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The Rebound Effect

A Simulation Model of Telecommuting

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Title: The Rebound Effect - A Simulation Model of Telecommuting
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Problem description:

In the report, "SMARTer 2020", the rebound effect is said to be "important but too complex to calculate". This thesis will try to quantify this phenomenon and discuss if ICT can be used to decrease the greenhouse gas emissions or if the rebound effect is too strong.

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Abstract

This thesis aims to highlight the relationship between telecommuting and the rebound effect with respect to greenhouse gas emissions. This was done by gathering and analyzing the latest research from various fields that could provide information about telecommuting and the rebound effect. By surveying these fields, an informative and well-documented framework for modeling telecommuting and the rebound effect was made possible. The simulation model simulated the adoption of telecommuting in Los Angeles over 30 years. The rebound effect of telecommuting was found to be 27.4%.

Sammendrag

Denne masteroppgaven har som hensikt å synliggjøre reboundeffekter som oppstår med fjernarbeid, med fokus på klimautslipp. Dette ble gjort ved å undersøke vitenskaplige rapporter og analyser fra de senere årene som fokuserte på fjernarbeid. Dette ga et rammeverk for utvikling av en simulasjonsmodell. Modellen skal representere adopsjonen av fjernarbeid i Los Angeles over 30 år. Reboundeffekten ble funnet til å være 27.4%.

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List of Acronyms

BTU British thermal unit.

CO_2e carbon dioxide equivalent.

EIA United States Energy Information Administration.

EPA United States Environmental Protection Agency.

FHWA US Department of Transportation The Federal Highway Authority.

GeSI Global eSustainability Initiative.

GHG greenhouse gas.

GWP global warming potential.

HVAC heating, ventilation, and air conditioning.

ICT information and communications technology.

IPCC Intergovernmental Panel on Climate Change.

IPTS Institute for Prospective Technological Studies.

kWh kilowatt hour.

LADWP Los Angeles Department of Water and Power.

WMO World Meteorological Organization.

Chapter 1
Definitions

In this chapter, definitions for the terms and expressions used in this paper will be explained. These terms are famously known for being loosely defined in the current literature and will therefore differ depending on the author and the context.

Telecommuting: Replacing the regular commute with the help of information and communications technology (ICT). Enabling the person to work from almost anywhere in the world.

Telework: A work arrangement that allows an employee to conduct work at an approved alternative worksite. In current literature, telework and telecommuting are often words that are interchangeable.

In this paper, both the terms telecommuting and telework will be used. Telecommuting will reference the fact that the worker is replacing vehicles and other means of transportation with ICT. While the term telework will be used to indicate that the worker is conducting the work from home.

Rebound Effect: An effect that refers to the behavioral or other systemic responses to the introduction of new technologies that increase the efficiency of resource use. The rebound effect is commonly split up into three categories: direct, indirect and economy wide.

Direct Rebound Effect: Increased efficiency lowers the cost of consumption, and hence increases the consumption of that good because of the substitution effect.

Indirect Rebound Effect: Through the income effect, decreased cost of the good enables increased consumption of other goods and services, increasing the consumption of the resource embodied in those goods and services.

Economy Wide Effect: New technology creates new production possibilities and increases economic growth.

Rebound Effect in Telecommuting: Although the "resource" in use is telecommuting, the research in this field is not interested in the self-reinforcing effect of telecommuting. In other words, telecommuting fosters more telecommuting. Current literature questions if telecommuting really is a green initiative. To answer this, the resource observed is the emission of greenhouse gases and if the rebound effects from telecommuting increase it. In respect to telecommuting, all of the rebound effects are more of a vague nature and is therefore categorized as economy wide effects. Telecommuting creates new possibilities for the consumer to consume more.

Chapter 2

Introduction

2.1 Background

With increased extreme weather and rising water levels, the world is seeing the consequences of climate change. Climate change and reducing GHG emissions has been claimed the most important and complex issue of the 21st century. The international community has recognized this challenge and are attempting to reduce the negative impact of human activities on the climate. This has been done by stating ambitious goals for reducing emissions by a certain fraction in the future, according to their own emission levels in 1990. The stakeholders in the ICT sector have observed these efforts and suggested that their sector could help governments reach their targeted emission goals. With terms like "Green IT" and "Greening through ICT", the stakeholders feel like their contribution could greatly help reduce the total amount of GHG emissions released each year.

Global eSustainability Initiative (GeSI) is an international strategic partnership of ICT companies and industry associations committed to creating and promoting technologies and practices that foster economic, environmental and social sustainability and drive economic growth and productivity. Formed in 2001, GeSI has grown to over 30 members over the past 13 years and includes major players like Microsoft, AT&T and Nokia.

In 2008, GeSI published a paper, [eI08], detailing how ICT and digitalizing could help reduce GHG emissions. The analysis was performed by an independent consulting agency, McKinsey & Company. This report quickly became an interesting read to governments and organizations involved in the efforts of reducing GHG emissions. As officials requested more information about the claims of the paper, GeSI released a revised version four years later. In 2012, [eI12] was released with *"enhanced data, analysis and breadth on end-use sectors as well as change levers"*. In this report, the analysis was performed by the consulting agency Boston Consulting Group.

In [eI12], the paper stated in the executive summary that "ICT-enabled solutions offer the potential to reduce annual GHG emissions by an estimated 9.1 GtCO2e by 2020, representing 16.5% of the projected total in that year." However, these calculations do not include rebound effects. The report assumes that the individual behavior and social patterns remain the same in a new and more efficient environment. GeSI recognizes the rebound effect as important and that policy makers should be aware of it, but the report does not include the rebound effect in any way in their calculations as they are *"incredibly complicated and difficult to model"* [eI12]. While the author highly agrees with this statement, the author feels that excluding this phenomenon in total from their calculations will greatly weaken the validity of their report.

This thesis will take an in-depth look at a sector affected by ICT and see how the rebound effect comes in to play. The ambition for this thesis was first to analyze multiple sectors. Later, the author realized that the scope of the project was too large to make any intelligent coverage of multiple sectors and it was better to research one particular sector intensively instead. As it was too late to change the description of the thesis the description claims multiple sectors will be studied. There will be only one sector analyzed in this thesis. The selected subject for this thesis will be telecommuting and telework. Telework is the concept of being able to work from home and still be able to perform all the relevant tasks their job may require. It is obvious that mitigating the pollutants from commuters may significantly help reduce the stress on the environment. However, not a lot of research has been done on what fraction of that mitigated GHG emissions are induced from other pollutant activities due to telecommuting. This thesis will look at what rebound effects come in to play when an individual refrains from commuting to work and rather works from home.

This thesis will conduct an extensive theoretical analysis of telecommuting and telework. As very few papers address the issue of telecommuting and rebound effects combined, it is necessary to survey other research areas as well. A comprehensive research survey in fields like telecommuting, rebound effect, residential and commercial characteristics, commuting and others are needed to conclude on such a complex topic.

In order to answer the thesis main question, this paper tries to simulate a real world where telecommuting is introduced and adopted by a major city. The results and findings from the theoretical research aims to build up a realistic simulation model. As the years go by and a higher percentage of the workforce becomes telecommuters, how will the overall GHG emissions develop? The result of the simulation model may provide detailed information about the environmental aspects of telecommuting and how policy makers can influence telecommuting to become even greener.

2.2 Problem

This thesis is concerned with the topic of how introducing new and effective ICT solutions to a sector can produce unexpected consequences. However, addressing this as a general problem is too big and too complex for one thesis to answer. This paper will therefore narrow its focus and only target one particular sector that has been affected by the introduction of ICT. The choice of sector fell to telecommuting. Telecommuting is pointed out in a consultant report to be one of the highest contributors to mitigate GHG emissions [eI12]. Although, in that report, only the positive emission savings from telecommuters who does not commute is presented. This thesis will try to address the rebound effect of telecommuting and observe the effect it has on the overall GHG emissions. Will the rebound effect be negligible, as that report gives an impression of, or will the increase in GHG emissions be significant and therefore need to be accounted for.

It is easy to agree if a substantial amount of people refrain from commuting to work in their personal vehicles, this can have a tremendous positive effect on the environment. But what will happen when these people stay home all day? This paper will try to identify the rebound effects that stem from telecommuting. Traditionally in this field, when talking about rebound effects in telecommuting, it has been about the induced pollution from other activities that are invoked due to telecommuting. Defining the rebound effects for a specific sector is something that slightly differs for each sector so the general definition of rebound effect will not always apply. For telecommuting, an increased consumption/use of telecommuting is not important in most of the research being done. In this field, the important aspect is the environmental aspect, which can be very complex and difficult to grasp. As telecommuting was introduced as a green initiative, it is meaningful to identify how green it really is. This paper will look at what kind of activities or effects occur when workers start telecommuting. These effects might reduce our GHG emission savings or, even worse, perhaps offset it.

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* RQ1: What are the rebound effects in telecommuting?
* RQ2: How strong are the different rebound effects in telecommuting?
* RQ3: Will the reduction of GHG emissions due to telecommuting be
offset by the rebound effects?
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These are the main question this thesis is going to answer. By researching these problems, a better understanding of how to create policies to counteract unwanted behavior may be possible. With a greater understanding of the rebound effect in telecommuting, advice can be given to help international organizations and countries reduce their total emissions. In this way, this research might help them reach their ambitious goals for reducing their pollution.

2.3 Limitation

Telecommuting as a concept has a wide definition and can be used in many different situations. A worker may telecommute a couple of hours each day to avoid commuting during rush hours or commute to a satellite office and from there telecommute to the main office. When studying this subject, it is necessary to set certain boundaries to keep the thesis focused, both on the definition of telecommuting and the telecommuters.

This thesis will target workers who regularly commute to work and who will start telecommuting at least one full day of the week. The focus will be on the commuters who commute to work in their own personal vehicles. These are the workers where telecommuting may help mitigate most amount of GHG emissions. Therefore, the work conducted in this thesis might not apply to all telecommuting situations. Assumptions and simplifications that are conducted in this thesis, especially in the creation of the simulation model, will be explicitly written in the appropriate section.

2.4 Build up

In this section, an overview over the coming chapters will be presented. This is meant to serve as a quick overview for the chapters to come.

In chapter three, an overview of the current situation in ICTs, the environment and climate change will be discussed. This chapter is meant to serve as a general introduction to the problem and make the reader observant of the fact that rebound effects are introduced in almost all sectors where ICT enable quicker and more efficient consumption of resources.

In chapter four, the focus is shifted from a general view to the study of telecommuting as a concept. In this chapter, telecommuting as a policy and its promised green contribution will be discussed. Additionally, it will go into a study of what kind of jobs are suitable for telecommuting and how employers today view telecommuting.

In chapter five, the in-depth research of telecommuting and rebound effects are performed. The rebound effects are classified into four categories; home, office, commuting and social. In these categories, different positive and negative polluting effects are introduced into the environment.

In chapter six, the simulation model is carefully explained and presented. In order to translate a real world scenario into code, some simplifications and assumptions are needed. The simulation model will ultimately produce an answer that describes the long-term effects that telecommuting has on the environment.

2.5 Contribution

Firstly, a new and critical way of thinking about the ICT sector is presented. Within this sector, ICT is viewed for its great and almost limitless possibilities it can offer. ICT has increased social welfare and economic growth like no other sector even can come close to. However, the changed consumption pattern and other effects that has lead to an increase of pollution is usually forgotten. This thesis aims to highlight the negative consequences of widespread ICT usage on the environment.

In order to analyze telecommuting and its rebound effects, it is necessary to combine knowledge and research from various fields. These fields have previously been unconnected before and by combining them, a new way of viewing certain issues emerge. This thesis will introduce ways to quantify and calculate the rebound effect for telecommuting.

Lastly, a simulation model will be created. In this simulation model, all the findings from the current research will be implemented to observe what the long-term consequence of telecommuting are. The simulation model will be created as an intuitive and general rebound effect simulator in Java. This way, other researchers may use the simulation model and modify or tweak it to their individual purpose. The model will provide unique data about telecommuting and GHG emissions, and will ultimately provide an answer to how much of the mitigated GHG emissions are induced by the rebound effects.

Chapter 3

ICTs, the Environment and Climate Change

3.1 History

The world is close to celebrating 100 years of climate change awareness. It was in the 1930's that the first talk of global warming came about. Considering a scientific field this young, it is not hard to understand it is under-researched.

Let's go back to the 1930's, where the world was about to discover something that later would be labeled as global warming. Ordinary people began to see change in their local environment. Codfish and wheat could be harvested in northern zones where they had not been seen in centuries. Meteorologists confirmed what people experienced, a warming trend was on the way. At that time, popular articles emphasized the opportunities that came with this, like vast new food-producing areas could be put under cultivation. A few meteorologists warned that if the average temperature continued to increase, it would lead to rising ocean levels and deserts. This seemed for most people like a distant future [Wea08].

The idea and the existence of climate change continued to be discussed through the 20th century. The question being debated was if this was caused by Earth's natural temperature cycle or by human activities. It was not before the late 70's that the issue was introduced on the world stage. In 1979, the first World Climate Conference was held in Geneva. This conference was unique of its kind. It was one of the first major international meetings on climate change. The conference led to the establishment of the World Climate Programme and the World Climate Research Programme. It also led to the creation of the Intergovernmental Panel on Climate Change (IPCC) by World Meteorological Organization (WMO) in 1988. These institutions and programs have had an incredible impact on the development and the scientific progress of climate research in the world.

With all the new organizations, both the scientists and research became more clear and unified. The world's scientists slowly came to a consensus that these climate changes the world were experiencing in fact were driven by human activities. The next logical step is to try to stop or reduce this dangerous development. The only way possible to do this, is for all the countries to agree on a common course. In 1997, almost all countries were represented in Kyoto to discuss the road forward. The agreements made here, later got known as the Kyoto Protocol. Although, not all countries ratified the binding agreement, the meeting solidified the issue on an international stage.

3.2 Greenhouse Gases

A GHG is any type of gas in the atmosphere which absorbs and re-emits heat, and thereby keeps the planet's atmosphere warmer than it otherwise would be. GHG have been in our environment since the dawn of time, however, since the discovery of fossil fuels these levels of GHG in the atmosphere have had an exponential growth. The most common GHGs in Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone [Bra12].

Each GHG has a different global warming potential (GWP) and persists for a different length of time in the atmosphere. As GHG emissions consist of various chemical gases, each with different properties, it was found necessary to somehow study how dangerous these pollutants were relative to each other. By having a method of comparing different pollutants to each other, it make it easier to compare various pollutant sources like coal and oil.

	GHG	GWP
1	Carbon dioxide (CO_2)	1
2	Methane (CH_4)	25
3	Nitrous oxide (N_2O)	298
4	Hydrofluorocarbons (HFCs)	124 - 14,800
5	Perfluorocarbons (PFCs)	7,390 - 12,200
6	Sulfur hexafluoride (SF_6)	22,800
7	Nitrogen trifluoride (NF_3)	17,200

Table 3.1: Kyoto Gases

Carbon dioxide equivalent (CO_2e) is a term for describing different GHG in one common unit. The purpose behind it is to make it easier to compare emissions of GHG, for example methane and nitrous oxide, and to be able to know how damaging each of these emissions actually are to the environment. For any quantity and type of GHG, CO_2e signifies the amount of CO_2 which would have the equivalent impact on global warming. This is measured over a specified time period, usually 100 years.

CO_2 was used as a reference unit because it is the most common GHG, excluding water vapor.

To calculate the CO_2e, it is necessary to know what the GWP of the gas is. Table 3.1 includes GWP numbers for all of the GHG ratified in the Kyoto Protocol. So what would 1 kg of methane be in CO_2e?

1 kg CH_4 * 25 GWP = 25 kg CO_2e

3.3 Today's Reality

The current state of the climate today is worse than ever before. The pollutants in the atmosphere are at an all time high. Researchers today argue that immediate actions need to be taken in order to minimize the negative impact on the environment.

Global Climate Change Indicators

The National Oceanic and Atmospheric Administration (NOAA) is a scientific agency within the United States Department of Commerce focused on the conditions of the oceans and the atmosphere. NOAA operates National Climatic Data Center (NCDC), which is the world's largest active archive of weather data. The Center has more than 150 years of data on hand. Data is received from a wide variety of sources, including weather satellites, radar, automated airport weather stations and many other methods.

