waste, which is the largest contributor to form methane at the sites (Naturvårdsverket, 2011d). In Sweden it is prohibited to put organic and burnable waste on the sites since 2005, which has decreased the methane formation (Naturvårdsverket, 2011e). The methane could also be reduced by covering the sites and collect the emissions which can be utilized as an energy source.

2.1.3 Consumption perspective

The GHG emissions from anthropogenic sources could be studied from different perspectives. Two of them are the consumption and the production perspective. The emissions included in the different perspectives are equal on a global level but differ between countries due to imports and exports (Naturvårdsverket, 2008). The consumption perspective is suitable for illustrating the total environmental impact of the private consumers since they are the final users of the products and services (Naturvårdsverket, 2008). In wealthier developed countries more than 30 percent of the emissions from the private consumption are imported from other countries (Davis and Caldeira, 2010). On a global scale 23 percent of the CO_2 emissions were traded in 2004 between the countries in the world. The largest share of the emissions is exported from China, but also countries like Russia, Middle East, South Africa and other emerging markets export a substantial part. For the private consumer in developed countries in Europe, 20-50 percent of the emissions are imported when using a consumption perspective. In Sweden more than 40 percent of the consumption emissions are imported. (Davis and Caldeira, 2010)

2.2 Climate change and consumption

The impact of Swedish private consumption has been studied by the Swedish Environmental protection agency in 2008 (Naturvårdsverket, 2008). According to the study the average Swede´s GHG emissions are distributed between the following activities; eating 25%, accommodation 30%, travel 30%, and shopping 15%. Further on the average total impact of one person’s consumption in Sweden was calculated to 10 tons of GHG emissions per year. Out of this, two tons are connected to the public consumption, which includes schools, hospitals and other available public areas.

2.2.1 Mitigation of GHG emissions from private consumption

Some of the activities related to household consumption contribute to GHG emissions more than others. Tukker et al (2010) have made a meta survey to categorize the areas for where incentives are most effective when wanting to reduce the GHG emissions derived from private consumption. The studied articles have used different methods and geographical areas to study the environmental impact of products and services. Despite the differences, they have come up with similar conclusions regarding the activities most contributing to GHG emissions. The general conclusions from the studies are; mobility regarding air transport and automobile, food including meat and dairy, as well as home building and demolition. Tukker et al (2010) suggest that these should be the areas of focus when it comes to reduce the impact from household consumption since they are responsible for 70-80 percent of the total impact of GHG emissions in industrialized countries. Similar priority clusters have also been identified by Spangenberg and Lorek, 2002.

According to the report by Naturvårdsverket (2008) five individual measures together stand for 50 percent of the GHG emissions from the consumer. The activities stated by Naturvårdsverket correspond with the areas stated by the other authors such as Tukker et al, 2010 and Spangenberg and Lorek, 2002, but are more specific. The identified measures are;

- How much and which car we drive,
- How much we heat our accommodation,
- Heating type of accommodation,
- How much and what kind of meat we eat, and
- How often and how far we travel by airplane.

These should therefore be the areas of focus when starting from today's circumstances, according to studied literature.

2.2.2 Factors influencing the amount of GHG's emitted

In literature, different factors have been identified to be responsible for the variation in caused GHG emissions among the private consumers. The *income* of the household is one variable affecting the difference. A Swedish study by Nässén et al, 2009 indicates that reducing the work time by ten percent result in eight percent decreased energy use and thereby GHG emissions. Households with higher income can generally spend a larger share of their income on energy consuming goods and services and by that causing more GHG emissions (Tukker et al, 2010). However, how much the GHG emissions will increase due to a higher income is not completely clear. Some argue that the additions of GHG emissions are not proportional to the extra money spent (Druckman and Jackson, 2008). They explain the phenomenon by saying that the extra goods the richer can afford tend to be less emission intensive than those fulfilling the basic human needs. It is also argued that a higher price paid for a product get a higher quality. This is also in line with the Swedish study (Nässén et al, 2009) which arguing that the energy use, MJ/SEK, grows slower for high income households than for low income households

Another factor influencing the variation between individuals is the *household size*. People living together consume less energy than single household since they tend to live on a smaller area and share energy consuming appliances (Tukker et al, 2010). However, household for single persons have increased partly because elder people stay longer in their own household (Sanne, 2002). An additional aspect related to the above stated factor is the *location* of the living. Transport and housing in urban areas have in general lower environmental impact than suburban and rural areas because, of smaller living area, higher building density which consumes less energy and better access to public transport. They also travel less due to shorter distances to stores, work place and other services.

An additional variable affecting the variation in GHG emission is what kind of *food* we eat. Least emissions are caused by people eating a vegetarian diet and a small intake of dairy products. Also seasonal grown foods generally cause lower emissions. The highest impacts are related to consumption of meat, vegetables grown in fossil fuel heated greenhouses and products transported by airplane (Tukker et al, 2010). FAO estimate about 18 percent of the GHG emissions originate from the global livestock system (Steinfeld et al, 2006). The GHG emissions from the agricultural sectors are projected to increase substantially due to increased demand of food as the population increase as well as increased demand for meat in developing countries (DeAngelo et al, 2006). FAO estimate the livestock production to double until year 2050 (Garnett, 2010).

2.3 One Tonne Life

One Tonne Life was a project conducted by the Swedish companies Vattenfall, Volvo and A-hus. The aim of the project was to identify how much it is possible to decrease the GHG emissions related to a family’s consumption by using energy efficient technology. The goal was to reduce the GHG emissions to only emit one ton per person per year. In the OTL-project only the GHG emissions caused by the family’ household consumption were included and not the public emissions, which are included in this study. The project was conducted by letting a Swedish family use energy efficient technology, which included a house with solar cells, an electrical vehicle as well as getting advisement from different experts within the different areas; food accommodation, transportation and other consumption. This is the first known experiment of this kind. The family consists of parents and two teenagers, and the house was situated in Hässelby in the western part of Stockholm. The family stayed in the One Tonne Life house for 20 weeks.

The project has been divided into three different periods reflecting the family’s progress. The *baseline* period represent the start value and illustrate how the family lived before they entered the project. *Mid time* corresponds to the first weeks in the house when the family used the energy efficient technology but without changed behavior. The last period, *low level*, corresponds to one week in the end of the project. During this period the family both used the energy efficient technology and changed their daily habits to minimize their GHG emissions.

3 Method

This chapter includes a description of the two methods lifecycle assessment and input-output analysis, which have been used to estimate the GHG emissions from the family's household consumption. Also the system boundaries for this study and the data collection are included in this chapter.

3.1 Lifecycle assessment and input-output analysis

Lifecycle Assessment is a method assessing the environmental impact of a certain product or service during its lifetime. The method is counting for all activities within the defined system with related impact during the whole lifetime of a product, so called cradle to grave. The cradle often corresponds to extraction of raw material for producing the product, and the grave corresponds to the waste handling system. There are also studies taking the perspective from cradle to gate, where the environmental impact only corresponds to activities until the product leaves the factory. There is an international standard for the procedure of an LCA study, called ISO 14040-14043 (Baumann and Tillman, 2004). The method LCA can be used to asses different types of environmental impacts, as for example global warming, acidification and eutrophication.

The LCA method takes a bottom-up approach which means that it starts from the product or process and then follows the activities upstream (Nässén, 2007). It is not possible to follow all processes infinite since there are too many paths to follow and clear system boundaries need to be defined. The exclusion of some activities when defining the system may lead to over- or underestimations of the result and to systematic truncation errors (Baumann and Tillman, 2004, Nässén, 2007). Truncation errors arise from the excluded activities which often have larger impact on the result then acceptable and by that cannot be seen as neglect able (Lentzen, 2008). The magnitude of the error depends on the studied product or process and requirements of system completeness for the specific LCA study (Nässén et al, 2007, Lentzen, 2008).

Other problems connected to the LCA method is when two different products use the same process and allocation is necessary (Baumann and Tillman, 2004). This is for example the case for cows, which both produce milk and meat. There are no clear procedures to follow regarding allocation problems but there are available recommendations (Baumann and Tillman, 2004).

Input-output analysis (IOA) is a method studying economic transaction data for different sectors. The method takes a top-down approach and studies the monetary flows, starting with statistics for trade between national sectors (Lenzen, 2001).The method can be extended to include resources and emissions correlated to the final consumption and is then called environmentally extended input-output analysis. (Wiedmann and Barrett, 2005) The EE input-output analysis illustrates the output of emissions related to the flow of material into the geographical area for each industry. The IOA data then specify the emissions for a service or product per SEK consumed in a sector (Hedenus, 2011).

Input-output analysis is seen as a more complete method than LCA since it considerers emissions from the whole sector (Lentzen, 2008). However, this leads to that the method gives a coarse result, which is not product specific (Hedenus, 2011, method report). Another advantage of the method is that it does not require extensive amount of data and is by that not time consuming (Lenzen, 2008).

The methodology input-output suffer from some sources of uncertainties. One of them regards the source data which among other things depends on reporting errors when collecting the data. The studied sectors often produce more than one product which differs in quality and refinement. The price for the product with high quality also has a higher degree of refinement and thus requires more energy. However, the price may increase more than the energy use and thus leading to overestimations of emissions. The input-output method is accounting with a weighted average between the produced products, which is the homogeneity assumption. (Nässén et al, 2007) Another factor which may give rise to uncertainties is the assumption of proportionality between the economic terms and the physical flows, which for example can be emissions (Lenzen 2001).

Some of the drawbacks earlier described could be overcome by combining the two methods (Lenzen, 2008). But combining the two methods for studying the emissions related to consumption may also lead to some overlaps or things missed accounting for. IOA gives a rougher estimation than LCA since it investigates the sector and not the specific product (Räty and Carlsson-Kanyama, 2007).

Life Cycle Assessment is a very time consuming method but on the other hand illustrate the emissions on a very detailed level. Input-output analysis in contrast gives a more coarse estimation of the emissions related to the consumed product or service, but has the advantage of being more complete since the accounting is on a larger scale and deals with aggregates so it is not dependent on individual cases (Lentzen, 2008). The drawback is that IOA does not take into account special choices and new products with not yet a stabilized sector. One example is electrical cars for which not has an established market and instead data for the average car sector is used. This sector however does not consider special improvements as use of recycled material included in the car.

The result between the two methods may differ due to different definitions of the included activities. The input-output analysis covers all upstream activities, while LCA always excludes some activities since it is possible to follow all paths. Nässén et al (2007) found this be the case when studying the energy use related to transportation, where the energy use calculated with IOA was substantially higher than calculated with LCA.

3.1.1 System boundaries

This thesis considers the GHG emissions caused by a family’s household consumption. The aim of the study is to estimate the GHG emissions with the underlying assumption that all people in the Swedish society cause emissions at the same level as the family. Due to this assumption average data has been used and not the marginal emissions caused by the family´s consumption.

Both the emissions directly caused by the family and the indirect emissions connected to production of goods and services are considered when calculating the total GHG emissions. The current energy system consists of several different energy sources, which both includes fossil fuel and low carbon emitting energy sources. The included energy sources are coal, oil, natural gas, nuclear power, hydro power, wind power, biofuels and solar energy. The study has considered that goods imported from other countries are produces in an energy system differing from the Swedish one. It is assumed that all services are produced in Sweden and that 36 percent of the goods are imported from countries within Europe. A weighted of Swedish and European electricity mix has been used to calculate the emission factors for the goods (Hedenus, 2011).

The two methods, lifecycle assessment and input-output analysis earlier described, have been used to calculate the GHG emissions related to the family’s consumption. The purpose of combining the two methods is to give a more accurate view of the caused GHG emissions, but at the same time there is also a risk for double or missed accounting. The choice of method is made according to data availability and which method describing the system in the best way. LCA has been used to calculate the emissions caused from transportation, the house with solar cells, direct electricity use and most of the food purchased at ICA. IOA has been used to estimate the emissions from all other products and services consumed by the family based on spent money. For meals eaten at restaurants a combination of the two methods has been used. The emission intensities for the different products and activities are based on 2006 input-output tables compiled by the National Accounts at Statistics Sweden (SCB, 2008) and adjusted to take imported goods into consideration (Hedenus, 2011). The emission intensities for the products and services are presented in Appendix A.

The GHG emissions related to the family's living and consumption have first been estimated for the whole family and then divided equally between the family members to get the emissions per person per year. The GHG emissions for the food purchased in the grocery store have been estimated by taking the average emissions over three weeks since the purchase may vary in quantity over the weeks. When accounting for the family's environmental impact the study considers the energy system and the used technology, both at present and the possible improvement until 2050.

The consumption perspective is used in this study to describe the family's household consumption with related GHG emissions. This implies that all emissions related to the product or service is taken into account disregarding country of origin. The consumption can be divided into private and public consumption (Naturvårdsverket, 2008) and this study has chosen to consider both parts to give a complete view of the emissions. Figure1 illustrate the system boundaries for activities included in the study.

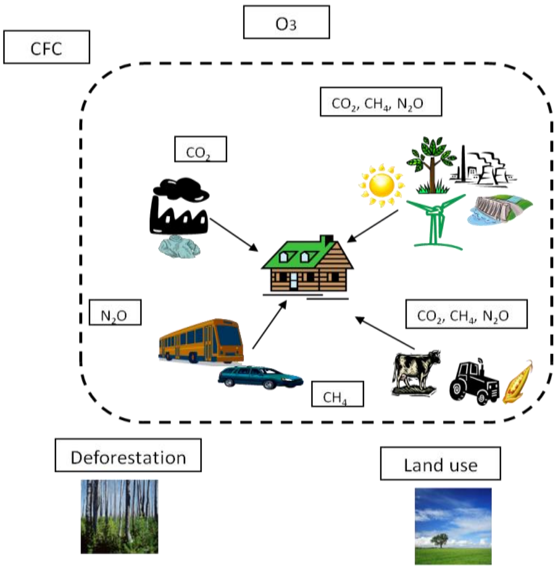

Figure1. Illustration of system boundaries for the study.

3.2 Data collection

Data have been collected from written sources, involved companies, interviews and observations. Chapter 3.2 describes the data collection for the three different phases of the master thesis.

3.2.1 Baseline

The One Tonne Life project started with estimating the GHG emissions profile for the family's consumption before they entered the project. Data regarding the family's accommodation, transportation, other consumption was estimated by the family based on guiding interview questions. All the expenditures were estimated during one year for the family. The cost estimated by the family were compared to other sources to verify the credibility and in some cases corrected after this, which was the case for clothes and beauty products. Information about the family's food consumption was estimated by ICA based on one week of food purchase registered on their ICA card. This was made during Christmas, which often implies larger food purchase than an average week over the year. To avoid overestimation of the emissions from the food, the average of the Christmas week and the first two project weeks was used as baseline. The family did not get any advice during their first weeks in the house and hence food consumption should correspond with the family's diet before the project. Based on the information from the family the GHG emissions were calculated either by LCA data or input-output data or a combination of the two methods.

The emissions regarding the transportation are presented in the One Tonne Life method report (Hedenus, 2011). However, the emissions from aviation traffic are not included in the report and data has been used from Hedenus (2011b). The emissions for other consumption are calculated with input-output data from SCB (2008), and stated in Appendix A. The GHG emissions from the food products have been based on different LCA studies of several different food products (Florén et al, 2007) and on other LCA's found in literature. The emissions from food eaten at restaurants and in school have been calculated with a combination of LCA and IO (Hedenus, 2011). The emission intensity for the energy use in baseline comes from the energy utility company Fortum (Fortum, 2010), who delivered the energy to the family's house. Emission intensities for other energy sources are stated in the One Tonne Life Method report (Hedenus, 2011).

3.2.2 The One Tonne Life project

The data collection during the project time was done on a weekly basis. Vattenfall reported all data concerned energy use in the house as well as the production of electricity from the solar cells. This also included the energy used for charging the electrical vehicle. The food purchased at ICA was registered with an ICA card and the calculations were also performed by ICA. LCA data for the food products are presented in Appendix B. The data about travelling, lunch and food eaten at restaurants and all other things purchased were reported in an Excel sheet every night by the family and was collected in the end of the week. The different reported areas are further described in the One Tonne Life Method report (Hedenus, 2011).

3.2.3 Future scenario

Data for the scenarios have been collected from studies regarding the mitigation potential for respective studied area. The mitigation measures are described in chapter 2.1.2. Data for the distribution of the different GHG emissions from the food products have been collected from different life cycle assessment studies made within the food industry in different countries. The majority of the GHG emissions derived from the food have been calculated with LCA and also for estimating the future mitigation potential. This has however not been possible for all food products where input-output instead has been used. The allocation of the three GHG emissions from the food products is presented in Appendix C. For the cases where IO has been used the mitigation potential from literature has been used to calculate new emission intensities for the future energy system based on mitigation potential found in literature.