The Center provides historical perspectives on climate which are vital to studies on global climate change, the greenhouse effect, and other environmental issues. In order to prove that the climate is in fact changing, NCDC provides seven points to illustrate this.

- The global surface temperature is rising
- U.S. surface temperature is rising
- Sea level is rising
- Global upper ocean heat content is rising
- Northern hemisphere snow cover is retreating
- Glacier volume is shrinking
- U.S. climate extremes are increasing

All these arguments are documented and presented in appendix A. By looking at the values over time, it is undeniable that the climate is changing. There is also a very clear consensus among climate researchers that climate change is driven by pollution from human activities.

Current Concentration of GHG in the Atmosphere

In [BS14], the recent GHG concentrations are stated. The pre-1750 era of GHG concentrations are believed to be the natural and normal concentration of gases. After this time era, the industrial revolution and other human activities fueled the heating of the atmosphere with GHGes.

Gas	Pre-1750	Recent	% Change
Carbon dioxide (CO_2)	280 ppm	395.4 ppm	41.2%
Methane (CH_4)	722 ppb	1762 / 1893 ppb	144.0 / 162.2%
Nitrous oxide (N_2O)	270 ppb	326 / 324 ppb	20.0 / 20.7%
Tropospheric ozone (O_3)	237 ppb	337 ppb	42.2%

Table 3.2: Recent Greenhouse Gas Concentrations

The concentration of the Kyoto gases are believed to have increased 41.2% - 162.2% from the natural amount of GHG in the atmosphere. In climate research, it is impossible to identify a certain threshold that will cause the polar ice to melt or deadly weather storms to occur. So identifying how much humans may pollute before causing irreplaceable damage to the climate is therefore difficult to pinpoint. Climate researchers urge us to show caution and limit our negative impact on the world before it is too late.

3.4 Solving the Climate Problem

Almost all countries agree that climate change is a real threat to our planet. So why should it be that difficult to solve this problem? To address this, all countries need to cooperate with each other on an international level. However, getting 194 countries to agree on anything is a complex and difficult task. Let alone getting 194 countries to agree on solving the difficult issues surrounding climate change by reducing their GHG emissions.

Economics lie at the heart of this discussion. When a country is reducing its GHG emissions, that country is also indirectly reducing its GDP. This will affect the welfare of the country, which again directly affects the citizens of that country. That country now has to limit itself to only a certain amount of GHG emissions each year or else it will be fined by the international community. This implies that the percentage of reduction a country agrees to uphold is very important. Essentially, how these reduction rates are decided are important for the cooperation of a country. One country will always compare itself to the other countries, the restriction imposed on them must be fair relative to the restrictions set on the other countries.

This concept of "fair share" is tricky. If all countries are to reduce their emissions to a certain percentage of 1990 levels, that would benefit the countries that were high polluters in the 90's. Developing countries would argue that the developed countries got rich by polluting and they should have the same right to do so. Another issue is the cooperation between big countries like USA, Russia and China. They will always eyeball each other and if one is not participating, the others will hesitate to join in. When China announced they would withdraw from the Kyoto agreement, USA was quick to withdraw as well.

Another proposed method is to calculate the allowed emissions based on the amount of people in a country. This scheme would greatly benefit countries with large populations like India and China. However, rich countries may be opposed to this idea since it would mean that the developed countries have to lower their standard of living. Another way to solve this is to introduce a CO_2e tax. This levy would tax a product on where it gets sold and not where it gets produced. This means that lower income countries can have a thriving industry while not being taxed by the international community.

As discussed, there are many ways to argue what is fair or not when it comes to solving the climate change issue. Enabling 194 countries to agree on what is fair is a very delicate process. This is why climate change is the biggest challenge of the 21st century and solving this is would be the greatest success for humankind in the 21st century.

3.5 The Digital Revolution

The Digital Revolution began somewhere around the late 50's to the late 70's and is the shift from analog, mechanical, and electronic technology to digital technology. The term also refers to the broad changes brought about by digitizing and ICT during and after the 1950's. The Digital Revolution marked the beginning of the Information Age. At the core of this revolution is the mass production and widespread use of digital logic circuits, which includes devices and technologies like the computer, cell phone, and the Internet.

In today's world, a person is able to connect to anyone in the world in a matter of seconds. Information and communication technologies enable companies to fuel market growth and reach higher profits than ever before.

Efficiency Gains

The efficiency gains have a huge socioeconomic impact. A product and service in today's world is much cheaper and quicker to produce than ever before. The efficiency gains ICT is able to deliver is on an unprecedented scale. One example being voice message solutions on the telephone. In the olden days, all recordings had to be recorded at home with a home answering machine. The service providers recognized that this challenge could be solved by using ICT and therefore made the home answering machine redundant.

	Home Answering Machine	Service from telcos	Factor
Weight (kg)	1.2	0.06	20
Energy use (kWh)	13 008	5.7	230
Greenhouse effect (CO_2e)	140 000	590	240

Table 3.3: Comparison of voice message solutions

This information in the table is collected from my supervisor's, Einar Flydal, lectures. This is only a comparison between two already digital solutions. If there was an analogous version presented too, like leaving a paper note at a person's house, the efficiency factor towards that solution would be immensely higher. These efficiency gains can be seen in all possible sectors. The Digital Revolution has truly impacted every business imaginable, along with creating new and innovative ones. This efficiency factor is also partly caused by the fact that some goods can be delivered as e-goods. When sending a letter to a friend, the preferred way today is to send an e-mail. Eliminating the physical letter and the energy needed for physically delivering it to that person. Nowadays, everything is done digitally to a much greater efficiency. This change is seen in common goods like newspapers, books, movies, encyclopedias and many others.

3.6 Greening Through ICT

By looking at these enormous efficiency gains ICT can contribute, it is hard to believe that it is not the savior of the climate change problem. ICT is able to mitigate a lot of GHG emissions that otherwise would have gotten into the atmosphere. Companies and organizations that have financial stakes in telecommunication or other technology companies often point to this. They advocate that technology can help society reduce the overall GHG emissions. This is documented in both of the reports published by GeSI [eI08] [eI12]. The two reports from GeSI called for the increased use of ICT in the daily life of the average citizen to help governments reach their reduced climate goals.

The organization behind these two reports hired consultant agencies to help dissect and quantify what ICT could contribute on the global level. The reports conclude that an increased usage of ICT could benefit the climate in the long term. The term greening through ICT is what describes this phenomenon. Unlike green IT, which focuses on lowering energy consumption for devices, greening through ICT focuses on how ICT can be used to lower other sector's emissions. It is known that the ICT sector would increase their emissions, however, the other sectors would reduce their emissions by a greater amount. This is a potent selling point to the world's government looking to tackle the issue of increasing emissions each year [Tom10].

3.7 EU and the Low-Carbon Economy

International organizations and governments all over the world are preparing for the next economical shift in the world's economy. The recognition of skewing businesses' carbon footprint into low carbon or carbon free businesses are vital. Incentivizing this from a legislator standpoint is crucial for the successful adoption into a greener world.

The first step to a low-carbon economy is improving energy efficiency. In this way, the carbon footprint will be reduced. The next part in realizing the low-carbon economy is a bit more farfetched. This part requires new innovative solutions, including new technologies and new energy sources that may not even exist yet. One way to make this part occur is to invest in companies that are developing clean technologies and clean energy sources. The concept of a low-carbon economy is an idea of how to act today in order to realize a green future tomorrow. [Del06]

The EU is one of these organizations that have made a big effort into this idea. The EU is one of the leaders within climate research and have established their own independent climate groups that are dedicated to this field. Institute for Prospective Technological Studies (IPTS) is one of the seven scientific institutes of the European Commission's Joint Research Centre. In 2004, IPTS published a report that aimed to explore and assess the way that ICTs influence environmental sustainability between 2004 and 2020. As future political and economic development is difficult to predict, the report showcased three different likely scenarios. In [EHGA04], the authors give policy recommendations to show how ICT can be used to lower the output of GHG into the atmosphere.

The EU has recently published an extensive roadmap for the enabling of the low-carbon economy in 2050, called Decarbonisation Roadmap 2050. In [EAGF11], the authors analyze the EU's climate policy. The authors claim the current scheme for incentivising businesses to reduce their carbon footprint in the EU generally is effective and is especially effective for the larger companies.

3.8 Jevons Paradox

Return to a few decades after the industrial revolution. Businesses were booming as never before and the economic growth was unprecedented. A fundamental element of the revolution was the introduction of the coal-fired steam engine. James Watt, a Scottish inventor and mechanical engineer, observed that the current design of the steam engine wasted a great deal of energy by repeatedly cooling and reheating the cylinder. Watt introduced a new design of the steam engine. This design was more efficient and could be run with less coal. A natural theory stemming from this would be that coal would be in lesser demand than before. However, a strange paradox became evident.

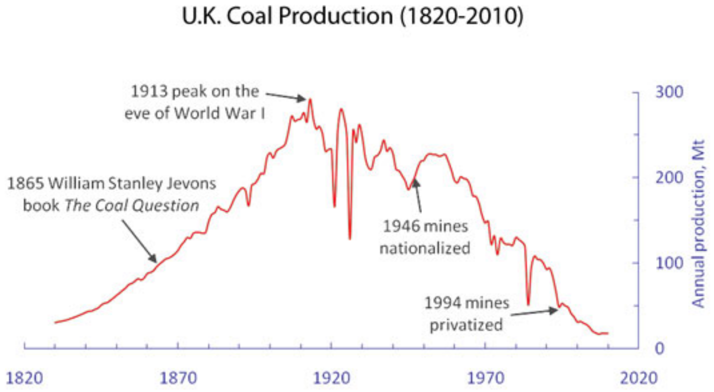


Figure 3.1: Consumption of coal in the UK over the years

William Stanley Jevons was an English economist and logician. In 1865, Jevons described this problem for the first time. Jevons published the book [JF65] in that same year. Watt's innovations made the coal engine a more cost-effective power engine which lead to an increased usage of this engine as a power source in various industries. This lead to an increased total coal consumption, even as the amount of coal needed for completing one particular task went down. At this time in Britain, many were worried about the dwindling coal reserves, but some experts argued that the improving technology would reduce coal consumption. This, however, was far from the truth and led to Jevons' famous quote: "*It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth.*" Jevons argued that the experts view was incorrect, as further increases in efficiency would tend to increase the use of coal. Hence, improving technology would increase, rather than reduce, the rate at which England's coal deposits were being depleted. [JF65]

Jevon describing this paradox was the first step in the direction of introducing a concept called rebound effects.

3.9 The Rebound Effect

In the 80's, the two economists Daniel Khazzom and Leonard Brookes independently brought forward controversial ideas about energy consumption and behaviour. They claimed that energy efficiency, paradoxically, has a tendency to increase energy consumption rather than decrease it. In 1992, the US economist Harry Saunders labeled this idea as the Khazzom-Brookes postulate.

Khazzom-Brookes Postulate

Just like the Jevon Paradox, the Khazzom-Brookes postulate states that a reduction of total consumption due to efficiency gains are largely counter-intuitive. At that time, there were some examples of a more energy efficient solution, that on the overall level, increased the energy usage rather than decreasing it. *"The effect of higher energy prices, either through taxes or producer-induced shortages, initially reduces demand but in the longer term encourages greater energy efficiency. This efficiency response amounts to a partial accommodation of the price rise and thus the reduction in demand is blunted. The end result is a new balance between supply and demand at a higher level of supply and consumption than if there had been no efficiency response."* [Her98].

Increased energy efficiency can increase the energy consumption in three ways. One, the increased energy efficiency makes the energy use relatively cheaper and that can encourage increased use. Two, the increased energy efficiency causes the economy to grow, which increases the general use of energy across the whole economy. Three, increased efficiency in any one bottleneck resource multiplies the use of all companion technologies. One example is if the fuel efficiency of cars go up, it can be offset by an increased number of cars and commuting trips. So instead of the total demand of fuel going down because of an improvement in fuel efficiency, it will cause an increase in the usage of fuel.

Rebound Effect

The research performed by Khazzom and Brookes laid the foundation for what conservation and energy economics would soon call the rebound effect. The rebound effect refers to the behavioral or other systemic responses that naturally enter a system when a new technology increases the efficiency of a resource. The rebound effect tends to offset some of the beneficial effects of the new technology. While the main focus of the current literature on the rebound effect has been on energy consumption, the rebound effect can be used on any natural resource or other input, such as labor or GHG emissions. The rebound effect is often expressed as a ratio of the lost benefit compared to the expected environmental benefit when holding consumption constant.

For example, if a 5% improvement in vehicle fuel efficiency results in only a 2% drop in fuel use, there is a 60% rebound effect (since $\frac{(5-2)}{5} = 60\%$). The 'missing' 3% have been consumed by driving faster or further than before.

The rebound effect is well-documented in the current literature and its existence is undisputed. However, the debate on the rebound effect is more focused on how significant it is. There are three possible outcomes for the rebound effect:

1. **Rebound Effect $<$ 100%**
   The actual resource savings are higher than expected. The rebound effect contributes to less use of the resource. Usually, this will occur with the help of government policies if they mandate the use of a more costly but highly efficient technology. This is not a common outcome.

2. **0% $<$ Rebound Effect $<$ 100%**
   This is the most common outcome of empirical studies on the rebound effect. The actual savings are less than the expected savings. This is sometimes referred to as the "take-back" effect.

3. **Rebound Effect $>$ 100%**
   The case of the Jevons Paradox. The actual resource savings are negative. This is sometimes referred to as the "back-fire" effect.

The rebound effect can be divided into three separate categories: direct, indirect and economy wide effect.

- **Direct Rebound Effect**
  Increased efficiency lowers the cost of consumption, and increases the consumption of that good because of the substitution effect.

- **Indirect Rebound Effect**
  Through the income effect, decreased cost of the good enables increased consumption of other goods and services, increasing the consumption of the resource embodied in those goods and services.

- **Economy Wide Effect**
  New technology creates new production possibilities and increases economic growth.

Chapter 4

Telecommuting

4.1 History

Telework and telecommuting are both terms that are used interchangeably. These terms were first coined in 1973 when ICT slowly started to make a significant impact on the working world. With these new tools available, it was now possible for workers to perform their jobs nearly anywhere. The efficiency invoked by telecommuting is heavily dependent on the technology being used. As the devices and the technology have been steadily improving since the 70's, the adoption of telecommuting are believed to increase as well.

In one way, the US Federal government can be seen as a contributor to the birth of telecommuting. Jack Nilles, who is thought to be the father of telework, started to telecommute from Los Angeles to Washington DC as a government employee in the 60's. Nilles was working as a consulting rocket scientist to the US Air Force Space Program. Inspired by this experience, Nilles coined the term telecommuting and telework in 1973. He began promoting the value and importance of the concept and thus gave birth to the telework movement. The government funded the first work arrangement that would later be known as telecommuting. However, despite Nilles efforts to promote telecommuting, the Federal government did not catch interest until some years later. [Joi00].

This early lack of Federal interest enabled the state government of California to earn the distinction of being the first major public sector entity to adopt telework. As Nilles stated; *"...after completing the NSF project in 1974, I was unsuccessful in inducing any other federal agency to test telework or support further research on it (it was no one's "mission"). So I ended up talking the state of California into it a decade later in order to have a platform for making the impact results public."*. It was not before the late 70's and early 80's the Federal government started performing experiments with telecommuting. From that point on, the Federal government has been a strong supporter of telecommuting. In 2010, the Telework

Enhancement Act of 2010 was signed into law December 9, 2010. This act requires that Federal agencies create telework policies for all eligible employees as well as training programs for teleworkers and telework managers.The act is a key factor in the Federal Government's ability to achieve greater flexibility in managing its workforce through the use of telework. [Joi00].

Jack Nilles and his research paved the way for other organizations to see the benefits of telecommuting. And therefore, effectively expanding this phenomenon into the private sector and the daily life of many workers around the world.

4.2 Greening Through Telework

Reports like [eI12] emphasize the drastic reduction in GHG emissions an initiative like telework could prompt. In the report, the authors state that the transport sector is one of the biggest polluters. The potential for reducing emission in this category is immense. Telecommuting removes the daily commute of a worker by enabling them to work from home instead. At first glance, the outcome is very appealing. This worker is no longer using their car and these avoided commutes will save the environment from GHG emissions.