4 Future Scenario

How large the emissions from the family's household consumption will be in the future are influenced by several different measures. First it depends on the energy system, which in this study are divided into the areas electricity, transportation and heating. The second part describes the potential mitigation of GHG emissions from the food system. The third part in this chapter describes the mitigation of GHG emissions dependent on the process caused emissions, which in this study corresponds to the steel and cement production. There are different possible ways to reach a one tonne lifestyle, and the future scenario presented in this study is one way to illustrate this.

4.1 Future Energy system

The energy system is constantly changing as new technology emerge, less carbon intensive energy sources are utilized and at the same time different structural changes are taking place. If the present development of the energy system will continue on the same line as the last years the future energy system for year 2050 will be less GHG emission intensive. The reduction of GHG for each studied category are affected to various extents depending on the supply between electricity, fuel and district heat as well as the allocation among the GHG emissions carbon dioxide, nitrous oxide and methane, due to varying mitigation potential.

The energy system has the potential to mainly be based on low carbon emitting energy sources until year 2050. To make this change possible strong policy instruments and structural changes are necessary (The Royal Swedish Academy of Science, 2010). The energy system can be divided into electricity, fuel and heat production. The constructed energy system in this study illustrates the future Swedish energy consumption, and is consistent with the one ton goal presented in One Tonne Life method report (Hedenus, 2011). Sweden has had an almost constant energy production the last 40 years, even if there have been a doubling of industries (The Royal Swedish Academy of Science, 2010). In this study it is assumed that the energy demand will continue to be constant, even if the population and industries would increase, due to further energy efficiency measures. The energy efficiency is assumed to be percent higher per SEK for the IOA data compared to present values. Table 1 below illustrates the amount of GHG emissions per MJ at present as well as in the constructed future scenario. The estimated intensities, CO_2-eq/ MJ, are the same for the Swedish and the European energy system.

Table 1. Emission factors for the present and the future energy system presented for service and goods.

	Electricity (g CO_2-eq/MJ)	**Fuels (g CO_2-eq/MJ)**	**District heat g CO_2-eq/MJ)**
2010 - Services	9	60	35
- Goods	50	62	-
2050 -Services	1	5	5
-Goods	1	5	5

The allocation of the energy sources for each area of the energy production are assumed on the basis of the emission intensities presented in table 1, and the potential improvement found in literature.

4.1.1 Electricity

The present Swedish energy system consists of more than 40 percent hydropower (Svensk Energi, 2011). In the 2050 scenario it is assumed that this will continue to be the situation. The other major part of the present energy system is supplied with electricity from nuclear power, which deliver about the same amount as hydropower. Until 2050 it has been assumed that the share of nuclear power would decrease and are assumed to 11 percent. The electricity delivered from wind power is assumed to increase substantially in the future and generate more than 20 percent compared to the present two percent (Energimyndigheten, 2010). The use of bioenergy has the potential to be increased (The Royal Swedish Academy of Science, 2010), and are in this study assumed to produce little less than a third of the electricity. The last part of the electricity production is assumed to be delivered from solar cells. Figure 2 below illustrates the share of the energy sources generating the electricity in the future.

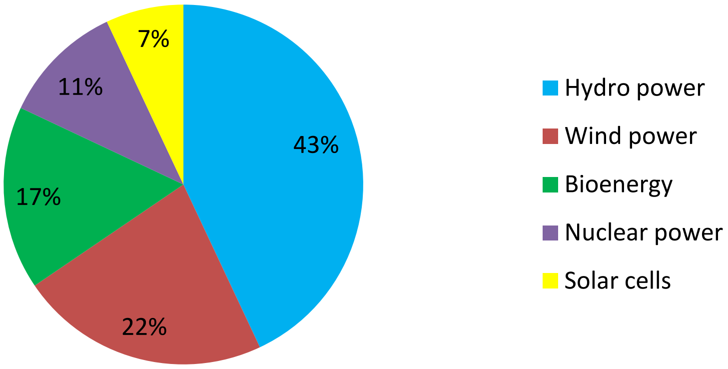

Figure 2. Percentage of energy sources included in the future electricity system in 2050

The reduction of GHGs per kWh for the different energy sources are based on the numbers for 2010 stated in The One Tonne Life Method Report (Hedenus, 2011). The emission intensities for 2050 for nuclear power, hydropower, and wind power have been estimated by changing in LCA data according to estimated mitigation potential regarding energy use, construction material and process emissions. The mitigation potential for solar cells has been estimated from Alsema and Mariska (2006). Energy produced from biomass has the potential to be reduced corresponding to N_2O mitigation from agricultural land, see chapter 4.2 about the food system for further description. The calculated energy intensities for 2050 are illustrated in table 2.

Table 2. Emission intensities for energy sources included in the electricity system at present and in the future.

	Present [g CO_2-eq/kWh]	Future-2050[g CO_2-eq/kWh]	Reference
Nuclear power	3,7	0,2	Vattenfall, 2010a
Hydropower	6	1,7	Vattenfall AB Generation Nordic, 2008
Wind power	17	1,1	Vattenfall, 2010b
Solar cells	30-45	4,7	Alsema and Mariska, 2006
Bioenergy	50	14	Concawe (2006)

4.1.2 Transport

In 2050 it is assumed that the largest share of the cars would be fueled by electricity and biofuels, but also a small share of fossil fuels will continue to be included in the system. This results in that the vehicles will either be fueled with pure biofuels or electricity or in combination with some fossil fuels, which is illustrated in diagram 2. The emissions from the electricity correspond to the electricity system earlier described, which is 1 g CO_2-eq per MJ. The production of biofuels for transportation is assumed to be produced by renewable energy sources, which does not release any process GHG emissions. However, the production of the biocrops or wood will still generate some emissions in form of nitrous oxide. Those emissions are released from the agricultural land as well as the fertilizing and are 4 g CO_2-eq/MJ electricity (Concawe, 2006). The fossil fuel is assumed to mostly be processed into diesel and used in combination with the biofuels or electricity, and emits about 20 times more GHG than the biofuels. The share of the energy sources included in the future system is presented in figure 3 below.

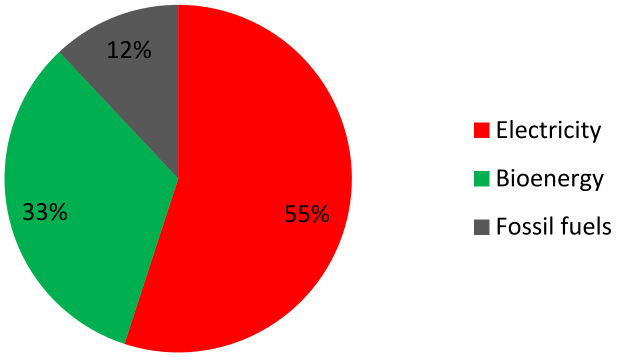

Figure 3. Percentage of energy sources included in the transportation system in 2050.

4.1.3 Industrial and residential heating

The heat production can be divided between industry and household consumption. The industry is assumed to mostly get their heat from bioenergy but a small part will also be generated by burning of fossil fuels. It is further assumed that the GHG emissions from burning of fossil fuels will be reduced by the use of CCS. With present available technology 80 percent of the GHG emissions could be captured from the flue gas from a CHP with potential for further improvement (Rootzén et al, 2009). In this study it is assumed that 95 percent of the GHG emissions could be captured during this process in the future. By using CCS in the heat production the efficiency would decrease by around 10 percent. This is however assumed to equal the estimated improvement until year 2050. The efficiency is thereby the same as present, which is estimated to be 80 percent (US EPA, 2010). The process of mining underground coal for the heat production releases large quantities of methane. Those emissions are possible to almost totally mitigate by using a methane burner (University of Sidney, 2010). This leads to that only emissions from the burning process are include in the future energy system and not emissions caused during mining. The emissions caused by the use of biofuels are released in form of nitrous oxide during the agricultural process of biocrops and is estimated to 2 g CO_2-eq per MJ fuel (Concawe, 2006).

In the future the buildings have the potential to become more energy efficient and require less heat supply. For 2050 it is assumed that the households will get most of their energy from heat pumps, both recovering heat from air and from underground. Some heat will also be generated from solar panels, placed on the roof of the buildings. The percentage of the energy sources in the heat production system is presented in figure 4.

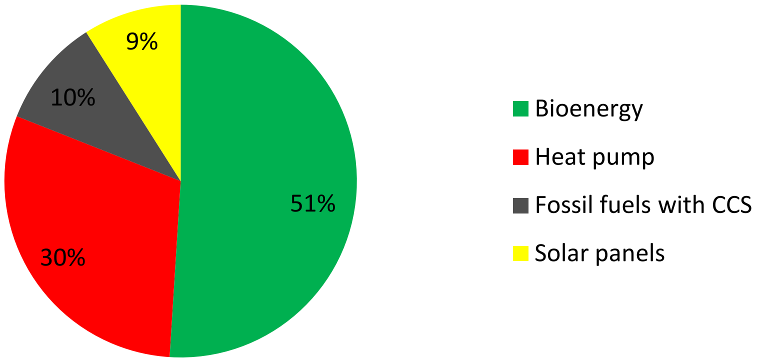

Figure 4. Percentage of energy sources for heat production in 2050

4.2 Food system

The GHG emissions from the family's food consumption have been changed according to the estimated improvements of the food system. For the food products LCA studies have been used to describe the allocation of the total GHG impact between CO_2, N_2O and CH_4. The percentage allocation is illustrated in Appendix C. The mitigation potential for each emission was then made for the different shares.

The mitigation regarding the carbon dioxide emissions are estimated from the future energy scenario described in chapter 4.1. Tropical fruits thus are assumed to have a smaller mitigation potential regarding carbon dioxide due to transportation by airplane. Airplane transportation has additional effects on the global warming than the direct from the fossil fuel used, which imply a smaller potential reduction of GHG. The additional effects enhance the global warming by 30 percent compared to only considering the direct effects of the carbon dioxide (Hedenus, 2011b).

The mitigation potential regarding nitrous oxide and methane from livestock production are based on estimated improvements for Europe between 2000 and 2050 (Hedenus et al, 2010). However, methane released from manure handling has a larger potential to be mitigated than those from the rest of the livestock sector, which is not considered by Hedenus et al (2010). The emissions related to the manure handling have been separated according to Cederberg (2009). The reduction of methane emissions from the manure handling and storing is estimated to be in the range of 25-80 percent (Cole et al, 1997; DeAngelo, 2006) and in this thesis to 50 percent. Only the emissions from beef, lamb and milk have been considered when adding the impact of manure management. Considering the three GHGs together give improvement factors of 25 percent for ruminant meat; 50 percent for dairy products and other meat like chicken and pork are estimated to 40 percent (Hedenus et al, 2010, Cederberg, 2009).

In a study assessing the European nitrogen, the mitigation of nitrous oxide from agricultural activities is estimated to be low and can only decrease with a few percent (Sutton et al, 2011). In this study the mitigation of nitrous oxide from the agricultural sector is estimated to ten percent. The emissions of methane from rice production have a larger mitigation potential and is estimated to 50 percent until year 2050 (Hedenus et al, 2010).

4.3 Process emissions

The GHG emissions caused by the consumption of goods and services are not only connected to the energy system but also from different processes. Both the production of steel and cement releases large amount of process emissions of carbon dioxide, which have the potential to be reduced by using CCS (Rootzén et al, 2009). As mentioned earlier the technology will become more energy efficient until year 2050 and by that consume less energy.

A large part of the car consists of steel, which has a lower mitigation potential than the energy production due to process emissions (Rootzén et al, 2009). Those emissions could however be reduced with carbon capture and storage. The mitigation potential for the iron and steel sector is estimated to be in the range of 30-70 percent compared to current levels and with an additional energy efficiency of 30 percent according to the storyline (Rootzén et al, 2009). For this study the best available technology is assumed and by that the highest estimated value is used.

The production of cement is another sector causing process emissions of carbon dioxide (Rootzén et al, 2009). Rootzén et al (2009) estimate the possible mitigation with CCS from 50 to almost 95 percent depending on the implemented technology. In this study it is assumed that the best technology will be used 2050 and thereby the highest potential are used.

4.4 Specific assumptions regarding the OTL

The GHG emissions in the future scenario have been calculated in relation to earlier description of the mitigation potential of the future energy system, the food system as well as process emissions. For the specific products included in the studied categories the mitigation has been made related to specific LCA studies or estimated mitigation potential found in literature.

The potential reduction of GHG from the OTL-house has been based on the LCA study performed especially for the house (Widheden, 2010). The house is built of wood and the foundation consists of concrete. The concrete foundation of the OTL-house is responsible for more than 20 percent of the total impact and the solar cells for about 25 percent (Widheden, 2010). The other activities included in the lifecycle of the building are responsible for about 40 percent of the climate impact. The solar cells, which also are a part of the panel of the house, are produced in Germany who has an energy system which to larger extent is based on fossil fuel sources than the Swedish electricity mix (Widheden, 2010). More than half of the total impact from the solar cells comes from the electricity production (Widheden, 2010).

The family used an electrical car from Volvo during the project. The car is not available on the market yet and no specific lifecycle assessment has been conducted for the car. However, the car body is similar to an ordinary internal combustion engine car and the motor has been substituted with a battery. About 60 percent of the car body consists of steel (Weiner, 2011). Other materials included are plastics, rubber, glass and aluminum. The mitigation potential for the car production has been made according to steel, since this is the material used to the largest extent. The emissions from the car battery have the potential to be reduced through improved energy efficiency, optimizing the method and substituting materials (Notter et al, 2010). The share of cars including battery is at current small and therefore the recycling of the batteries are not yet established, however it will increase as the demand does (Nemry et al, 2008).

The GHG emissions from meals eaten at restaurants have been calculated with a combination of LCA and IOA. The improvement potentials for the future scenario have been assumed related to each calculation method. The allocation of the LCA part of the meals is made according to the protein source, since this is the ingredients causing most GHG emissions.

For sweets purchased in other stores than ICA, alcohol, café visiting and spices the GHG emissions have been calculated using input-output data. The improvement of the emission intensity is calculated according to the estimated energy scenario for 2050 as well as the mitigation of non-CO_2 emissions, which has been assumed to 50 percent.

The impact from the category other consumption is calculated with emission factors from IOA. The mitigation potential is base on the future energy system and reduction of methane and nitrous oxide from natural gas processes and storing places as well as disposal places. Based on earlier described mitigation potential in chapter 2.1.2 for non-CO_2emissions the factor for 2050 is assumed to be 50 percent.

The Swedish public consumption has been estimated to two ton per capita and year by the Swedish Environmental Protection Agency (Naturvårdsverket, 2008). Data have been used for 2003 which was a very dry year in Sweden. This resulted in lower production than average from hydropower plants, which usually produce more than 40 percent of the electricity (Svensk Energi, 2011). Sweden had to import energy from other countries which to a larger extent was based on fossil fuels. (Energimarkandsinspektionen, 2004) Due to the background of this the public consumption at present will be lower and is therefore estimated to be 1.5 ton per person per year in this report. The largest part of the GHG emissions from the public consumption makes up of energy for residential heating and another major part of the GHG emissions comes from transportation (Hedenus, 2011c). The improvement of the public consumption in this thesis is made according to input-output of heating of buildings since this is the dominating activity.

5 Result and analysis

This chapter presents the main findings from the OTL-project, describes changes in each category in detail and the results and analysis of the future scenario.

5.1 *Main findings*

The family's emissions from private and public consumption before the project started corresponded to 8.1 ton per person per year. The baseline emissions have been estimated from the family's consumption of goods and services during 2010. The public consumption corresponds to 1.5 ton CO_2-eq and is the same for all periods, since the family could not affect this part. By letting the family move in to the house with the solar cells and use other energy efficient technology they reduced their emissions to 4.5 ton CO_2-eq per person per year. For the mid time period the largest reductions were made within transportation and accommodation. During this period the family to the largest extent used the electrical vehicle and public transportation and lived an energy efficient life in the house.