This is a very compelling selling point from stakeholders in the ICT business. The big players within the Telecom and Internet markets are jointly financing an organization called GeSI. GeSI constitutes firms such as AT&T, Microsoft and Nokia. In 2008 and 2012 GeSI published a paper with a focus on how ICT can help the world become greener by reducing emissions in other sectors. This has been called greening through ICT. As the ICT helps other sectors dramatically reduce their pollution levels, the ICT sector will only increase their pollution level to some degree. GeSI hired the consultant firms Boston Consulting Group and McKinsey to perform analysis and verify their results. In both reports, it was concluded that ICT can help other sectors reduce their carbon footprint significantly while maintaining economic growth.

Achieving these incredible reductions in GHG emissions could be very beneficial for governments around the world. The majority of governments in developed countries have signed treaties and set ambitious goals for reducing their carbon footprint on the environment. In order for this to happen, the government and private companies have to work together. Governments can help private companies make it more profitable to go green by introducing various incentives. A company helping the government reach such goals can be rewarded with tax deductions or similar monetary benefits. The public will therefore sponsor firms that are green and try to reduce their pollution levels. In other words, the government can sponsor ICT businesses, like the members of GeSI, to build infrastructure in their country which in the long-term will mitigate GHG emissions.

Induced Activities & Resource Use

When an individual is changing their daily life, this may lead to a shift in their consumption pattern. This can lead to activities or consumption that would not have occurred otherwise. These new activities and consumption patterns may come with some negative consequences in regard to pollution. Telecommuting is changing the daily life of workers and changes in consumption patterns are therefore a natural consequence. These new changes can be divided into four different categories; home, office, commuting and social.

4.3 Suitable Jobs for Telecommuting

All jobs cannot be performed by telecommuting. Jobs that require a physical presence are very difficult if not impossible to perform off-site. The nature of telecommuting makes some jobs more suitable for this practice than others. It is important to identify these types of jobs in discussing the adoption of telework. Usually, both the company and the workers have to agree to such an arrangement. As telecommuting often requires some kind of investment in electronic equipment and other expenses, upper management is heavily involved in the decision of telecommuting.

To determine if a job is fitting for telecommuting, the characteristics of the job can be analyzed to identify potential benefits and drawbacks of implementing such a work arrangement. A theory known as the *Job Characteristics Theory* [HO76] aims to break down a job into five different categories; skill variety, task identity, task significance, autonomy, and feedback. These five categories will affect five work-related outcomes; motivation, satisfaction, performance, and absenteeism and turnover. If these five characteristics of a job are present, then the employee will experience more *"internal work motivation, satisfaction with personal growth opportunities, general job satisfaction, higher job performance, and lower absenteeism and turnover"* [HO76]. Studies have shown that job characteristics influence employee's behaviors and attitudes [FF87]. For an employer thinking about allowing telecommuting, this is an important aspect to consider. Of the mentioned job characteristics, telecommuting changes the categories autonomy and feedback more compared to regular work. This can impact the employee's behavior and attitude toward their job. According to *Job Characteristics Theory*, changes in autonomy and feedback influence work behaviors and attitudes more than a change in skill variety, task identity, or task significance [HO05].

- **Autonomy**
  Autonomy is characterized as responsibility such that if the job provides freedom,

independence, and scheduling flexibility, the individual should feel responsible for their work outcome.

- **Feedback**
  Feedback refers to the degree that an individual receives direct and clear information about his or her performance related to work activities.
- **Skill variety**
  Skill variety is the degree that a job requires a variety of activities and skills to complete the task.
- **Task identity**
  Task identity is the degree that the individual sees work from beginning to end or completes an identifiable or whole piece of work rather than only a small piece.
- **Task significance**
  Task significance is the degree that the individual feels his or her work has a substantial impact on the lives or work of other people within the organization or outside of the organization.

However, the individual may vary in their reactions to the job characteristics in telecommuting. For example, some workers may manage their job tasks well without the need to get feedback in a face-to-face situation.

4.4 Motivation and Drawbacks

When adapting to a new work arrangement like telecommuting, different parties are often motivated by contradicting goals. For a successful transition over to a new work system like telecommuting, there is a lot of different interests that have to reconcile, most of them economical. The key pieces in this puzzle are the employee and the employer. However, there are also other parties that could potentially gain from workers becoming teleworkers, such as the government, local authorities and other commuters.

This chapter will go through motivations and drawbacks for each of the involved parties. This new work arrangement will affect all parties to a varying degree. The benefits and drawbacks of telecommuting are mainly drawn from [RB09], [PSdLC02] and the author's own intuition.

Employee

For an employee, telecommuting may present many new opportunities and disadvantages. The main selling point for most workers is the time saved from commuting.

There is no longer a need to spend thirty minutes in traffic to work. This extra time may lead to a better work-life balance for the telecommuter. This again might lead to increased job satisfactions as flexible arrangements like telecommuting make the work more individually suited. By reducing the total amount of time spent associated with work, the worker will get a virtual raise by removing one hour of travel time.

Telecommuting may also lead to serious drawbacks for the workers as well. By being home, the worker never feels as if they left work. A less structured work day may lead to confusion of when to perform certain tasks and that may ultimately result in time management issues. The extreme end of it may be that the worker always feels the need to put in work, and ultimately, becomes a workaholic. By having the work environment shifted to their own home, the space and noise management of the house can interfere with the job performance of the workers. An employee that spends too many days telecommuting may also feel social isolation from the other employees. Telecommuters are excluded from the social interactions that naturally occurs when being stationed at the office. The lack of on-site IT personnel or a help-desk service can impact the response time in solving an issue. The lack of rapid technical support can decrease the efficiency and productivity of telecommuters.

Employer

The biggest concern for an employer is to maintain or even increase the productivity of the workers. There are many reports that conclude that telecommuting can increase the employee's productivity. By enabling the workers to work from home, this can lead to great cost savings for the company. Chapter 5.4.2 contains historical examples of companies that have implemented telecommuting which has made it possible to reduce expenditures associated with the office. For an employer that is flexible with their employees, it is easier to retain the workforce. A company with good workforce stability use less resources in finding and training new employees.

Telecommuting empowers the employees to take more control over their own work day. This loss of control for an employer can seem intimidating. A telecommuter also needs a few basic resources and equipment in order to perform their job. The equipment usually consists of a cell phone and a computer. The employer is often left with the equipment acquisition and the maintenance cost of the devices. Another risk introduced by letting the telecommuters work off-site is the potential difficulties with data security. The safe transfer of data between home and office should not be disregarded for companies that work with sensitive data.

Other Parties

For the local and Federal government, there are almost no negative consequences of telecommuting. In the transport sector, telecommuting helps to reduce the overall traffic and road congestion that is an increasing problem for major cities. Telecommuting is also said to increase productivity, which will help grow the economy and the country's GDP.

If more people telecommute, the rest of society will get quicker travel times for their commute, assuming there are traffic congestion problems in the city. Telecommuters are also more inclined to spend their money where they are. This is beneficial to the local communities where the telecommuters reside, as it will help the local community develop and grow.

4.5 Today's View On Telecommuting

A lot has been said about telecommuting through the decades of its existence. Many predictions about future growth and adoption rate of telecommuting have been stated. So what is today's view on telecommuting? The overall view from both private and public sector is positive. In general, employers and upper management view this as a proper work arrangement that helps promote efficiency and productivity.

An early adopter of telecommuting is AT&T. In 1992, AT&T established a formal, corporate-wide telecommuting policy. Their initial reason for implementing this work arrangement was to reduce automotive emissions. Since 1992 telecommuting benefits have been increasingly recognized within AT&T. As they implemented, promoted and evaluated their program, they found that flexible work arrangements produce productivity gains and employee commitments that benefit the enterprise. In order to emphasize their broader focus on telecommuting, rather than just substituting travel to and from a traditional workplace, AT&T instead started using the term telework [ABR02]. Companies like Cisco, IBM, Hewlett Packard and Fortis Bank are all acknowledging the conclusion reached by AT&T on telecommuting. At Cisco System in San Jose, management observed a 20 percent average productivity increase among teleworkers [IV04].

But not all companies share this passion for telecommuting. When Yahoo hired Marissa Mayer as their new CEO, one of her first acts as commander in chief was to remove the ability to telecommute. Software engineering projects in places like Yahoo are extremely complicated and need a broad collaboration from a big group. Her intention by denying telecommuting was to promote better communication within teams. In media richness theory, the richest media for communication is face-to-face. Below face-to-face communication is video conferencing, then telephone, addressed documents and finally at the bottom, unaddressed documents. By forcing her employees to use the richest media, she believed this would stimulate collaboration and produce better products. Research in media richness theory have found individual preferences of what stimulates workers to group commitment. In virtual groups, some workers achieve more group commitment from face-to-face meetings than others [WKB03]. By enforcing a company-wide ban of telecommuting, Yahoo will prevent employees that do not work productively at home from using telecommuting. However, Yahoo is not singling out workers that would manage this kind of work arrangement in a positive way for the company. Mayer said in an interview that this decisions *"... has fostered a collaborative, inventive environment"*. She continued that there was never the intention of launching a debate over telecommuting, she said *"we were just saying that it's not right for us, right now"*.

This kind of thinking is familiar with other technological companies as well. However, no one has taken such a firm stance as Mayer. Mayer was previously an executive and spokesperson for Google. Many believe her firm stance on telecommuting comes from Google's own experience and data on that kind of work arrangement. Google is not a firm to promote telecommuting either. Google's chief financial officer, Patrick Pichette, stated, *"The surprising question we get is: 'How many people telecommute at Google?' And our answer is: 'As few as possible.'"*.

Chapter 5

Rebound Effects from Telecommuting

When a worker starts telecommuting to work, a lot of things change. Some of these points are well studied, while others are just briefly touched upon in current literature. To fully understand the comprehensive nature of such a complex work arrangement as telecommuting it is important to study and apprehend all the different aspects of it.

Current literature points to the four most important environmental effects in regard to telecommuting [KH08]. These are transportation, use of electrical equipment, energy consumption, in the home and in the office. This thesis will discuss all of these environmental effects while also examining other more complex effects.

When analyzing the different aspects of telecommuting, it is vital to define certain aspects of it. This is to make certain simplifications and impose some limitations to make it possible to model such a universe.

5.1 Assumptions

The study presented in this paper will focus on telecommuting in Los Angeles and California as a whole. However, the research will attempt to keep a general approach to the subject so the results will be easily transferable to other regions. In order to analyse telecommuting in Los Angeles, some assumptions need to be taken. These assumptions may be unique to Los Angeles and therefore not applicable to other regions. This thesis makes three important assumptions about telecommuting in Los Angeles.

1. Active householder
2. Drives alone to work
3. Dedicated home office

A householder is a person who is the head of a household. This analysis assumes that each worker is an active householder who is interested in saving money. This is done by turning off heating, ventilation, and air conditioning (HVAC) systems and electronic devices in the house when they are not needed.

In states like California, there are no real public transportation options for people wanting to commute to work. In 2000, 72% drove alone to work and 77% are pleased with their transportation mode to work [Bar06]. Ten year later, 75% of the workforce commuted alone in a private car to work [MR11]. Therefore, most commuting to work is in people's own, personal vehicles. This reinforcing effect has kept California as one of the highest ratios of people to car states in America. So for an average Californian, the car is the only real transportation mode to get anywhere.

If a person is telecommuting, it is assumed that the worker will have a dedicated room in the house to work. In a paper that describes the implementation of telecommuting, having a dedicated room as a home office is recommended for telecommuters [Ham02]. This room would have been left untouched and unused if it had not been for telecommuting.

5.2 Energy Sources

If a telecommuter is consuming more energy than before, it is important to know what kind of energy source they use as GHG emissions differ depending on the energy source. In order to calculate the GHG emissions from the rebound effects from telecommuting, it is first necessary to find the various energy sources used. A complete analysis of a telecommuting world requires in-depth research of the energy sources and their polluting effect on the environment.

Energy is on a similar level of consumption in both residential and commercial sectors in California. Official statistics provided from the U.S Energy Information Administration shows that in 2012 the residential sector used 13.9% and the commercial sector used 12.0% of the energy consumption in California. In this report, the transportation sector is the major energy user with 50.0% of the energy consumption. In another report, the commercial sector was consuming slightly more energy than the residential sector [oESD13]. Seeing how the residential and commercial sector is almost identical in overall energy use, it is now necessary to see if these two sectors differ on the type of energy source used. Although it would be beneficial to consider that there are more residential houses than commercial buildings.

5.2.1 Residential Sector

In 2011, the residents of the city of Berkeley used 78% and 22% of residential energy consumption on natural gas and electricity, respectively [oESD13]. The main sources of residential natural gas consumption are water heating and space heating [oESD13]. This trend is also visible in the state as a whole. According to U.S. Department of Energy, about 71% of the California homes use natural gas to heat during the cold season, while 22% of California homes use electricity instead. The last 7% is spread over a various category of energy sources, but mainly propane. In highly urbanized areas, like Los Angeles, the percentage of this last category is much lower [CHJ+12].

In order to gain more knowledge about the consumption pattern, the next step is to find out what energy is spent on in the house. The report [EIA09] gives information about the consumption pattern of households in California. This information will prove useful later when calculating the energy use of heating and cooling a home office.

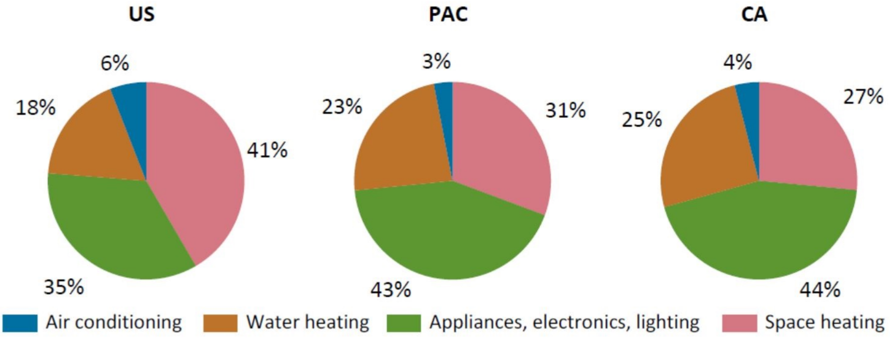


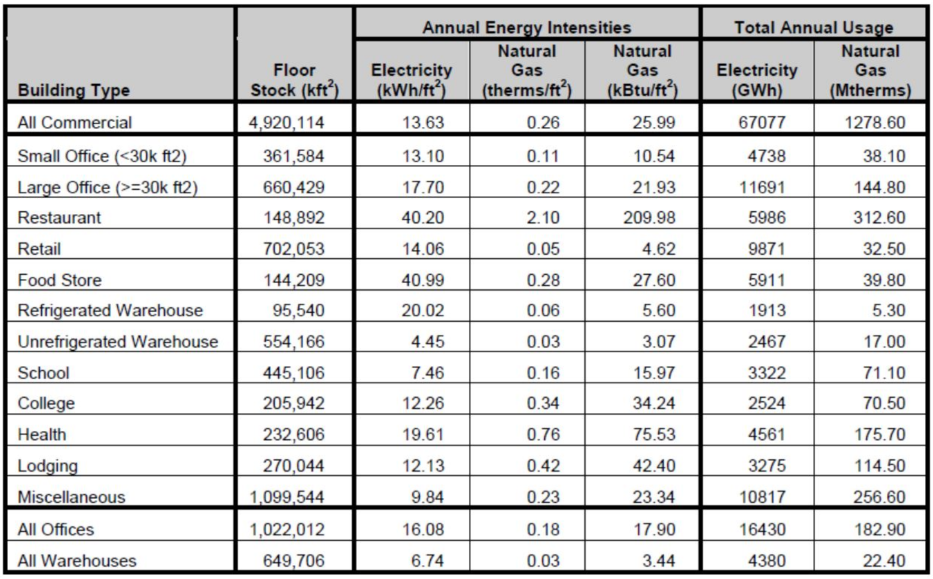
Figure 5.1: Residential consumption by end use

This illustration above shows the average energy consumption for households. US is the national average, PAC is the average of the pacific states (Alaska, California, Hawaii, Oregon and Washington) and CA is the average household consumption in California. These three pie graphs look very different and there is a good reason for that. Since California has a milder climate than most states, this impacts how the energy is spent in this state. It is clear that Californians spends less of their energy on heating relative to the other categories. It is also worth noting that Californian households use less energy in general than other households in America. The major energy drain in California is appliances, electronics and lighting. Thereafter, space heating and water heating are listed as energy demanding services.

5.2.2 Commercial Sector

A commercial sector consists of business establishments that do not engage in transportation or in manufacturing or any other types of industrial activity. Examples of such businesses are agriculture, mining or construction. Commercial establishments include restaurants, hotels, motels, wholesale businesses and retail stores among others. This thesis is concerned with telecommuting and the only relevant building types within the commercial sector are the ones that are able to adapt to this. This excludes establishments such as restaurants, retail, food stores, and warehouses. In order for a business to adopt telecommuting, it needs to provide the ability to work off-site. The establishment type within the commercial sector that is best adjusted for this purpose is the office. Office-based workers are a majority of the telecommuters in today's world. Around 90% of teleworkers work in managerial, professional, associate professional and technical, and skilled trade occupations within an office [DB07].

In a report prepared for the California Energy Commission, an extensive survey of the commercial sector has been performed regarding the end use consumption of energy. The report categorizes the offices into two categories; small offices and large offices. Small offices are defined as less than 30,000 ft^2 and large offices are equal to or bigger than 30,000 ft^2.



Building Type	Floor Stock (kft^2)	Annual Energy Intensities			Total Annual Usage	
		Electricity (kWh/ft^2)	Natural Gas (therms/ft^2)	Natural Gas (kBtu/ft^2)	Electricity (GWh)	Natural Gas (Mtherms)
All Commercial	4,920,114	13.63	0.26	25.99	67077	1278.60
Small Office (<30k ft2)	361,584	13.10	0.11	10.54	4738	38.10
Large Office (>=30k ft2)	660,429	17.70	0.22	21.93	11691	144.80
Restaurant	148,892	40.20	2.10	209.98	5986	312.60
Retail	702,053	14.06	0.05	4.62	9871	32.50
Food Store	144,209	40.99	0.28	27.60	5911	39.80
Refrigerated Warehouse	95,540	20.02	0.06	5.60	1913	5.30
Unrefrigerated Warehouse	554,166	4.45	0.03	3.07	2467	17.00
School	445,106	7.46	0.16	15.97	3322	71.10
College	205,942	12.26	0.34	34.24	2524	70.50
Health	232,606	19.61	0.76	75.53	4561	175.70
Lodging	270,044	12.13	0.42	42.40	3275	114.50
Miscellaneous	1,099,544	9.84	0.23	23.34	10817	256.60
All Offices	1,022,012	16.08	0.18	17.90	16430	182.90
All Warehouses	649,706	6.74	0.03	3.44	4380	22.40

Figure 5.2: Commercial consumption by end use

The report gives information about energy consumption depending on the size of the floor space. The larger the floor space, the more energy, on average, the establishment consumes. This leads to the next question; how is it possible to determine the floor space of an office?

Floor Space

It is a known fact that office walls are closing in on workers. A shift to an emphasis on teamwork and the reduction of personal offices have propelled this trend. Office employees in the 1970's could enjoy much more space than their colleagues today. Employment density refers to how many workers there are to the total floor stock. In the 1970s, American corporations typically thought they needed 500 to 700 square feet (46 to 65 square meter) per employee to build an effective office.

In 2003, United States Energy Information Administration (EIA) published The Commercial Buildings Energy Consumption Survey (CBECS) which is a national sample survey that collects information on the stock of U.S. commercial buildings. In this report, EIA data show a national average of about 430 square feet (40 square meter) per worker for office buildings.

An article posted in the LA Times (2010) claims that today's average is around 200 square feet (18.5 square meter) per person. The article cites Peter Miscovich, who studies workplace trends as a managing director at brokerage firm Jones Lang LaSalle. This amount of space is also something that is recommended in the industry as a standard. According to OfficeFinder.com, in typical office scenarios, you can estimate 175-250 square feet per employee. The employment density has, as stated, been sliced in half during the last 30 years in corporate America.

When using the fact that offices on average have 200 square feet per employee, it implies that an office becomes a "large office" when the company has 150 or more employees. If the company has less than 150 employees it means that it is labeled as a "small office".

Number of Employees

By using the data from the report for California Energy Commission, the core metric used to estimate energy consumption is floor space. As previously stated, floor space of a commercial building is dependent on the number of people, so it is now necessary to determine the number of employees in the various offices in downtown Los Angeles.

However, there does not exist any statistical distribution over number of employees in offices in downtown Los Angeles or in any other major city in the US. That makes it difficult to make an informative decision on this matter. Knowing this distribution is, however, not imperative to the end result of this thesis. This will not impact any of the results that are found on telecommuting or rebound effects, but will affect the calculation of the flexible office concept. As the total number of employees in downtown Los Angeles is known (half a million), the number of employees per firm will impact how many offices there are.

5.2.3 Climate & Temperature

With some cities having over 325 days of sunshine a year, California is widely known for its sunny weather and hot temperatures. However, California is a large, drawn out state with almost all climates represented in it. So even though we are discussing one state, it has an impact where in the state the commuter is situated.

	Sacramento	San Francisco	Los Angeles
January	12 / 4	14 / 8	22 /10
February	16 / 6	16 / 9	23 / 11
Mars	19 / 7	17 / 9	24 / 12
April	22 / 8	18 / 10	26 / 13
May	27 / 11	19 / 11	27 / 16
June	31 / 13	20 / 12	30 / 18
July	33 / 15	20 / 13	32 / 19
August	33 / 14	21 / 13	33 / 21
September	31 / 13	22 / 13	33 / 20
October	26 / 11	21/ 12	29 / 16
November	18 / 6	18 / 11	25 / 13
December	12 / 4	14 / 8	22 / 10

Table 5.1: High and Low Average Temperatures in Various Cities in California

In the table above, some cities in California are presented with their average high and lows for each month. This is to help show the disparity in temperatures that cities in the same state can have.

In appendix B, the daily energy consumption of offices are presented. Here it is clearly visible that the energy consumption is highly dependent on the temperature. The consumption varies greatly on the season and if the day is considered as hot, cool or an average day. It was not possible to find this kind of research for residential houses but it is assumed to be very similar when it comes to seasonal fluctuation of energy consumption. There is a discrepancy between the residential houses and office buildings in energy consumption on the weekends. A residential house is not empty on weekends as most commercial buildings and offices.

5.2.4 Emissions From Natural Gas

According to the EIA, natural gas is most widely used in homes and commercial buildings for space heating and water heating. The residential and commercial demand for natural gas is therefore highest during the cold periods of the year. Since few people cool their home or business in summer with natural gas air conditioners the summer demand is much lower.

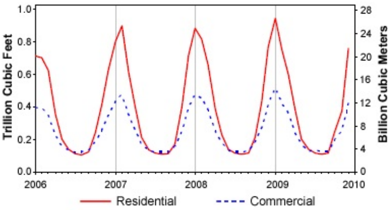


Figure 5.3: Residential and commercial demand for natural gas

In energy statistics, the household's yearly energy consumption is often listed in British thermal unit (BTU). BTU is a traditional unit of energy equal to about 1055 joules. A joule is the amount of energy needed to cool or heat one pound of water by one degree Fahrenheit. In our daily language, the joule, the SI unit of energy, has largely replaced the BTU. In order to calculate emissions from natural gas, it is necessary to have a method to transform BTUs into the scientific unit of measurement joule or kilowatt hour (kWh). When performing these calculations, it is important to recognize that the energy content of natural gas varies with the composition of the natural gas. Other important characteristics are the quality of the natural gas and how it is burned. Therefore, calculating the emissions from a general gas source will always have some variations.

In [HSI11], the author investigates the GHG footprint of natural gas. In order to calculate the footprint, the author includes the total GHG emissions from developing and using the gas. The result is expressed as CO_2e per unit of energy obtained during combustion. The paper includes analysis of both conventional natural gas and shale gas. However, the shale gas is not used in California and is therefore irrelevant for this thesis. The report gives an estimate for both the 20-year and the 100-year time horizon. The 100-year time horizon has been the standard way of calculating emissions in the industry, and this thesis will continue to use this time horizon as reference. As for reasons mentioned earlier, the emissions related to natural gas will fluctuate and the estimate will include a maximum and minimum estimate. In the 100-year time horizon, the report gives an estimate between 21 and 28 grams Carbon per million joule. In the calculations that follows, an average of these two estimates will be taken.

A Californian Household

Californian households consume 62 million BTU annually [EIA09]
78% of the energy consumed is generated with natural gas [oESD13]
0.78 * 62 million BTU = 48.36 million BTU used on natural gas
48.36 million BTU = 51 023 mega joules
24.5 gram Carbon per 1 mega joules [HSI11]
51 023 * 24.5 grams = 1.25 Metric Tons CO_2e

A Californian Office

Given a office with a floor stock of 30 000 ft^2
Then the BTU is 30 000 * 1 000 * 17.9 = 537 million BTU
537 million BTU = 566 565 mega joules
24.5 gram Carbon per 1 mega joules [HSI11]
566 565* 24.5 grams = 13.88 Metric Tons CO_2e

5.2.5 Emissions From Electricity

Electricity as an energy source is tricky when it comes to GHG emissions and its polluting effect on the environment. Electricity can be generated in numerous ways, which makes it difficult to generalize as an energy source. The generation of electricity may range from environmentally friendly to very pollutant sources. It can be generated from water fall, solar panels, nuclear reactors, burning of fossil fuel and in many other ways. Identifying how much GHG emission is related to 1 kW usage, it is necessary to know how the electricity was generated. Therefore, to analyze this part it is necessary to know how the electricity was generated for a specific city or area.

In [SRG03], the authors analyze the different energy sources used for generating electricity. They present a cost analysis of the different energy sources and how much these sources pollute the environment per kilowatt electricity produced. From that, they suggest solutions and policy changes to help reduce the overall GHG emissions. However, the paper only concentrates on carbon emissions and ignores the impact of other GHG gases. As this paper has stated earlier, it it is important to include all relevant GHG when performing a pollution analysis. This is a significant limitation of their paper but their conclusion will still give a valuable insight to how environmentally friendly each of these energy sources are for generating electricity.

The table above, from [SRG03], shows how different energy sources emit carbon dioxide to the atmosphere. These estimates are based on Annex I countries, which the US is part of. Annex I countries committed themselves specifically to the aim of returning individually or jointly to their 1990 levels of GHG emissions by the year

Energy Source	Technology	Emissions (g C/kWh)
Coal	PF + fgd, NOx, etc	229
Coal	IGCC and super-critical	190 - 198
Gas	CCGT	103 - 122
Coal	PF + fgd + CO2 capture	40
Gas	CCGT + CO2 capture	17
Uranium	Nuclear	0
Water	Hydro	0
Wind	Wind turbines	0
Biofuel	Biomass IGCC	0
Solar	PV and solar thermal	0

Table 5.2: Carbon emission from various energy sources

2000. The only difference in the estimates for the non Annex I countries are the first row, which have a higher amount of gram carbon dioxide per kilowatt hour. These carbon emission numbers presented are long-term carbon emission and does not take into account constructing the infrastructure. It is only how much carbon dioxide is emitted when producing an additional kWh. As the table shows, the most polluting energy source to produce electricity is coal.

When discussing these different energy sources, it is necessary to clarify an additional limitation. Potential environmental issues concerning nuclear waste or other catastrophes that may occur to certain energy sources are not touched upon in this thesis. Therefore, this paper will only discuss the energy sources and their GHG emission.

California is one of the largest users of energy in the US and the electricity generated comes from various sources. The electricity generated is divided into 46.5% from natural gas, 15.5% from coal, 14.9% from nuclear, 13.5% from renewable and 9.6% from large hydro. In California, there are many different providers of electricity inside the state, so these percentages will vary when looking at cities or areas within the state.

Statistics from the Los Angeles Department of Water and Power (LADWP), which is responsible for delivering water and electricity to Los Angeles and surrounding communities, differ greatly from the statistics for the state of California. The electricity generated for LADWP comes from 52% from coal, 26% from natural gas, 11% from nuclear and 11% from hydropower and other water sources. How big these different fractions are have a great impact on how environmental friendly the electricity generated is. When discussing how green electricity is, it is always important to know how it was produced.

Emissions From Electricity Generation

As discussed earlier, how environmentally friendly electricity actually is depends on how the electricity was generated in the first place. This will therefore impact the result of emissions of carbon per energy unit generated.

Californian average
0.465 * 112.5 + 0.155 * 229 + 0.149 * 0 + 0.135 * 0 + 0.096 * 0 = 88
88 gram Carbon per kWh
(24.4 gram Carbon per MJ)

An interesting observation here is that consumption of natural gas and electricity in California today share a remarkable thing in common. The GHG emissions related to the consumption of electricity and natural gas are almost identical. For a consumer that is environmentally conscious in this region, it is difficult to make the suggestion on which energy source to consume more of. Since the generation of electricity may rapidly change the distribution of energy sources, it is hard to tell if it will be more or less green in the future. However, it looks like California is trying to introduce more renewable sources into their electricity grid. Although, it is impossible to say for sure.

However, since this analysis is set in Los Angeles, this thesis will use the numbers from LADWP. LADWP uses more coal in their electricity generation and this will of course make it less environmentally friendly than the Californian average.

LADWP
0.26 * 112.5 + 0.52 * 229 = 148.33
143.88 gram Carbon per kWh
(41.2 gram Carbon per MJ)

A Californian Household

Californian households consume 62 million BTU annually [EIA09]
22% of the energy consumed is generated with electricity [oESD13]
0.22 * 62 million BTU = 13.64 million BTU used on electricity
13.64 million BTU = 3997 kWh
3 997 * 143.88 grams = 0.5751 Metric Tons CO_2e

A Californian Office

Given a office with a floor stock of 30 000 ft^2
Then the kWh is 30 000 * 16.08 = 482 400 kWh
482 400 * 143.88 grams = 69.41 Metric Tons CO_2e

5.3 Home

In the previous section, the energy consumption per household was found. The purpose of this chapter is to analyze how much more energy is spent when a worker stays home as a teleworker rather than commuting to work.

5.3.1 Heating & Cooling

One of the major contributors of GHG emissions from a residential house is the HVAC systems. These systems can be run on various power sources, the most common one being electricity. The energy consumption of these systems are fluctuating with the local climate and how well insulated the house is. Usually, in the summer season it is common to rely on air-conditioning and ventilation and in the winter season the usage is shifted to heaters.

Overall energy consumption of an HVAC will rely on the daily temperatures and the characteristics of the house, in addition, the GHG emission related to HVAC systems are dependent on one more factor. The last piece is what type of energy source is used to power the HVAC systems. By analyzing these three factors, it is possible to make a conclusion on how much GHG emissions one household will emit in terms of operating the HVAC system.

House Characteristics & Efficiency

The size of the house is an important and influencing factor on consumption of energy and HVAC system. A bigger house implies that a bigger volume needs to be heated up or cooled down. It is a known fact that the distance from the house to the city center has an impact on property prices. As most people would want to live closer to downtown, these houses are in higher demand. Therefore, it is more common for the suburban houses to have higher square feet than their urban counterparts. According to the 2010 US Census, the average size of a house in California is 146.8 square meters. From this information, we can assume that the houses closer to the city are smaller than the average while the houses further away are bigger than the average.

If the house is not insulated well enough, a lot of the generated temperature can escape outside. For a HVAC system to be efficient, it is therefore vital that the energy spent will stay within the house. Houses in warmer climates, like California, usually have houses that are not well insulated [Gaj01]. This indicates that houses in these regions have to use additional energy to maintain an indoor temperature that is different from the outside temperature. However, houses in warmer climates compensate by heating less during the cold season than houses in colder climates. In Los Angeles, a residential house is usually heated to 18.3 °C (65 °F) during the winter [Fri87]. In the summertime, the air-condition system is set to 18.3 °C.

The efficiency of the HVAC system is important. It is known that residential houses use more energy on heating or cooling a room than an office would. The reason for this is two-fold. First, an office will be better insulated than a regular house and therefore there will be less air infiltration from the outside. Secondly, an office will have more people by square meter compared to a teleworker having to heat up his own home office. As workers in an office share work and office space, the HVAC system will work for them collectively.

Heating/Cooling a Home Office

It is assumed that every teleworker will dedicate one of the rooms in the house as a dedicated home office. This room would otherwise not be in use and therefore not require any additional energy consumption. One way to estimate the energy used to heat or cool a home office is to look at the energy used to heat or cool the entire house. In chapter 5.2.1, there is an illustration that shows 31% of the energy consumption in a Californian house is used on HVAC systems. The teleworker will now occupy a room of the house that was previously unused. This fraction can therefore be used to estimate what it would require to heat or cool one room of the house.