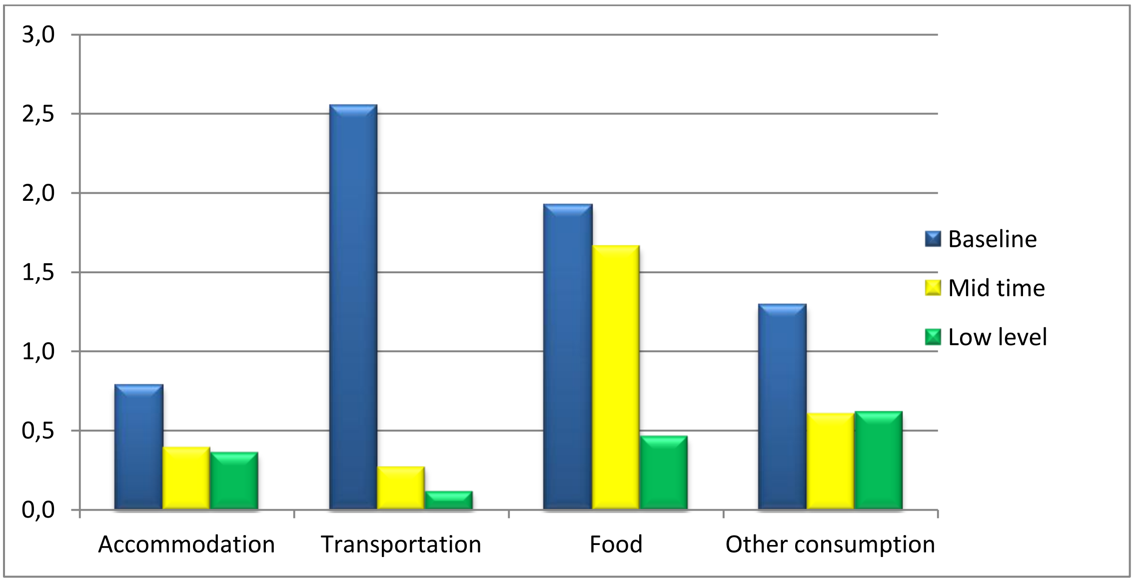

Figure 5. The main findings from the OTL project for the tree different cases for respective category presented in ton CO_2-eq per person per year.

During the 20 weeks the family stayed in the house they gradually changed their habits and consumption patterns to reduce their environmental impact. The lowest emissions were measured one of the last weeks of the project and corresponded to 3.1 ton CO_2-eq per person per year, illustrated with the low level bars in figure 5. The largest reduction in the low level case compared to the mid time period was made in the food category, where the emissions were drastically reduced. The emissions were reduced within all categories except other consumption. The reason is that the family could only influence this category by reducing their purchases. The things bought in the beginning of the project also followed the family to the end depending on life length. During the project the family reduced their total emissions with 62 percent compared to baseline. The largest reduction was made in the transportation category which decreased by 95 percent, and was both a result of technical fix and lifestyle change. The second largest reduction was reached within the food category and was solely a result of changed diet. The lifestyle change made by the family resulted in 75 percent reduced GHG emissions within the food category.

5.2 *Accommodation*

The accommodation category has been divided into the activities: house, solar cells and electricity use, with related amount of CO_2-eq illustrated in figure 6. During the project the family reduced the GHG emissions from accommodation and electricity with 50 percent. Before the family entered the project they lived in a house built around 1970 and heated directly with electricity. In the emissions representing the house also maintenance is included. Even if the OTL-house was new and not much maintenance will be necessary in the nearest future a template value of 150 kg CO_2-eq per person per year have been added. The OTL-house is both energy efficient and produces some of the electricity and heat to the house through the solar cells and panels attached on the facade. The family's own house consumed around 30 000 kWh per year compared to the OTL-house which only consumed about 6000 kWh per year.

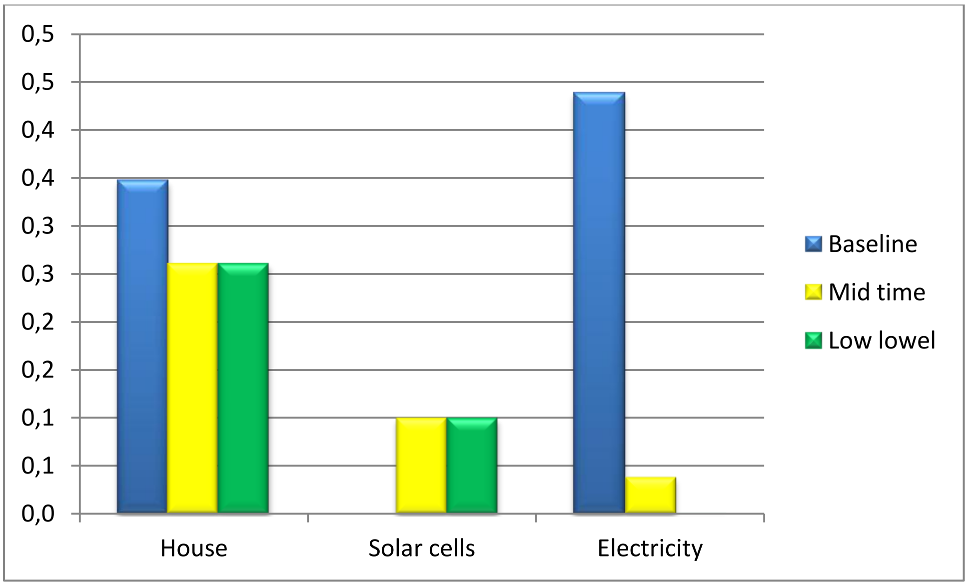

Figure 6. Ton CO_2-eq per person per year for the activities included in the accommodation category.

The electricity to the family's own house was delivered from an electricity mix from Fortum including fossil fuels. When the family moved into the OTL-house they instead got their electricity from hydropower. During the project the family got help from advisors to change behavior to cause less emission, which is illustrated by the low level bars in figure 6. Further on in the project the family changed behavior which resulted in less consumed energy. At this point of time it also started to get warmer and the sun was out for more hours per day and more electricity and heat was generated by the solar cells and solar panels. During some weeks the solar cells have delivered more energy than the family utilized and the surplus could be generated back to the electricity grid.

The most imported measure for reducing the GHG emissions within the accommodation category is the energy efficient house, which also produced heat and electricity. The largest reduction was made by technical fix, and the lifestyle change only had a smaller impact on the total reduction.

5.3 *Transportation*

The emission in the transportation category has been reduced with more than 95 percent during the project and is the largest reduction among the studied categories. The emissions caused by the different transportation modes are presented in figure 7. Before the family entered the project they had two petrol driven cars which accounted for the most of the family's travelling. In baseline one vacation trip with flight is included, which made up a substantial part of the total emissions in baseline. One of the most important measures for reducing the GHG emissions from this category was that the family chose not to travel with airplane and instead used the train for travelling longer distances during the OTL-project.

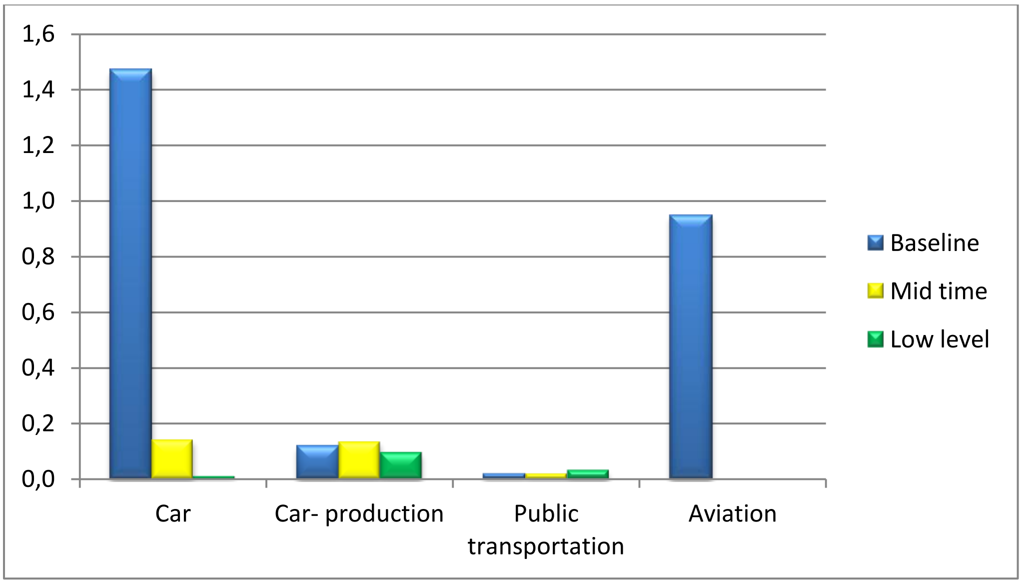

Figure 7. GHG emissions caused by the activities include in transportation for the three studied cases, presented in ton CO_2-eq per person per year.

Another important measure for the reduction of GHG in the transportation category was the change of two petrol cars to one electric car. The family chose to get their electricity delivered from hydropower which causes emissions corresponding to 1 g CO_2 per km compared to 202 g respective 224 g CO_2 per km for the family's own petrol cars. An additional measure is the reduced driving distance. By substituting their two cars for one electric vehicle, with limited driving range, has reduced the driving distance with 20 percent on a yearly basis. The reduced driving distance is an outcome of car pooling within the family and more frequent utilization of public transportation. The bar in figure 7 illustrating the mid time case also includes some driving with one of the family's own cars, since the family needed some time to adapt to the new situation. The large reduction of GHG within the transportation category is both a result of technical and lifestyle change.