Assuming a house has 4 rooms, this would mean one of these room would now need to be heated or cooled more than before. Excluding other small rooms like bathrooms and similar, this would be equal to roughly 25% of the area in the house. If it is assumed that the room requires only additional energy consumption for half the day, then an equation for estimating the required consumption can be made.

Heating or cooling a home office = Daily energy consumption * Daily energy expended on HVAC systems * Time spent in the room. So an actual equation would look something like this:

62 000 000 BTU * 0.31 * 0.25 * 0.50 = 2 402 500 BTU

This energy consumption can easily be translated to GHG emission by analyzing which energy source the energy is drained from. The daily energy consumption to a house is normally associated with the size of the house. This would mean that every house will perform its own calculation.

5.3.2 Personal Electronic Devices

Working from home will introduce certain logistical problems. The equipment and devices the worker relied on at the office to get the job done are no longer available in their new work environment. This will certainly interfere with their job performance. Every telecommuter will need their own set of work equipment. As telecommuters begin to purchase their own devices, the total number of devices in circulation increases [BVH09]. As the number of devices in circulation increases, more products will be produced each year which leads to a higher amount of pollutants released each year.

The devices needed to execute a job will differ from what kind of tasks need to be accomplished. A necessity for commuting to work electronically is a computer with internet access. However, other devices are also usually needed. In [Ham02], the authors identify possible devices and supplies necessary to a telecommuter. The authors mentions items like desk supplies, business cards, a phone, a printer, a fax machine, a photocopy machine, file cabinets and office decoration. IBM issued all sales, marketing, technology and administrative staff portable computers, printers and fax/modems to transform their home to a fully-functional work place [NG98]. Most of these resources would have been shared among numerous employees at work, but now each telecommuter needs their own set.

In [KH08], the authors describe a telework scenario where the teleworkers are assumed to only need a laser printer at home. However, this report no longer represents today's work environment and the need for a wide variety of devices for certain careers. Office-based workers are a majority of the telecommuters in today's world. Around 90% of teleworkers work in managerial, professional, associate professional and technical, and skilled trade occupations [DB07].

Life-cycle Assessment of Devices

In today's technological world, change happens at an increasing rate. The product of today will be outdated tomorrow. Corporate America knows how to exploit the consumers need for more with discounts and promotional offers. In recent years, the average consumer changes their mobile phone more often than before. The devices get faster and cheaper for every year that passes by. Not only that, the devices tend to become smaller and more complex on an atomic level. This makes it very hard to repair a device if it first fails for some reason. Failed devices are usually just replaced with brand new devices. A trend of increasingly rapid exchange of technological products will impact the telecommuters GHG emissions.

In [HR11], the authors find the buying frequency of devices for an average Norwegian household. The average household size in Norway is 2.2 persons. The authors found that the average household bought a new cell phone every year and a computer every 1.9 years. According to the US Census of 2010, the average household size in California was 2.63 and in Los Angeles it is 2.0. The difference in consumer difference between Norway and California in consumer electronic is assumed to be very similar.

Which device a company purchases for its employees vary greatly from firm to firm. Some firms require their workers to have the latest technological innovation at their hand while others just need a reliable computer. The devices acquired are not that relevant, however, the emissions the devices contribute is important in this context. To get educated about the pollutants in relation to these devices, it is necessary to determine how much these devices typically pollute. The devices that are chosen and analyzed are from two commonly used brands in the commercial sector.

In [OS10], the authors analyze the product carbon footprint of a mainstream Dell portable computer. The computer, a Dell Latitude E6400, in this report is estimated to have a life span of four years. The authors state that this computer was chosen because *"it is typical high volume, mainstream business laptop and therefore representative for a range of similar laptop products"*. Product carbon footprint is defined as the *"life cycle GHG emissions of goods and services"*. In other words, PCF assesses the life cycle GHG emissions that are released as part of the processes of creating, modifying, transporting, storing, using, providing, recycling or disposing of goods and services. The authors assesses the life cycle GHG emissions of that computer to be 350kg CO_2e in the US.

Every year Apple release product environmental reports that show the impact each individual device has on the environment. A comprehensive life-cycle assessment is performed to find out the amount of GHG emissions associated with that device. The lifetime they operate with for a portable computer is four years and for the cell phone it is three years. A 15-inch MacBook Pro with retina display is set to 870 kg CO_2e. A iPhone 5s is set to 75 kg CO_2e, iPhone 5c to 60 kg CO_2e and iPhone 4s to 55 kg CO_2e.

In order to use these personal electronic devices, these are usually kept on at all times as long as the person is working. Having a device in standby mode usually drains electricity. Because every teleworker has a set of these necessary work devices, the numbers really start to add up. The usage of these devices are accounted for in the life-time assessment of these devices.

5.3.3 General Usage of Electricity

Now that the home is occupied during the daytime, some induced consumption is a natural consequence. In this section, the general aspects of electricity consumption will be analyzed.

Lighting is a necessity for humans to operate efficiently. The need for lighting in the home office is obvious, but the light in other rooms may also stay on as a convenience. The amount of hours needed for the light to stay on will increase as the workers time in home grows. Just as with the electronic devices in the previous section, this is more inefficient as the energy used on lighting will serve less people compared to an office.

While there is not much scientific data about this, it is easy to imagine that staying at home will put more pressure and usage on electronic appliances. Since the teleworker is already home, it is easier do half a load of laundry or start the dishwasher before its full. The worker could use the radio as background music or watch TV during their lunch break. There are countless electronics a stay-home worker may interact with over a day. When the consumption begins to happen more frequently than before, this can be attributable to the fact that the teleworker is home more often and therefore naturally consumes more. The electronics may not even be actively used. Another great drain of electricity is the standby mode. This feature of many products enable the devices to remain ready for the owner in a moments notice, by a press of a button. There are papers discussing this phenomenon in telecommuting but there are no actual statistics available on this topic. Therefore, it is necessary to survey how much these electronics require of electricity and perform an intelligent decision of what kWh number to assume is induced.

Emissions From Lighting

How much GHG emissions are gained from being in a home office? Calculating the GHG emissions attributable from lighting is a complicated picture as it relies on many factors. These factors include questions like how many light bulbs are being used in a room and how many hours they remain on and what the bulb wattage of each bulb.

There are two typical light bulbs which are used in homes and offices today. Incandescent light bulbs have a typical rating of sixty watts and compact fluorescent light bulbs have a typical rating of thirteen watts. The compact fluorescent light bulbs are more costly to buy but have a light output that is comparable with a traditional sixty watt light bulb.

In order to perform a calculation, it is necessary to assume certain conditions about the environment. We are to assume the teleworker has five light bulbs on at any time he is working and he will be working for eight hours straight.

60 watt * 5 bulbs = 300 watt = 0.3 kW, 0.3 kW * 8 hours = 2.4 kWh

13 watt * 5 bulbs = 65 watt = 0.065 kW, 0.065 kW * 8 hours = 0.54 kWh

A traditional light bulb will require 2.4 kWh per day and the compact fluorescent light bulb will require 0.54 kWh per day.

Emissions From Appliances and Electronics

In [RM02], the authors analyze the electricity consumption of common devices in Californian homes. The results of their work is shown below.

Other actives that are more active for the user include washing dishes and cleaning clothes. The average dishwasher uses six gallons of water per cycle; the average Energy Star-rated dishwasher uses four gallons per cycle, and their energy use ranges from 1.59 kWh per load down to 0.87 kWh per load. Doing one load of laundry will require around 4 to 5 kWh.

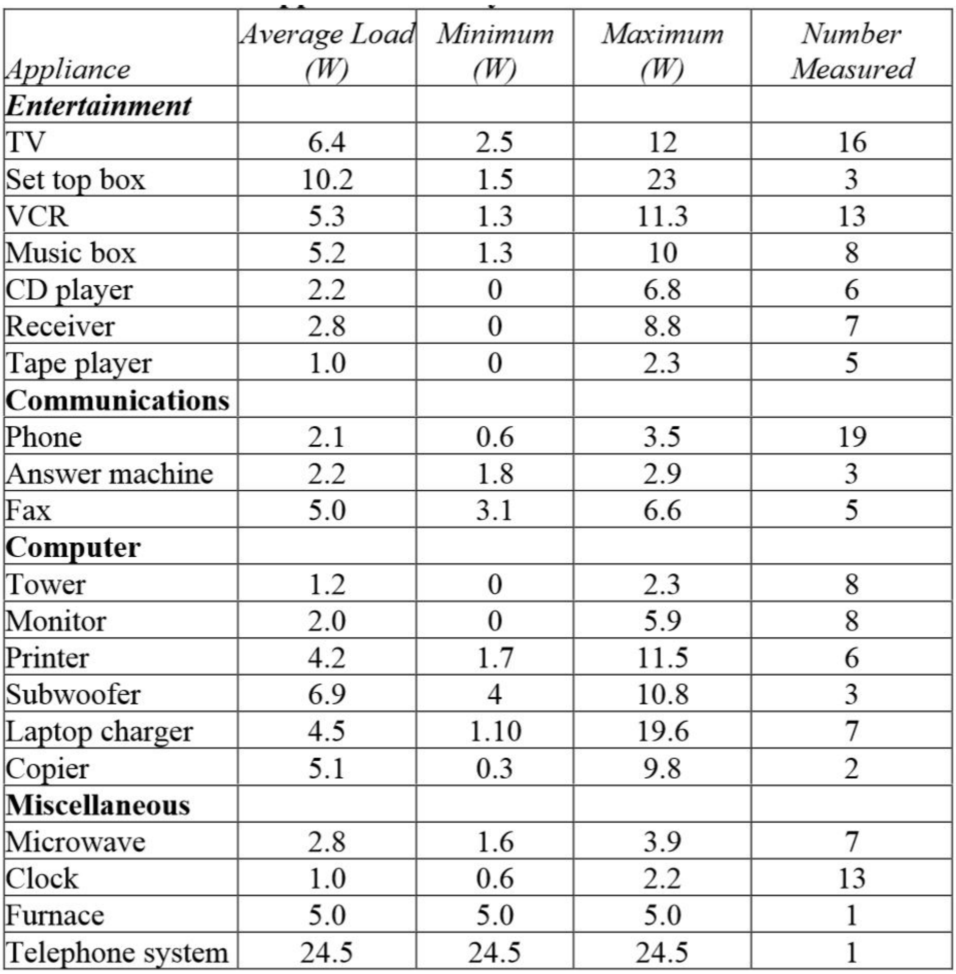
To assume that a worker will use these items, in both active and standby mode, while staying at home is not unrealistic. Assuming a teleworker will use these products for an average of ten kWh a day would be a fair assessment. That is equal to eight hours of consuming 1,250 watts per day.

Assuming that around ten kWh are generated from a worker staying at home that day, on average, is not too unrealistic.

5.4 Office

In a world where the home starts becoming the new workplace, changes to the traditional office are inevitable. This section will go through the changes that will happen to a company when telecommuting is accepted as a work arrangement. In the previous section, it was observed that the home would contribute to an increase of GHG emissions. This opposite reaction will happen in the office as the companies will house a smaller and smaller number of workers.

The California Commercial End-Use Survey is a comprehensive study of commercial sector energy use, primarily designed to support the state's energy demand forecasting activities. A stratified random sample of 2,790 commercial facilities was collected from the service areas of Pacific Gas and Electric, San Diego Gas & Electric, Southern California Edison, Southern California Gas Company, and the Sacramento Municipal Utility District. The sample was stratified by utility service area, climate



Appliance	*Average Load (W)*	*Minimum (W)*	*Maximum (W)*	*Number Measured*
Entertainment				
TV	6.4	2.5	12	16
Set top box	10.2	1.5	23	3
VCR	5.3	1.3	11.3	13
Music box	5.2	1.3	10	8
CD player	2.2	0	6.8	6
Receiver	2.8	0	8.8	7
Tape player	1.0	0	2.3	5
Communications				
Phone	2.1	0.6	3.5	19
Answer machine	2.2	1.8	2.9	3
Fax	5.0	3.1	6.6	5
Computer				
Tower	1.2	0	2.3	8
Monitor	2.0	0	5.9	8
Printer	4.2	1.7	11.5	6
Subwoofer	6.9	4	10.8	3
Laptop charger	4.5	1.10	19.6	7
Copier	5.1	0.3	9.8	2
Miscellaneous				
Microwave	2.8	1.6	3.9	7
Clock	1.0	0.6	2.2	13
Furnace	5.0	5.0	5.0	1
Telephone system	24.5	24.5	24.5	1

Figure 5.4: Energy consumption of devices in standby mode [RM02]

region, building type, and energy consumption level. This report will be used to calculate the emissions associated with an office. The table the authors presented in this survey is shown in chapter 5.2.2. This table will be used to calculate the energy consumption and therefore decide the GHG emissions associated with an office.

In compliance with the survey, this thesis will categorize offices into two distinct categories: small offices and large offices. Small offices are defined as a premises with total area less than 2,787 square meters (30,000 ft^2). Large offices are defined as a premises with a total area larger than or equal to 2,787 square meters (30,000 ft^2). The net amount of energy spent will be calculated based on this survey. Therefore, there will be no individual calculation for HVAC systems and the general energy consumption. These two categories will, however, be discussed and analyzed from a theoretical standpoint.

5.4.1 Heating & Cooling

In comparison to a residential house, office buildings have a higher amount of automation. Automation is used in an effort to save work hours on management of room temperature and similar activities. Offices usually have a centralized HVAC system that is controlled by thermometers and time to help maintain the correct temperature.

In [BFA$^+$12], the authors found that offices in California have their HVAC systems set to twenty-four degree Celsius. This is due to the fact that during the warmer season, the temperature outside is around or sometimes much higher than twenty-four degrees Celsius. It was also found that office buildings are often over-cooled in the summertime, with at least one location in six of eight offices having temperatures below comfort level. The temperature set during the winter season was slightly lower. In the winter, the temperature was set to twenty-two degrees Celsius.

5.4.2 Flexible Office

A company that starts implementing telecommuting as a work arrangement may observe that the office is less occupied and busy in terms of people. For the new teleworkers, their home is the work place for the day. How observable this event is at the office, is dependent on how many telecommuters there are and how often they telecommute. A company looking to cut costs may take advantage of these structural changes.

Usually, the GHG emissions from an office increase as the size of the office increases. This is attributable to electricity consumption of HVAC systems needing to work harder to cool a larger office space. The owners, which are in charge of turning a profit, may not care about pollutants and being green. However, the owners care about reducing cost and would always like to minimize the expenses used on renting an office or energy consumption. By reducing the office space, it is possible for the telecommuters to share a workplace, like a desk or similar and the company to reduce expenses. If the telecommuters are coming to the office on alternating days, it is possible for management to have the employees share the resources at work and eliminate the unused desk. Since the desk is no longer in use, the company no longer needs that space. Depending on how many desks get eliminated, the company may rent out this space, or maybe an entire floor, to a third-party. This downsizing of the office is dependent on the percentage of telecommuters within the company and the frequency of telecommuting days [DB07].

A descriptive analysis of fourteen companies that have experienced the transition to telework can be found in [NG98]. One of them, IBM, has been one of the companies in the forefront in encouraging their employees to become teleworker. After implementing this work arrangement, IBM gathered cost savings in the seven figures. In the spring of 1993, still reeling from massive layoffs and facing huge competitive pressure in a rapidly evolving industry, IBM initiated a "virtual office" work model. This meant that the workers now were able to work from almost anywhere, as long as they had the necessary resources available. Some divisions were now able to significantly downsize their office in response to this. The Midwest division was able to reduce its office space by 55% and raise the ratio of workers to workstations from 4:1 to 10:1. IBM's Denver operation was able to decrease its office space from nine floors to four, for a projected savings of $6 million over the next few years [NG98].

Reducing Office Space

As previously stated, the employment density in today's business world is 200 square feet per employee. However, a reduction of this office space can only be performed when a certain condition is met. When an employee starts telecommute one day a week, it is not recommended to reduce the office space by 200 square feet because the worker will still be there the remaining four days. If two workers start to telecommute three days a week and this arrangement makes it possible that one of the two will be out of the office, it is possible to downsize. There is no longer a need for both of them to have their own dedicated work station.