5.4 *Food*

For the reduction of GHGs related to the family's food consumption there were no technical fix to help the family to reduce the emissions. This resulted in that a lifestyle change was necessary for the family to be able to reduce their impact. During the project the family got information about the impact different food products have and guidelines to continue to eat healthy. The purchased food often vary in amount and things we buy over the week and to avoid this an average of three weeks food purchase has been used in this study. The caused emissions from each food group are presented in figure 8.

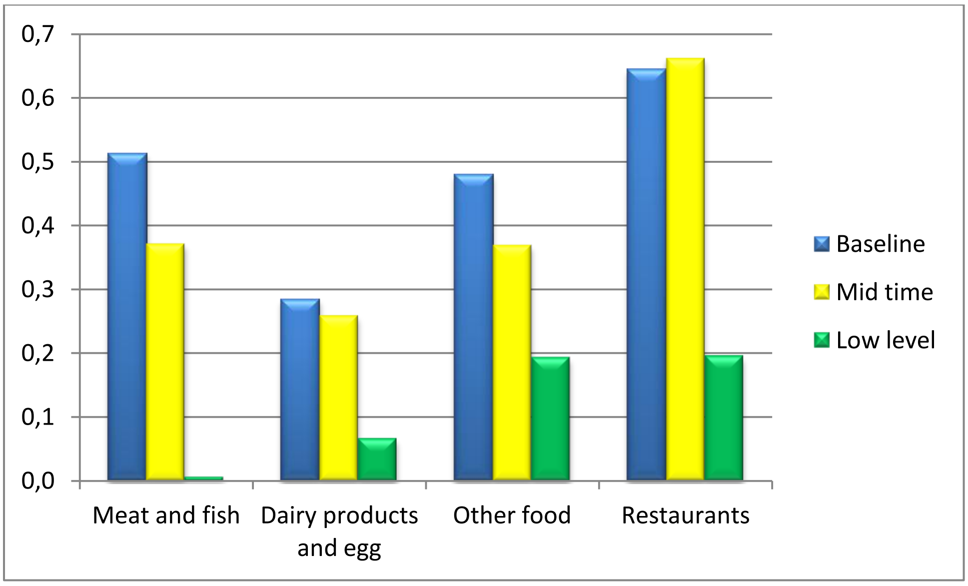

Figure 8. GHG emissions caused by the family's food consumption presented in ton CO_2-eq per person per year.

At the end of the project the family decided to almost exclude meat and dairy products from their diet since these products caused the largest part of the emissions in baseline and mid time week. However, the parents decided that the kids not should exclude all their intake of meat since they still are growing. During the week corresponding to low level, the family increased their intake of soy and oat based products as well as beans, which cause substantially lower emissions then meat and dairy products. The family also tried to eat seasonally grown fruit and vegetables and avoid products transported by airplane, which resulted in decreased emissions in this group as well.

Restaurants meals were in baseline and the mid time week one of the largest contributing factor the total impact. All family members ate lunch at restaurants most of the days during weekdays. During the project it has proven that meals eaten at restaurants generally causes higher emissions than meals cooked in the One Tonne Life house. One explanation is that the OTL-house has more energy efficient kitchen equipment and that the family to a larger extent could minimize the waste. During the period the family made extra efforts to change lifestyle the parents took lunch-box with them to their work to further decrease the generated GHG emissions. The dietary change and the lunch-box resulted in a reduction of 75 percent of GHG emissions from the food compared to the baseline value. The reduction within the food category was solely a result of changed lifestyle.

5.5 *Other consumption*

The activities in the “other consumption” category include things as home- and beauty products, insurance, clothes, furniture, and spare time activities. The activities have been grouped into three sub categories, illustrated in figure 9. Compared to baseline, the emissions from the “other consumption” category have been reduced by 50 percent during the OTL-project. The emissions from these activities are caused during the production process of goods and services, and transportation, because they are driven by fossil fuels. There were no technical fix for the family to reduce the emissions from this category; they could only lower the emissions by holding down their consumption.

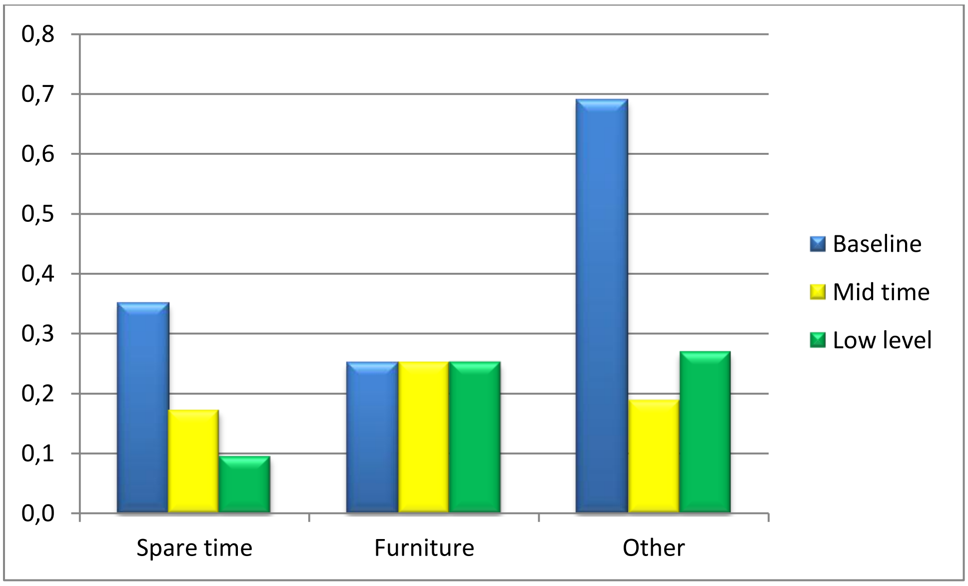

Figure 9. GHG emissions caused by the activities include in other consumption for the tree studied cases, presented in ton CO_2-eq per person per year.

The spare time activities in baseline include a vacation trip where the family stayed on hotel. The weeks during the project corresponding to mid time and low level, have not included any travels only the sport activities riding, judo and gym. In the end of the project the family decided to give up all activities except riding and judo, which further reduced their emissions. The emissions caused by the production of the furniture have been separated to illustrate that they make up a substantial part of the emissions caused by this category. The piles representing “other” have decreased the most during the project and are solely a result of changed lifestyle, by consuming less compared to their earlier life.

5.6 *Future scenario*

Some of the GHG emissions caused by the family's household consumption of goods and services are difficult to influence because they are more dependent on the energy system than lifestyle changes. By creating a scenario for an future energy system based on low carbon emitting energy sources, it could be illustrated what kind of measures and areas that need to be prioritized to be able to substantially reduce GHG emission from private consumption. Diagram 10 illustrates the GHG emissions caused by the family's consumption during the different three studied periods with the current energy system and with the estimated future energy system. Consuming as the family did before they entered the project and only changes the energy system, result in that the GHG emissions decreased from 8.1 ton to 2 ton of CO_2-eq per person per year. When only changing the energy system the food category make up the largest part of the emissions in 2050.