An office implementing a wide-spread practice of telecommuting may hugely benefit from this. Firstly, the company can downsize their office space to the actual number of people coming to work. Secondly, a reduction of both office size and workers in the office means that less energy is required each day. Saving money on the energy bill and rent is something all companies would benefit from.

5.4.3 General Usage of Energy

In today's office, there are a lot of other expenses that require energy to function other than HVAC systems. These expenses include lighting, power of electrical equipment and devices and many others. These are all included with heating and cooling in the numbers from the California commercial end user survey. So there is no reason to individually calculate the usage.

When a company starts implementing telecommuting, some of the floor space becomes vacant. It is now possible for the company to reduce their floor space and reap the benefits from a smaller floor place. This means less floor space in total. It means less light bulbs illuminating the office. It means less people using electrical equipment and devices at work. It means less people using hot water. Clearly, the energy demand from the office is reduced.

5.5 Commuting

California is a state known for their addiction to personal vehicles. It is also the state with the highest commuting times in America. According to numbers provided by US Census' American Community Survey, three of the top 10 worst commuting times belong to cities in Southern California and four are in northern California. Teleworking has a great impact on commuting and its potential to mitigate both GHG emissions and road congestion.

5.5.1 Pollution From Driving

Telecommuting makes it possible to avoid the commute to work, therefore, avoiding the GHG emissions related to using the car for that trip. There are a couple of features that determine how large this reduction may be. These include commuting length, type of car, type of fuel used and road congestion that day. With all of these conditions together, it is possible to make an informed decision on how much CO_2e the atmosphere will avoid.

In a world of commuting, the car is essential. Workers will spend a small portion of the day in these large, moving, bricks of metal. However, it is not what type of car it is or what color it is that is important. The only vital characteristic of the car will be its carbon footprint from traveling. As the American car park offers a wide range of different vehicles, it is important to analyze it to determine this aspect.

The fuel efficiency of a car determines the GHG emissions from a car. Since it is consumption of fuel that releases pollutants into the air, it is important to consume as little fuel as possible. The average fuel efficiency for light duty vehicles of the American car park has remained the same for the last few decades [DF00]. The technology, however, has improved dramatically with the years. So why are cars not able to drive further per tank today than a few decades ago? The reason can be contributed to the consumer's preference in cars. As it has stayed at the same level, cars are becoming heavier and offer more luxuries than before.

In "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2013" published by the United States Environmental Protection Agency (EPA), the agency reviews the car park of America from 1975 to 2013. The agency found the average carbon footprint of newly produced vehicles that are set to be used in America every year. In 2012, the average gram of CO_2 released per mile driven was 376. However, the vehicles on the road today were produced in many different years. It is therefore important to look at earlier years numbers as well. As we step further back in time, the average increases. In 1990, the average was 420 g/mi CO_2.

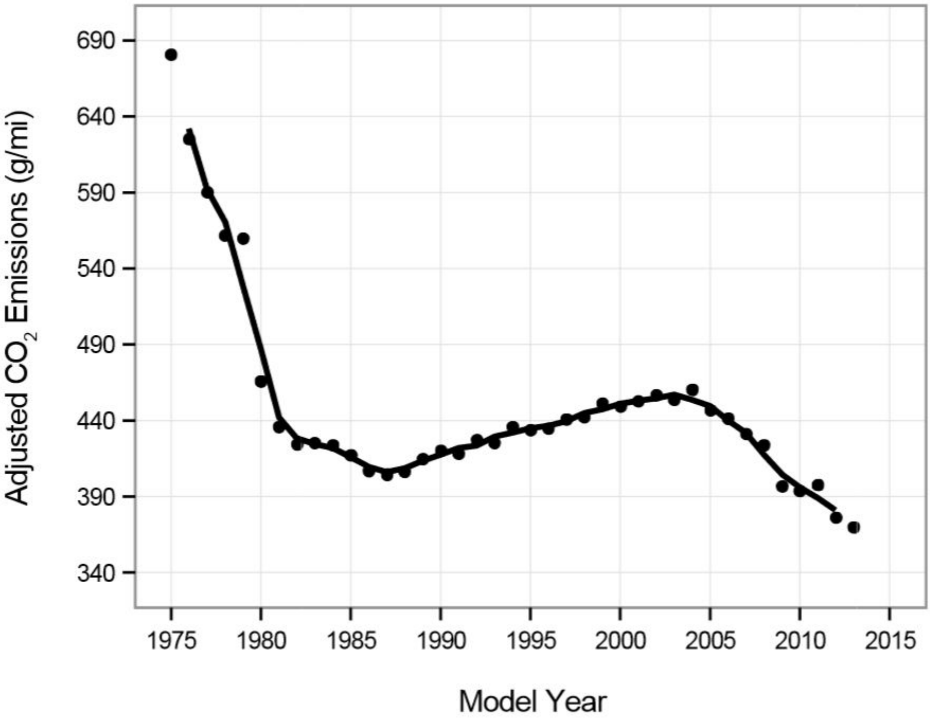


Figure 5.5: CO_2 gram per mile of newly produced vehicles

In an article in LA Times (2013), the automotive information firm R.L. Polk & Co. said the average age of the 247 million vehicles on U.S. roads stands at an all-time high of 11.4 years as of this year. That means the average car was produced in 2003.

5.5.2 Road Congestion

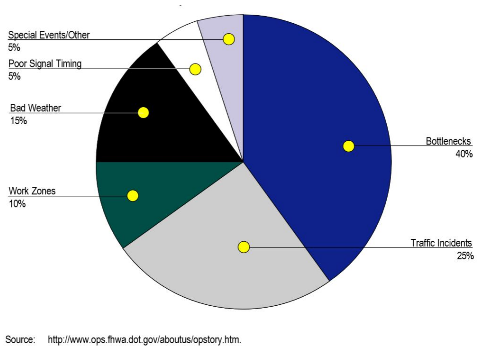
Most highways in major cities are not unfamiliar with road congestion. More often commuters have to deal with traffic jams and road congestion on the journey to work. The definition of congestion and when it appears is the speed at which a commuter cannot travel at free-flow speed. This is a growing trend in almost all large and growing metropolitan regions around the world. The growing traffic jams will remain or, even increase, if nothing changes [Dow04]. Driving to work in Los Angeles is one of the worst commutes in the country. This is not due to the fact that Los Angeles is spread over so many miles or the need for commuters to drive for miles to get anywhere. According to the US Department of Transportation The Federal Highway Authority (FHWA), Angelenos drive 23 miles (37 km) per resident per day. This ranks the Los Angeles metro area 21st highest among the largest 37 cities. The cities with the longest commutes in the country are Houston, followed by Jacksonville and Orlando. The fact is that Angelenos spend more time stuck in traffic than any other. According to the Texas Transportation Institute's 2005 Mobility Report, Angelenos who traveled in the peak periods suffered 72 annual hours of delay. This was number one in the nation, by a large margin.

Car-following and the psychology and the engineering behind it, is it's own research field. From this field, the known rules of safe following and how to analyze traffic have been developed [BM99]. The most common rule of thumb is to keep a three second distance to the car in front. This will give you time to react properly and decelerate the vehicle to avoid crashing. In California, the safe following rule described in the Motor Vehicle Code states that adopting at least one-car length of following distance to every 10 miles per hour (16.09 km/h) [Ran99]. As the most common speed limit on the freeways in California is 104.6 km/h (65 mph), the distance between the cars should be equal to six car lengths.

One of the most common observations a commuter has about road congestion is that as a road is running at or near its full capacity, the drivers naturally start to get closer and closer together. When a driver comes too close to the car in front of him, that driver will slightly use the break to put more space between the cars in response. The person behind this driver will then step on their break slightly harder to avoid crashing in to the driver. This effect will go on for as long as there is someone behind the person who is breaking. If the length of the car trail is long enough, it may result in a full halt and ultimately cause tremendous traffic jams.

In order to be better able to tackle congestion problems, it is necessary to identify the sources that create it. Therefore, the FHWA have categorized causes of road congestion into seven different categories; bottlenecks, traffic incidents, work zones, weather, traffic control devices, special events and fluctuations in normal traffic. These estimates are national estimates and FHWA state that individual estimates may be necessary for traffic engineers to combat congestion on specific highways.

Congestion has not only grown the past few decades, it has also become more volatile as well. Congestion levels are never the same from day to day on the same highway because of the variety of traffic inducing events that influence congestion. Because congestion levels are so unreliable, commuters must adjust for that by leaving earlier to be sure to arrive on time. A commuter on their way to work cannot rely on the average length of time but rather must rely on a maximum time. This is why the



Source: http://www.ops.fhwa.dot.gov/aboutus/opstory.htm.

Figure 5.6: Causes of traffic congestion in America

FHWA have introduced a term called travel time reliability. Travel time reliability is defined as how much travel times vary over the course of time. This variability in travel times from one day to the next is due to the fact that underlying conditions vary widely. By knowing the travel time distribution of commuters, it is possible to determine the GHG emissions caused by traffic.

Time Spent Traveling to Work

In the report "Travel Time Reliability: Making It There On Time, All The Time" published by FHWA, an extensive survey on the development of congestion on US highways is presented. In this report, the authors emphasize the commuters need to arrive on time. For some commutes, like the one to work, the commuter is dependent on arriving before a certain time. As congestion is random, precautions from the commuters are needed to be taken. It is necessary to plan the trip according to the maximum travel time instead of the average. Only this way the commuter is ensured to always arrive on time to work.

In order to decipher the conclusion in the report, it is necessary to explain a few terms the paper uses. As described earlier, travel time reliability indicates the commuters need to arrive at a specific place repeatedly. Travel time index is an index over the time spent on the commute. Time spent traveling to work without any traffic or interruptions implicates a travel time index of 1.00. This free-flow travel time is the ideal dream of any commuter, however, it rarely occurs in major cities like Los Angeles. Out of 100 commutes, planning time index is the fifth longest travel time. Planning time index represents the 95th percentile of the travel times. It rarely occurs, but this is what the commuters will remember.

The graph above depicts the time spent traveling to work in Los Angeles. Observing this graph, it is easy to see where the peak hours of traffic occurs. These two

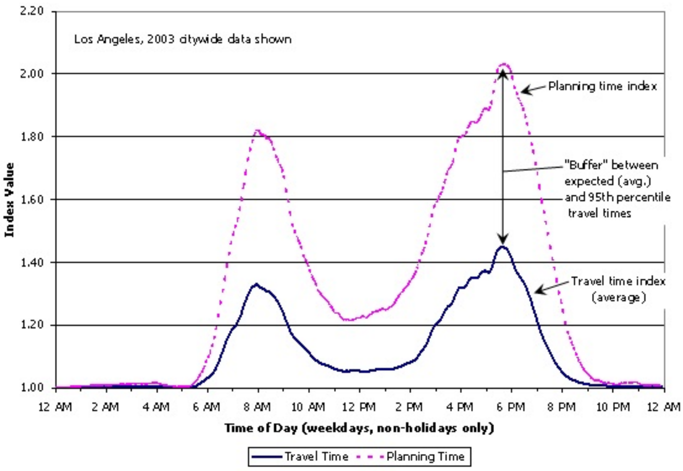


Figure 5.7: Time spent traveling to work in Los Angeles

peaks are in the morning, when people are going to work and in the evening when people are going home.

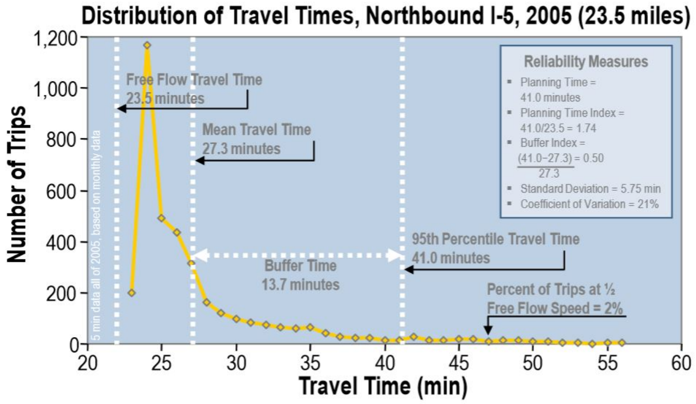


FIGURE 3 Northbound I-5 travel time distribution for 2005.

Figure 5.8: Distribution of travel times northbound I-5

In order to represent a distribution of travel time, it is necessary to choose a realistic representation. In [LB08], the authors show the distribution of estimated travel times for northbound I-5 in Portland, Oregon (2005). It is assumed that the time spent traveling to work in Los Angeles resembles this distribution. The rush hour values in figure 5.7 will be used when calculating the travel time.

Pollution From Traffic

Earlier, the GHG emissions from driving a certain distance was found. However, the GHG emissions related to being in traffic are also an important part of the equation. The time travel index indicates the additional time that is caused from traffic. Given a time travel index of 2.0, this indicates that the commuter is spending twice as long on the commute as if the conditions were ideal. If the time spent commuting to work under ideal conditions is ten minutes, the pollution from these ten minutes are easily accounted for from the table in the previous section. However, the next ten minutes spent in traffic are more difficult to translate into CO_2e.

The GHG emissions attributable to active driving compared to "traffic driving" are different. Intuitively, driving in traffic will produce less pollutants per minute than regular driving. The GHG emissions from traffic are significant and should be accounted for. A way to incorporate the pollutants from "traffic driving" into the equation is to determine the percentage of GHG emissions released in comparison to regular driving. It is assumed that this percentage is twenty-five percent.

Telecommuting and Travel Time

This thesis is looking at specific problems that current research is not preoccupied with. Traffic engineers and other governmental agencies are observing the problem of road congestion to direct their research at implementable and realistic solutions to reduce congestion now. Telecommuting is seen as a contributor to reducing congestion, however, telecommuting is not calculated into travel time or included in their statistics. Numbers or research on how telecommuting reduces congestion is therefore not possible to retrieve.

However, reducing the amount of cars on the road will lead to quicker travel time. How big of a reduction of congestion, is unfortunately difficult to determine. As there is a reduction of travel time on one highway, commuters may change their commuting patterns. However, in a global telecommuting setting, the reduction of vehicles should be uniformly distributed over all highways. This leads to quicker travel time for all commuters on all highways. As all telecommuters may not telecommute every day, the travel time may vary a lot more day to day.

In terms of quantifying the effect telecommuting has on road congestion, the author has to make a reasonable assumption on the impact. It is assumed that for each percent staying home, one point on the travel time index is removed. For example, if 20% of the workforce stayed home one day and the travel time index was 1.60, this would then imply a travel time index of 1.40 (1.60 - 1*0.20) for the other commuters. Originally, the travel time would have been 1.40 if the entire workforce was traveling to work that day.

5.5.3 Commuting Distance

People who telecommute have a longer commute to work than people who do not telecommute. The days the teleworkers have to be present at the office, their commute is significantly longer than their colleagues who do not telecommute. This has been observed in multiple reports [OM06] [MCG03]. A question that is much debated is whether or not telecommuting is encouraging people to settle down further away from work. A question raised is if teleworking, introduced as a purpose to reduce emissions from cars, actually just incentivises urban sprawl and just induces longer commutes to work. In [DB07], the authors acknowledge this statement and survey the current research to find an answer. They find little evidence to support that teleworking influences where people want to live. The same reasoning can also be found in [OM06]. However, these papers may not look far enough into the future. One survey on the telecommuting of state workers in California may indicate a relationship between residential relocation and telecommuting. In [KGP90], the authors state that there is no immediate relationship but in the long term it might be different. They believe there is a relationship between residential relocating and telecommuting. However, the authors also believe this might just be a common trend of urban sprawl.

An empirical study on telecommuting and commuting distance were published on this topic in Finland. In this Finnish study, the authors found that teleworkers drove on an average 3.9 km longer than non-teleworkers [HR07]. The teleworkers had on average a commuting distance of 16.2 km while non-teleworkers had on average a commuting distance of 12.3 km. However, the commuting distances and times tend to be higher in America than in European countries. In order to make the Finnish result transfer to an American reality, it may be interesting to look at the percentage increase for the telecommuters. The 3.9 km longer commute equals to a 31.7% longer commuting distance for telecommuters. According to statistics from 2009, the average commuting time of commuters in California is 26.9 minutes to work [MR11]. Since the Census does not include commuting distance, only commuting time, it is necessary to translate time into distance. If, on average, a car travels at 64.37 km/h (40 mph), the car will drive 28.86 km in 26.9 minutes. If now the telecommuters have a 31.7% longer commuting distance to work, that will then equal 37.8 km.

In [RRP08], the authors claim that, on average, the telecommuters have longer one-way commute than non-telecommuters in the US. Telecommuters have a commuting distance of 35.4 km to work while non-telecommuters have a commuting distance of 19.3 km to work. The distance to work for telecommuters seem to align with the calculated distance to work for telecommuters based on the Finnish study (translated to an American reality). However, in [RRP08], the fraction of distance to work between telecommuters and non-telecommuters are much higher than in the Finnish study (83.4% vs 31.7%).

5.6 Social

In this section the more complex and difficult rebound effects will be explored. These more complex issues relate to the social aspect of telecommuting. A common theme for most is the difficulty to quantify. Even though it will be difficult to draw final conclusions from the analysis, it is an important aspect of telecommuting that will be highlighted.

5.6.1 Human Behavior

Humans are social pack creatures; the need for social interaction between us are of a human nature. Telecommuting can hinder this urge and make us feel isolated. The irony, however, is that ICT also has a great possibility to connect us together. The "always online, always reachable" principal for cell phones and devices today bring us closer than ever before. This is something that can stimulate meetings in person. As an example from the history of the telephone can provide, one of the first reported telephone messages consisted of Alexander Graham Bell saying *"Mr. Watson, come here; I want to see you"* - thereby generating a trip, even if only down the hallway to the next room. By switching to an online presence, companies may collaborate with other companies on the Internet. This collaboration may develop the need to have a meeting in person. Instead of finding business with local companies, the online companies can be anywhere in the world. It becomes necessary to fly to another country instead of walking across the street. The claim that ICT directly stimulates additional travel is documented in [Mok09]. The author of [Mok09] also points at the increasing globalization as an added driving force behind the heightened use of travel, despite the fact that companies are implementing telecommuting.

This effect is, however, only a theoretical rebound effect. There has been no survey or quantifying of this effect in literature to today's date. However, it is still important to be aware of this effect.

5.6.2 Car Availability

A convenient benefit for the household is that the car that was previously occupied with transporting a member of the household to work is now free. The car is now available for anyone to use. Traditionally, this is a side effect that is rarely touched upon when telecommunication companies or consulting firms are trying to emphasize the benefits of telecommuting.

There is a great debate on how legitimate it is to include effects like travel rebound in assessing the impact of telecommuting, as discussed in [DB07]. This thesis believes this is a valid and real effect that occurs directly because of the nature of telecommuting. Therefore, it should be included in assessing teleworks GHG emissions.

This somewhat unexpected rebound effect is talked about in literature regarding the rebound effects of telecommuting [Rie11]. However, there are not many reports that estimate what kind of induced traveling this would entail. In [KH08], the authors bring forth an estimate based on other official surveys. The authors claim that 6 km of traveling is induced by having the car free for the household to use during a day's work of teleworking.

5.6.3 Income Effect

A telecommuter is essentially getting a raise by working from home. The monetary cost of commuting, which the worker itself paid is no longer necessary to pay. The teleworker will have more money left at the end of the month compared to other workers. This additional income will increase the wealth of the teleworker. Additional wealth is often combined with increased consumption.

This increased wealth could be spent on trips to places further away than before or more frequent vacations. The GHG emissions associated with flying is high compared to driving. However, the consumption can manifest itself in other ways than just more travel. Increased purchasing power can lead to increased consumption of products and services. If a person has the money to replace his cell phone every other year instead of every fifth year, this will also heighten the pressure on the climate.

However, this effect is also just a theoretical rebound effect. There have been no studies on this particular effect seeing how complex and difficult it is to measure.

5.7 Summary

As this chapter contained a lot of information, it can be useful and interesting to summarize everything that was found in a table. The table is meant to give an overview of the different rebound effects in telecommuting. The "GHG Impact" is meant to indicate if that particular category is associated with an increase or a decrease in GHG emissions. If the category is associated with an increase, it is labeled with a plus sign and a negative sign if it is associated with a decrease. Quantifiable means that it is possible, with current research available, to estimate the impact of that particular effect on the environment.

Category		GHG Impact	Quantifiable
Home	Heating & Cooling	+	Yes
	Personal Electronic Devices	+	Yes
	General Usage of Electricity	+	Yes
Office	Heating & Cooling	-	Yes
	Flexible Office	-	Yes
	General Usage of Energy	-	Yes
Commuting	Telecommuting	-	Yes
	Road Congestion	-	Yes
	Distance From Work	+	Yes
Social	Human Behaviour	+	No
	Car Availability	+	Yes
	Income Effect	+	No

Table 5.3: Summary of the Rebound Effects

As it turns out, there is a visible pattern that emerges. The overall category an effect is in will determine if this effect will increase or decrease GHG emissions by using telecommuting. The categories home and social will increase their pollution while the categories commuting and office will help decrease their GHG emissions. In order for telecommuting to be a green and environmentally friendly policy, the mitigated GHG emissions need to be higher than the induced GHG emissions.

Chapter 6

Simulation Model of Telecommuting

6.1 Purpose of the Simulation Model

Simulation modeling is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world. The simulation models a closed world and its inter-working between the different elements. A good simulation model makes informed simplifications in order to reduce the complexity of the world it is trying to describe. However, these changes must not impact the result in any substantial way. These simplifications help the developers make it possible to transform a real world scenario into bits and bytes.

A city filled of workers who either commute or telecommute to work is the world this simulation model is trying to portray. In this city, an action from one entity may cause changes to multiple other entities. An example being that one less car on the road will make an impact on the travel time for the other motorists on the road. These interconnections between entities are what a simulation model is effective at representing.

As we are modeling entities with specific attributes, it led to developing this simulation model with an object-oriented language. As the author is most familiar with Java, and the fact that Java is one of the most commonly used programming languages, it was a reasonable choice.

The main goal of the simulation model is to uncover how much, in terms of GHG emissions, the rebound effects of telecommuting impacts the environment. This is done by quantifying the pollution workers generate when they are working from home and at the office. Ultimately, it will produce an answer of the amount of mitigated emissions from the telecommuting that is induced by other polluting activities.

6.2 Overview

The year is 2014 and the city is Los Angeles. At this point in time, half a million workers commute alone to work in their own personal vehicles. The new work arrangement called telecommuting has not reached Los Angeles yet. In the coming thirty years, a fraction of the workforce will be transformed into telecommuters at the end of each year. The many workers who will become telecommuters at the end of each year will depend on the S-shaped growth function, which will be discussed later. Once a worker has become a telecommuter, the worker will then stay a telecommuter for the rest of the simulation.

The real-life working world exhibits a dynamic nature of constantly interchanging elements. In order to reduce complexity as well as being able to compare the annual result from 2014 and 2044, it is necessary to keep some elements constant. A company will maintain the same employees over the thirty year period. This implies that there is no hiring of new employees or getting rid of employees as the years pass. The only changing variable in the simulation model is the percentage of telecommuters. This makes it easier to attribute the changes observed in the simulation model to telecommuting.

Simulating a workers actual work life can be a complicated and tricky ordeal. In real-life, workers have vacation time and sick days during the year. This is something that is difficult to transform into code. Therefore, the workers life has been simplified a great deal in the simulation model. Every worker is working a full work week, Monday through Friday, at eight hours per day. Every worker has the weekend off and the workers have no time off or vacation time during the year. They all continuously work every week of the year.

All the offices are located in the city center of Los Angeles. In order to simplify the commuting, there is one highway that connects the city center to the residential houses. These houses are next to the highway at different distances from the offices. Each work day, every commuter is getting in their car and commuting to work.

Every day of the year will be simulated. As it already has been mentioned, the interesting and processing heavy part of the simulation happen during the weekdays. The weekends are not that fascinating as commuters and telecommuters alike are going about their day as normal.

After simulating thirty years of telework adoption in Los Angeles, the annual GHG emissions from 2014 can be compared to the annual GHG emissions from 2044.

6.3 Becoming a Telecommuter

In [SNMS07], the authors simulate telecommuting and the adoption rate of telecommuting. The authors claim that telecommuting, like all other forms of technological innovation, exhibit an S-curved growth function. This growth function will start out slow, then escalates rapidly before it dies down and reaches a maximum plateau. After each year, a set amount of workers will become telecommuters. The number of workers that become telecommuters at the end of each year will be decided by the S-curve. The workers that become teleworkers will be randomly assigned from the pool of all the current non-telecommuters.

The next step is to determine the frequency of telecommuting such as the amount of days a week the teleworker would telecommute to the office. In [YBNL97], the authors reference a survey conducted in Florida of several hundred telecommuters about frequency of telecommuting. The frequency of telecommuting days presented was this: 37% 1 day per week, 39% 2 days per week, 13% 3 days per week, 8% 4 days per week and 3% 5 days per week. This is the probability function this simulation model will use when it determines the number of telecommuting days a newborn telecommuter will have.

After the number of telecommuting days have been decided, the last step is to figure out which days would be used for telecommuting. This thesis assumes the actual telecommuting day does not matter to the teleworker. This simulation model assumes dedicated telecommuting days are assigned to the individual employee by the employer. Assigning days is independently and uniformly assigned by the employer. Therefore, the telecommuting days will be uniformly distributed and being assigned a Monday will not interfere with getting assigned a Wednesday.

In [SNMS07], the authors suggest that the upper bound, based on historical evidence, should be 20% and that it will take thirty years to reach this upper bound. Therefore, a realistic limit of 20% of the overall workforce will be used in the simulation to represent teleworkers. The adoption of telecommuting will happen over the coming thirty years, in accordance with the S-curve growth function.

$f = \frac{F * e^{(c_1 + c_2 t')}}{1 + e^{(c_1 + c_2 t')}}$

The equation above is taken from [SNMS07]. f is the current percentage, F is the upper bound, t' is the current year $(t - t_0)$, c_1 and c_2 are constants. The constants are used to tweak the S-curve to fit potential data points. This thesis will use the numbers found in [SNMS07] as the growth function.

$F = 0.20$
$t = [0, 30]$

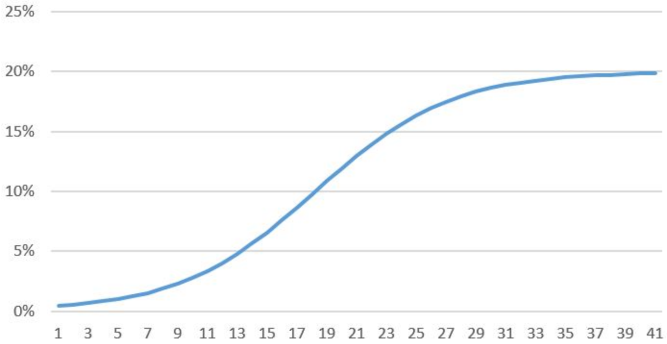


Figure 6.1: Growth of telecommuting over the years

$c_1 = -3.8194$
$c_2 = 0.2218$
$f = \frac{0.20 * e^{(-3.8194+0.2218t')}}{1+e^{(-3.8194+0.2218t')}}$

The equation above is implemented into the simulation model as the growth function for telecommuting. However, using this equation, with the given parameters, will reach a telecommuting percentage of 18.5% after thirty years. The authors in [SNMS07] made the equation based on historical data and that is why it stopped before it had reached one fifth of the workforce. However, the authors intended it to reach 20%, and for consistency, this thesis will continue to label it as 20% even though it is below that number.

6.4 Class Description

The different classes are set to represent one of the entities needed to portray a working world in Los Angeles: workers, cars, offices and so on. These are vital in order to create the simulation model. The interconnection between these classes help to understand the overall view of the model.

In this section, the different java classes will be discussed. A summary of what the class itself is meant to represent and the methods it executes will be presented. If there is any need for a simplification or assumption, this will be explicitly written and discussed in the appropriate section.

6.4.1 Simulation

This class is where the simulation occurs. First, the simulation class is responsible for creating all the instances of various classes. The simulation class keeps track of all the different instances. After every instance has been initiated, the simulation

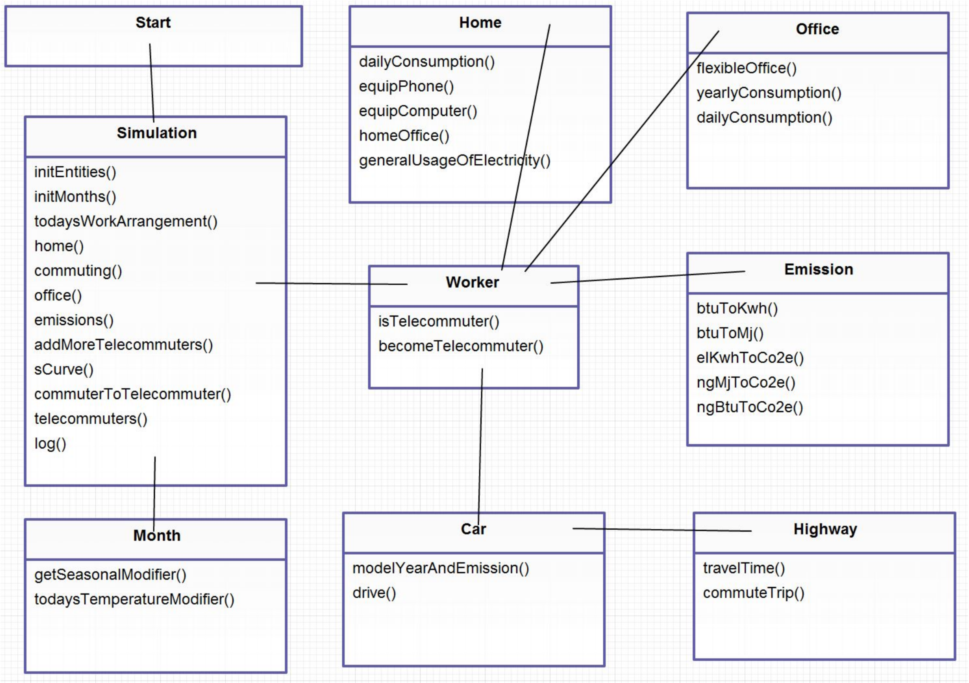


Figure 6.2: Class diagram relationship

class goes on to simulate the working world in Los Angeles. The way this is done can be labeled into two categories: day-by-day and year-by-year. This class will continuously simulate the GHG emissions per year until 20% of the workforce has become telecommuters.

Day-By-Day

For each day of the year, a certain set of actions are simulated. Every day will have their own, independently assigned temperature. How this temperature is set will be discussed in 6.4.5.

The next important step is to find out who will telecommute on this specific day. This is done by looping through all the workers and see if they are scheduled to telecommute that day. The telecommuters will stay at home while the commuters will have to commute to work. After this has been identified, the program will begin going through the major categories to determine the GHG emissions associated with commuting, staying home and staying at the office for that day. How each of these methods perform will be further specified in the classes that handle those situations.

Year-By-Year

After the last day of the year has been simulated, it is now necessary to perform certain actions in order to precede to the next year. The growth function for telecommuting is run after each year has been successfully simulated. Now, the simulation class is responsible for picking out the new workers that will become teleworkers.

Other important methods include checking if a teleworker needs to buy new equipment, which therefore contributes to the GHG emissions, and determining if a teleworker will relocate to a house further away from the office.

6.4.2 Worker

The worker class is set to represent an employee and all the relevant attributes associated with it. The worker class is a binding entity between offices, cars and homes. In the simulation, the worker is categorized as either a telecommuter or a commuter. There is not much occurring in this class except the binding of the different elements together.

The most important method in the worker class would be once a worker is determined to become a telecommuter, the frequency of telecommuting is decided by the method becomeTelecommuter() in the worker class. As previously stated, the model assumes each telecommuter gets randomly and uniformly assigned telecommuting days by its employer. These assigned telecommuting days are stationary and will not change over the years.

Number of Workers

When discussing the worker class, it is vital to know how many workers should be generated in the simulation model. As one worker will create many other entities, the number of workers will determine the total amount of entities created in the simulation. The higher the amount of created entities in the simulation model will impact the run time of the model. The run time of the model is therefore heavily dependant on the number of workers.