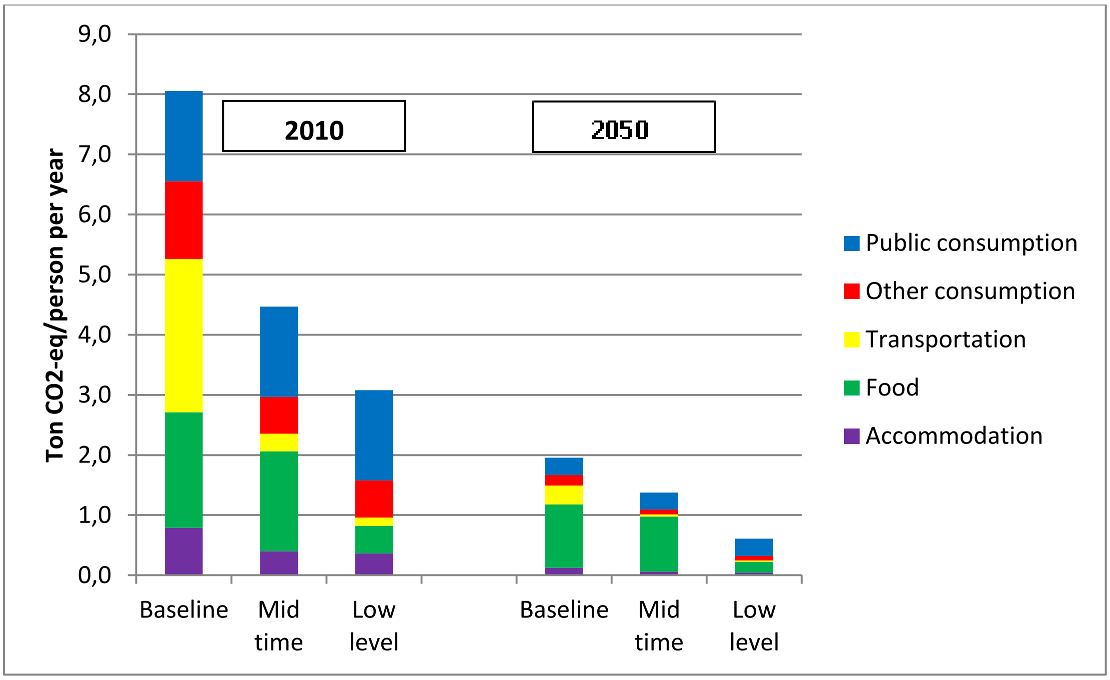

Figure 10.Ton CO_2-eq per person per year for the three different cases for the studied categories in the present as well as the future system

The GHG emissions for the mid time week were measured to corresponding 4.5 ton CO_2-eq per person per year during the OTL project. If the family lived in the same way in 2050 the GHG emissions would instead correspond to 1.4 ton per person per year. By implementing energy efficient technology with the present energy system reduced the GHG emissions by 45 percent compared to baseline. However, if the same measure should be implemented when having the future estimated energy system it would have given a smaller effect on the result, only corresponding to a 30 percent reduction. The reason is that the measures taken at present by the family differ more compared to the present energy system than it would have done in the estimated future situation. The easiest categories to abate by a changed energy system for both baseline and the mid time week are accommodation and transportation. The most difficult category to decrease by only changing the energy system is the GHG emissions from the food, where most of the GHG are caused by the animals and agriculture activities.

By having a changed energy system during the low level week the emissions caused by the family reduced from 3.1 to 0.6 ton of CO_2-eq per person which is illustrated in figure 10. During this week the family almost entirely excluded meat and dairy products from their diet. This contributed to that the food no longer is the dominating category. Instead the public consumption is the most contributing category to the family's GHG emissions. The public consumption is the most difficult one to affect by the private consumer and is more dependent on the energy system and political decisions. The dietary change had a much greater effect on the reduction in the future energy system than in the present. The reason is that the emissions from the consumed food makes up a larger part of the total caused GHG in the future scenario than the present and that the technical improvement for reducing the GHG emissions from the food sector is lower than for the energy system.

To reduce the emissions to a level corresponding to one ton of GHG emissions per person per year several measures need to be taken. A one tonne life requires both to transform the energy system to be entirely based on low carbon emitting energy sources, technological improvement as well as lifestyle changes. To only transform the energy system would result in emissions corresponding to 1.8 ton per person per year. Implementing energy efficient technology will further reduce the emissions but not as much as needed. A level corresponding to one ton of CO_2-eq is first reached when lifestyle changes are added to earlier described measures, especially included dietary changes.

6 Discussion

6.1 Limitations of the method

Chapter 3 described the merits and demerits of LCA and IOA analysis respectively, and gave an account of the combined LCA/IOA method used in this study. However this combined method generates other limitations. As described earlier, in IOA there are no product specific data but only for product groups. The emissions from beef meat are about 20 times higher than meat from chicken, which leads to over- or underestimation of the emissions depending on the family's diet. To get the best estimation LCA has been used to account for the GHG emissions from the food purchased at ICA. However, for food eaten at restaurants this has not been possible due to lack of information, and the two methods have hence been combined. The family's emissions caused by restaurant meals often made up a substantial part of the total impact from food. Since the two methods have been combined it cannot be excluded that double accounting has occurred. Another explanation to the higher numbers may be that cooking in the OTL-house consumes less energy than in a restaurant kitchen.

Another limitation to the study is that the result for the different cases are measured during one specific project week, reflecting technical as well as lifestyle change, and extrapolated to annual emission estimates. However in real life we do trips and similar activities and larger purchases a few times per year which cannot be captured by only studying one week at the time. Only studying one week at the time can be seen as a limitation of the method and may underestimate the emissions for one year. This was however not the case for the baseline emissions where all emissions caused by the family's consumption during one year is included. If the emissions from the family's ski trip and two weekends spent in Gothenburg are allocated over the 20 project weeks and are included, 0.5 ton CO_2-eq emissions would be add to the total emissions. This result in that the emissions for the mid time case should have been 5 ton instead of 4.5 ton CO_2-eq per person per year, and for the low levels case 3.6 ton instead of 3.1 ton CO_2-eq per person per year. The largest part of the GHG emissions from the longer trips is caused by hotel stay and ends up in the category *other consumption*, only a minor part of the emissions are caused by travelling since the family chose to go by train.

Also, this study uses European electricity mix in the estimation of emissions from all imported goods, since Sweden imports the largest share from these countries. However, a recent study (Davis and Caldeira, 2010) indicate that the largest share of the emissions are imported from China and other emerging markets which have a higher emission intensity per economic unit than goods imported from developed countries in Europe. Goods are traded between different countries before it ends up at the consumer which makes it difficult to estimate the imported emissions. This means that also things bought from Germany originally may be imported from China, and by that has higher emission intensity then counted for. For Sweden this result in that around 40 percent of the consumption emissions are imported and the total amount is estimated to 10.5-12.5 ton CO_2-eq per person in Sweden (Davis and Caldeira, 2010). This implies that the emissions connected with the OTL-family's household consumption in this study seem to be underestimated.

6.2 Theory compared to the measured One Tonne Life results

To answer one of the stated purposes of the study the OTL- results have been compared to the theory described in chapter 2.2. Both Tukker et al (2010) and Naturvårdsverket (2008) identified areas where incentives are most effective for reducing GHG emissions caused by private consumption. The identified incentives included transportation focusing on automobile and airplane, food including meat and dairy products, and heating of accommodation. The identified areas of focus presented in literature correspond well to the results from the family's consumption during the project.

Transportation is one of the discussed areas in literature and before the family entered the project this category caused most of the family's emissions, counting for 35 percent. The family had two petrol driven cars and had made a vacation trip by airplane. Transportation was also the area where most emissions were reduced during the project. The second area identified by Tukker et al (2010) was food with particular focus on meat and dairy products. The emissions caused by the family's food consumption were almost as large as from transportation, 31 percent. The last area identified in literature was home and demolition. This was the category with lowest generated GHG emissions, only accounting for 13 percent in the family's baseline. The family's other consumption accounted for 21 percent of the emissions from their private consumption. This is an area not widely discussed in the literature even if it composes a substantial part of the family's impact. This may be the reason because the "other consumption" is a kind of diffuse category and the emissions to a large extent depends on the things we buy, how much and for how long period of time the GHG emissions are allocated over. Private consumer could for example reduce their emissions from this category by minimizing their consumption of goods or buying services instead of goods.

The identified areas by Tukker et al (2010) and Naturvårdsverket (2008) agree well with how the family consumed before they entered the project. However, during the One Tonne Life project when the family got access to the energy efficient technology and information about how their choices affect the emissions, also the area of focus changed. Transportation, which was the largest contributor in baseline, went to be the least emitting category. Food, on the other hand was the second most contributing category in baseline and during the project its importance even increased. The GHG emissions from all categories except food could be abated by technological change and improvement while the emissions from food in the present system could only be reduced by a lifestyle change. During the first weeks of the project the family consumed similar food as before, during this period the emissions from the food accounted for half of the emissions from the family's total private consumption. Also the importance of the emissions caused by the category "other consumption" increased when more efficient technology was implemented, since the family could not influence the manufacturing process.

The Swedish Environmental Protection agency has estimated the Swedish private consumption to 10 ton of GHG emissions capita and year, with the public consumption included. The family's consumption was in this study estimated to 8.1 ton of GHG emissions per person per year. The largest difference is found in the accommodation category. The difference is due to the different methods have been used. The Swedish EPA use IOA while this study used a combination of IOA and LCA. As earlier described IOA are rougher in its estimates but covers more of the emissions than LCA. A further explanation to the differing numbers is that Naturvårdsverket has calculated the GHG emissions for the average Swede and in this thesis the emissions are calculated for one specific family (Skånberg, 2011).

6.3 Future 2050

Technical and lifestyle changes will still be necessary in the future scenario, even with a changed energy system, for reaching a level of one ton CO_2-eq per person per year. The required lifestyle changes especially concerns altered diet to contain less meat and dairy products. Decreasing the consumption of meat and dairy production will also free substantial aerials of land, which instead could be used for other products. One example is the possibility to grow energy crops which can be used as fuels. Another way of reducing the GHG emissions from food is to minimize the waste. At present about 20-30 percent of the purchased food end up as waste (Sutton et al, 2011), on a global scale this could reduced waste the GHG emissions significantly.

The GHG emissions related to the private consumer's consumption can be divided between direct and indirect emissions. The direct emissions are those caused by the use of for example electricity and fuel and are easier for the private consumer to mitigate. Indirect emissions are affected by the energy system to a large extent, and thereby more difficult for the consumer to influence. The indirect emissions require a transformation of the energy system and are dependent on political decisions. The private consumer can thus decrease those emissions by reducing their purchase of goods and to choose products with higher quality and longer lifetime. But at the same time it is often difficult for the consumer to get information about the best alternative from a climate perspective.

The energy system described in chapter 4 is based on a scenario assuming all inhabitants causing emissions corresponding to one ton of GHG emissions per person per year. The energy sources in the energy system have been estimated on the basis of capacity and availability. Energy generated from nuclear power was included in this study to achieve the pre-defined emissions intensities due to its low emission factor. In this study emission intensities from Vattenfall have been used and nuclear power is in this case the energy source emitting least CO_2-eq from a lifecycle perspective. On the other hand nuclear power has other disadvantages which include risks and storing of the spent fuel. This also needs to be considered when deciding to continue to use the technology. Sweden has at present 10 active reactors, with a life length of an additional 20-25 years (Vattenfall, 2011). This implies that if nuclear power should be included in the energy system new reactors need to be build. Both Finland and France are building new reactors, which still will generate electricity in 2050. But reactors can also be closed before their expiration date due to political decisions, which was the case for Barsebäck, or because of serious accident as in Japan. The future emission intensities are based on improvement of current technology. However, the development of even more efficient, and by that less GHG intensive energy sources, may arise during the years which can further reduce the emission intensity.

The emissions estimated for 2050 are based on the family's present consumption of goods and services. However, it is not considered in the future estimations that the income is likely to increase. This makes it possible to consume more goods and services, which may result in higher GHG emissions per capita. This means that the estimated emissions for the family in the future may be underestimated. But on the other hand it is difficult to predict our behaviour in the future. The prediction of increased consumption is based on the previous years, when the consumption steadily has increased. It should also be noticed that the result in this study only reflect the GHG emissions from one family. If people around the world get better living standard, which is desirable for many people, this will result in an additional increase of GHG emissions.

7 Conclusions

This thesis has used data from the One Tonne Life project, which aimed at examine if it is possible to live in present society only emitting one ton of GHG emissions per person per year. To be able to reduce the emissions the test family got access to energy efficient technology and advisor during the 20 studied weeks. The aim of this thesis was to describe the family's reduction of GHG emissions with the present as well as an estimated future energy system based on low carbon emitting energy sources.

During the 20 project weeks the family reduced their GHG emissions from 8.1 ton to 3.1 ton CO_2-eq per person per year. Out of these, 1.5 ton is CO_2-eq from public consumption which the family could not influence. By implementing energy efficient technology the family reduced their emissions to 4.9 ton CO_2-eq per person per year. In the 2050 scenario the GHG emissions were reduced from 2 ton in baseline to 0.6 ton GHG per person per year in the low level case.

The measured results from the One Tonne Life project indicate that:

- The largest reduction was achieved within the transportation category and was a result of technical change in combination with changed travelling patterns.
- The second largest reduction was achieved within the food category and was solely a result of a dietary change.
- It is not possible, with the OTL-family's living standard, to reach a one tonne lifestyle with the current energy system.
- To reach a one tonne lifestyle in the 2050 scenario, both technical improvement and lifestyle changes would be necessary. The result points to the increased importance of mitigation of non-CO_2 emissions from the food sector in the 2050 scenario.

GHG emissions caused by household consumption are one part which is important to consider when working towards mitigating the climate change. However, this does not necessary mean that the private consumer is completely responsible for the GHG emissions from the consumption, but also industries and politicians are. The consumers can contribute by reducing their household emissions, but they will need guidance during their path to a less GHG intensive lifestyle.

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Appendix

Appendix A

CO_2-eq intensities for goods and services for the current and future energy system.

Category	**g CO_2-eq/SEK (2011)**	**g CO_2-eq/SEK (2050)**
Clothes and shoes	26	4
Furniture	26	4
Culture and education	14	3
Services- phone etc.	6	1
Home and beauty products	24	3
Hair dresser	12	3
Consumer electronics	20	2
Riding	40	14
Health center	13	3
Boat- insurance	6	1
Boat- maintenance	12	2
Boat- operating cost	25	4
Vacation trip	35	6
Cottage	9	3
Other things- books etc.	24	3
Garden	113	45
Car-operating costs	21	2
Moped- operating costs	22	2

Appendix B

Total amount of CO_2-eq for different food products in kg CO_2-eq per kg product. The numbers are from Florén et al (2007).

Food product	**Tot CO_2-eq**
Meat and fish	
Beef Swedish	18,5
Lamb UK	27,5
Pork Swedish	4,8
Chicken	1,7
Fish (salmon)	3,6
Fruit and vegetables	
Oranges (imported)	0,8
Tropical fruit (airplane)	11
Apples (imported)	0,4
Tomatoes (Spain)	0,6
Tomatoes (greenhouse)	1,7
Carrots (Sweden)	0,1
Potatoes	0,1
Broccoli	0,3
Green beans	1,3
Soybean	0,92
Milk, cheese and egg	
Milk	1,5
Cheese	10,5
Egg	2
Cereals, rice, pasta	
Bread	1,8
Rice	6,4
Pasta	1,1
Sweets and beverages	
Crisps	2,2
Chocolate	2,7
Sweets (foam)	3,8
Sweets (jelly)	2,4
Coke	1,3

Other food	
Rapeseed oil	2
Sugar (granulated)	0,6

Appendix C

Allocation of the three studied GHG, carbon dioxide, nitrous oxide and methane, for different food products. The distributions of the GHG are based on different sources find in literature.

	CO_2	**N_2O**	**CH_4**	**Reference**
Meat and fish				
Beef Swedish	12,5	25	62,5	Cederberg et al (2009b)
Lamb UK	6	45	49	Allard and Wallman (2009)
Pork Swedish	24	48	28	Cederberg (2009)
Chicken	48	48	4	Cederberg et al (2009b)
Fish (salmon)	100	-	-	Pelletier and Tyedmers (2007)
Fruit and vegetables				
Oranges (imported)	92	8	0	Carlsson-Kanyama and González (2009)
Tropical fruit (airplane)	98	2	0	Carlsson-Kanyama and González (2009)
Apples (imported)	98	2	0	Carlsson-Kanyama and González (2009)
Tomatoes (Spain)	60	40	0	Sonesson et al (2010)
Tomatoes (greenhouse)	98	2	0	Nielsen (2008)
Carrots (Sweden)	9	10	0	Carlsson-Kanyama and González (2009)
Potatoes	73	25	2	Kramer et al (1999)
Broccoli	67	33	0	Angervall et al (2006)
Green beans	92	8	0	Carlsson-Kanyama and González (2009)
Soybean	100	0	0	Carlsson-Kanyama and González (2009)
Milk, cheese and egg				
Milk	18	22	60	Cederberg and Mattsson (1999)
Cheese	46	12	42	Carlsson-Kanyama and González (2009)
Egg	50	41	9	Sonensson et al (2008)
Cereals, rice, pasta				
Bread	50	50	0	Andersson and Ohlsson (1999)
Rice	30	0	70	Sonesson et al (2010)
Pasta	96	12	0	Carlsson-Kanyama and González (2009)

Sweets and beverages				
Crisps	76	11,5	12,5	Nilsson et al (2011)
Chocolate	25	29	46	ChokoFa augusti 2009.
Sweets (foam)	68	31	1	Nilsson et al (2011)
Sweets (jelly)	84	14	2	Nilsson et al (2011)
Coke	68	28	4	Nilsson et al (2011)
Other food				
Rapeseed oil	50	50	0	Carlsson-Kanyama and González (2209)
Sugar (granulated)	60	40	0	Nordic Sugar (2009)