In the "Downtown LA Demographic Study 2013" published by Downtown Center Business Improvement District (DCBID), gives a clear and concise overview of downtown Los Angeles. For the city of Los Angeles, these reports give valuable information on the current state of the city. This knowledge can be used to further improve and grow the city. Combined with the fact that Los Angeles is a rapidly changing city, the need for constantly producing these reports are necessary. In the last five years, three of these reports have been published and released by DCBID. According to the report, downtown Los Angeles is a major hub for commuters. With some 45,000 residents and more than 500,000 weekday employees, it is clear that commuting to work from an outside location is the norm here. With this in mind, a fitting number of commuters to simulate would then be half a million workers.

6.4.3 Office

The office class is meant to represent a firm and their physical location. An office can either be classified as a large or small office. This classification is dependent on the size of the office, as it was previously documented. The difference between these two office types is that the larger office is using more energy per size.

Earlier, it was discussed that the distribution of employees for firms in downtown Los Angeles was unknown. This information is needed so it is possible to create the number of offices that exist in Los Angeles. Since this information was not available, the author needed to make an intuitive guess on what it could be. As the office space in a central location like downtown Los Angeles is quite expensive, it seems to attract bigger and larger firms that can afford to rent there. These firms are usually large in employee size. So to assume that the distribution will look like a natural distribution with a mean of 100 and a standard deviance of 50 might be a good estimate. However, getting the exact distribution will not impact the validity of the conclusion of this paper.

In order to represent a company and an office in a simulation model, over a long time period, while still having the calculated data easily comparable with each other, certain simplifications have to be implemented. In the simulation model, all the workers are assigned to one firm and they will maintain that job for the rest of the simulation. In other words, this means that there is no adding or removing of workers from a firm. Once the workers have been created and assigned in the initial startup, no new workers will enter the simulation and no old workers will leave the simulation. It is not possible for the workers to change jobs.

Daily Consumption of Energy

In 5.2.2 and 5.4, the various reasons for consumption of energy for an establishment was extensively analyzed. The annual consumption level of energy was found based on the total floor size of the company. It was also found that the firms hiring was based on a certain number of square meters per employee. After finding these two attributes of a firm, it is possible to calculate their annual GHG emissions.

In the simulation model, each day of the year will be simulated. It is therefore necessary to have an idea of the daily consumption of energy for the company. As seen in appendix A, the consumption of energy is dependent on the seasons and the daily temperature. This complicates the issue and makes it more difficult. However, it is necessary to try and translate the annual consumption into daily consumption.

This means that the simulation model will use the annual consumption as a basis for calculating the daily consumption. To do this, the annual consumption is divided by the number of days in the year. This number is now the basis the simulation model works from. This produces two numbers of daily energy consumption; one for electricity and one for natural gas. These two averaged numbers that are now calculated is daily energy consumption in kWh and daily energy consumption in BTU. Since these numbers are now averaged numbers, it is necessary to do further calculations to get a more realistic daily energy consumption numbers.

By looking at the graphs in appendix A, it can be clearly seen that the consumption of energy during the weekends are significantly less than during the week. This is of course due to the fact that the normal workweek is Monday through Friday and the need for energy during these other days are minimal. However, there is no other supplied data than the charts so the only way to incorporate this survey into our model will be through measuring the approximate value with the eyes. This is of course not optimal but it makes a valuable impact on the simulation model. During the weekend, the daily energy consumption is set to half of what the average daily energy consumption is.

By further looking at the graphs in appendix A, it can be clearly seen that the consumption of energy is seasonally dependent. The winter season is associated with the lowest amount of energy consumption and summer is associated with the highest amount of energy consumption. Therefore, a seasonal multiplier will be introduced to skew the averaged numbers. If it is a winter day, the averaged numbers will be decreased by -20%. If it is a summer day, the averaged number will be increased by +20%. In other two seasons, the average number will not be adjusted.

Even within the same season, the energy consumption can greatly vary. A hot day requires more energy than an ordinary day which again requires more energy than a cold day. From table 5.2, the high and low temperatures from Los Angeles are listed. These highs and lows vary greatly with the different months. In appendix A, the graphs are divided into seasons. A hot summer day would then presumably be the average of the high temperatures in the summer months. A cold fall day would then be the average low temperatures of the months in fall. And lastly, a typical spring day would be the average of the temperatures in the middle of the high and low temperatures for the spring months. It is easy to see that an office consumes more energy on a hot day than a typical day and cold days require less energy than a typical day. This is true for all the different seasons. In the model, it is assumed that the highest high temperature will add a modifier of +20% and the coldest low temperature will add a modifier of -20%. It will be calculated with a linear equation between these two endpoints. The modifier on a typical day would therefore be 0%.

After the energy consumption for natural gas and electricity have been determined, it will be translated into CO_2e. However, this will be covered in the description of the class “Emission”.

Downscale Office

Every year, an office may be down-scaled to a smaller size. As the research on flexible offices showed, it is in the employer’s best interest to perform such a structural reduction of space. Since reducing space is both a monetary and time consuming event, it is realistic that such an effort only will be done once a year. In the simulation model, the office will only rely on previous year’s numbers when the calculation of an eventual down-scaling is made.

If two or more telecommuters are collectively away from the office for the entire week, it is possible for the company to downscale. The GHG emissions related to a restructure of the office will not be included in the simulation model. The way the method flexibleOffice() performs this operation in the code, is by adding the different days the telecommuters are gone. For example, Monday: five people gone, Tuesday: ten people gone, Wednesday: four people gone, Thursday: six people gone and Friday: five people gone. The method then finds the least common number, which in this case is four. During the whole week, the company can remodel their office for four less people in the office. Thereby, removing four workstations and letting ten telecommuters share the space of six employees. Whenever a company is able to reduce it’s space, it will immediately make an impact on its GHG emissions the following year.

It is worth noting that, in the realm of the model, it is not possible to upscale as there are no hiring of new employees. The firms are static in that sense that the number of employees stay the same for the entire simulation. This is done to compare emissions from year to year easily.

6.4.4 Home

The house’s yearly consumption, set aside from the specific rebound effects, are constant over the years. The yearly consumption of energy of every house in this simulation is set to 62 million BTU, which is the annual average energy consumption for Californian houses.

Daily Consumption of Energy

In order to simulate the daily level of GHG emissions, it is necessary to find out the daily energy consumption of every party involved. Unlike the commercial sector, there is less research available on the residential sector. That makes it more difficult to tweak and adjust the daily energy consumption of a household. The well-documented fact is the annual energy consumption of an average household in California and the proportions between the two energy sources used.

It is assumed that residential houses follow the same energy consumption pattern as the commercial sector when it comes to seasonal changes. However, the difference between weekday and weekend might be different for the residential and the commercial sector. Because of the lack of research available, the author must base some assumption out of own intuition. In the model, it is assumed that the difference of energy consumption between weekday and weekend is insignificant. The daily energy consumption, before being adjusted for seasonal effects, is derived from the annual energy consumption divided on the number of days that year.

Home Office

In a home office, the need for heating or cooling is necessary in order to make a comfortable working environment. Depending on the climate, this may require a lot of energy. In chapter 5.3.1, an estimate of the required energy for HVAC systems in a home office were provided. This calculation will be used in the simulation model to retrieve the GHG emissions related to the induced heating or cooling of a home office. This calculation also takes into account the seasonal fluctuations, as the result is derived from the daily energy consumption which is seasonally varied itself.

Another element that is needed is lighting. In order for the telecommuter to do his job efficiently, it is necessary to see well and not strain their eyes. The calculations for energy usage of lighting in an office has previously been calculated in 5.3.3. It is assumed that half of the workers use traditional light bulbs while the other half use fluorescent light bulbs.

Personal Electronic Devices

When a worker becomes a telecommuter, there are certain resources that are deemed as a necessity for this arrangement to function properly. If it had not been for the telecommuting, these resources would not have been needed and the environment could have been spared for the GHG emissions contributed to producing and managing them.

In the previous chapter, the life-cycle assessments were documented for cell phones and portable computers, two resources that are seen as a necessity to work from home nowadays. Every telecommuter will be equipped with these two resources by their employer. Every third and fifth year, the phone and the computer, respectively, will be replaced with brand new devices. The GHG emissions related to the life-cycle of these devices, will be added to the first day of the year. Another solution was to average out the emissions on the expected lifetime of the respected devices. However, since a major part of the GHG emission is already released into the air, even before the user has the device in their hand, it is more appropriate to attribute all the GHG emissions to the day of purchase.

In assessing the current phone's life-time GHG emissions, it was found to range from fifty-five kg CO_2e to seventy-five kg CO_2e. As different phones have different carbon footprints, it is necessary to try to represent all of them. Doing this by a natural distribution around sixty and a standard deviation of four will therefore manage to represent the carbon footprint of phones found in this range. The same thought process is done for computers. In the world of computers, the range is much greater. The lowest carbon footprint was found to be three hundred and fifty kg CO_2e and the largest was eight hundred and seventy kg CO_2e. However, business computers supplied by an employer would probably be closer to the Dell computer rather than the state of the art MacBook. The natural distribution for computers will therefore have a mean of five hundred and a standard deviation of ninety.

Residential Relocation

Residential relocation is the most debated rebound effect in telecommuting today. It is difficult to get a clear view on how much telecommuting influences residential relocation. In other words, how telecommuting encourages workers to move further away from work.

In [KGP90], the authors were researching how telecommuting affected state workers of California. The authors claim that there might be a relationship between telecommuting and residential relocation for state workers in California. However, it was not an immediate response but a long-term effect. In a US study, it was found that telecommuters lived 83.4% further away from work than workers who did not telecommute.

The residential relocation aspect of telecommuting seems to be an interesting effect of telecommuting and should be incorporated into the simulation model. However, it is important to not make the effect too strong as researchers still debate if this is an actual response. Therefore, telecommuters will move 83.4% further away from work after five years of being telecommuters. To keep the effect of residential relocation down, only 25% of the eligible telecommuters will be relocated.

The residential relocation effect is incorporated by tracking the number of years a worker has been a telecommuter. When the worker has been a telecommuter for five years, there is a probability of 25% that the telecommuter will relocate. If the telecommuter has to relocate, the variable that contains the distance from work will be multiplied with 1.834.

Other Telecommuting Effects

When analyzing the rebound effects for telecommuting, two other effects were identified as important. The first one was induced travel. It was found that when a telecommuter stays home, the vehicle is left vacant. Other people in the household are now free to use the car. It was found that the induced travel distance from having the car available was set to six km per day. Each day the telecommuter stays home, six km of driving pollution will be added to the worker's carbon footprint.

Staying at home does not only induce travel, it also induces energy consumption in the house. If the worker would have commuted to work, these actions would have been avoided. It was assumed that for every day a worker stays home, ten kWh was induced on various appliances and electronic devices. Every telecommuter will add ten kWh to their daily energy consumption each day they telecommute.

6.4.5 Month

Energy consumption, and therefore GHG emissions, fluctuate according to external factors like the weather. In a hot climate like California, energy consumption is at its highest during the summer. This is due to all the ventilation and cooling the buildings require. To get a realistic simulation model of telecommuting, the climate is a necessary part to include in the model.

The place of telecommuting is set in Los Angeles. The historical temperature data is taken from this city and used in the simulation model. The reported numbers are high and low temperatures for every month. From these numbers, the average temperature is calculated each month.

The simulation model will simulate each day of the year. Each of these days will be assigned a temperature. This daily temperature is generated out of a natural distribution where the monthly average temperature is the mean. The standard deviation will skew the distribution and determine what kind of temperatures are likely to occur. The high and low temperatures reported for a month are not that common to see. The temperatures will be more clustered around the average temperature that month, and distribute itself in a declining order against the outskirts where the high and low temperatures are. By putting the standard deviation of the natural distribution to the square root of the distance between the high temperature and the average temperature, the extreme temperatures of that month are less likely to appear. These extremes will lie in the fifth percentile of the distribution.

6.4.6 Car

The essential characteristics of the car is the amount of carbon dioxide it releases per kilometer. The average car age for the American car park and the average amount of carbon dioxide per kilometer for a vehicle was found in the previous chapter.

It is assumed that the amount of manufactured cars are somewhat stable over the years and it was previously found that the average age of cars on the American roads are 11.4 years old. This can indicate that the cars on the American roads today are more or less uniformly spread over this interval. In this simulation, the model year of the cars will be evenly spread over the years 1992 to 2014. The mean of the model year of the cars used in the simulation model will therefore also be eleven years old, meaning the average car was produced in 2003.

6.4.7 Highway

The class highway is meant to illustrate the entity that connects the homes to the offices. In California, workers must use various highways in order to travel to work. The highway will be filled up by cars who want to get to work as quickly as possible. In reality, cars enter the highway at different times, different places and at different speeds. Implementing such a realistic simulator seemed like a complex and impossible task. In the simulation model, some simplifications and assumptions have been made to make it possible to integrate the highway part into a java model.

In order to integrate this kind of process into the simulation model, it is first necessary to set explicit borders of what the model can and will represent. These simplifications are necessary to convert a realworld scenario into code. In the list below, all the assumptions are clearly listed.

1. All workers share one common highway to work
2. All offices are located at the end of the highway
3. All workers travel to work at the same time

A general highway will be set to represent the commute all workers must drive to get to work. This level of abstraction makes it possible to ignore interconnecting highways when looking at different intersections. The highway can be thought of as a ray. The highway has a start point and the highway keeps expanding in one direction. In the start point, the city center is located. All of the offices are located in the city center. Every commuter must reach this destination in order to get to work. The houses the workers live in will be spread at different distances from the city center next to the highway.

All the commuters will travel to work at the same time. This time will be during the peak of rush hour in Los Angeles. It was earlier found that the mean travel time in the morning rush in Los Angeles was 1.40 and the 95th percentile was 2.03. The travel time index was previously explained in chapter 5.5.2.

Each day, two highways will be simulated: one for the commute to work during the morning rush and one for the commute back home during the evening rush. Here, the travel time index for each rush will be determined after a negative exponential distribution. By determining the travel time index for the commute, combined with knowing the distance a worker has to travel to work, it is possible to estimate the GHG emissions for that commute. This calculation can be separated into two problems; pollution from driving to the office and pollution from being in traffic. First, the pollution associated with the traffic-free travel to work is when the travel time index is 1.0. This is found by multiplying the cars carbon footprint of driving a kilometer with the distance it has to driven.

Second, if the travel time index is over 1.0, that means the commuter will be delayed by traffic at some point, and this will be included as well. When a car is stuck in traffic or in any other way impeded at driving full speed, it releases less GHG emissions than it normally would at full speed given the same time period. As only the carbon footprint for a car is known for driving a kilometer, it is necessary to reduce this number to represent how much would have been released by just having the car traveling slower or being at a halt in traffic. This fraction is assumed to be 25%. The GHG emissions related with being in traffic equal the GHG emission from the first equation multiplied with the extra travel time (travel time index minus 1) and multiplied with 25%. In this manner, the GHG emissions from both the commuting and road congestion is introduced to the simulation model.

When telecommuting gets introduced to the system, fewer cars will occupy the highway. This will impact the travel time index. Less cars on the road means that the travel time index will decrease. The magnitude of the impact, however, is more difficult to quantify. The assumption made in this model is that for every percentage of the workforce that telecommutes that day, one point of the travel time index will be removed.

6.4.8 Emission

In all of the other classes, only the energy consumption or distance driven is calculated. The emission class was created to transform consumption to CO_2e. In the emission class there are multiple methods to perform this process. Listed below are the most important transformations that are performed in the class.

BTU to kWh
$kwh = \frac{52752792631}{180000000000000} * btu$

kWh to gram CO_2e
$co2e = kwh * 143.88$

BTU to mega joule
$MJ = \frac{52752792631}{50000000000000} * btu$

MJ to gram CO_2e
$co2e = MJ * 24.5$

Every pollution creating class (office, home, car, workers) will have an emission class attached to themselves. It is easy to keep track of how much each class is polluting every day and it is easy for an external method to calculate the monthly or annual GHG emissions.

6.5 Managing the Data

There are three main steps to this simulation model. The first step is to initialize all the entities. The second step is to simulate the introduction of telecommuting in a working city. The last step involves saving the information generated by the simulation model.

After the execution is done, all the generated data is written to text files. In Java, writing to text files are done with the class FileWriter which can be found in the java.io package. This is done so it is easier to further analyze the data. The information written out to the text files contain development over the different time periods (years, months and days) and for the different rebound effects in play.

The files created are comma separated value (csv) files, which can be imported to external programs for further analysis and creating illustrations. In this paper, the data was imported to Excel to make illustrations and graphs.

Chapter 7

Results

Annual GHG Emissions

All units are in billion grams of CO_2e.

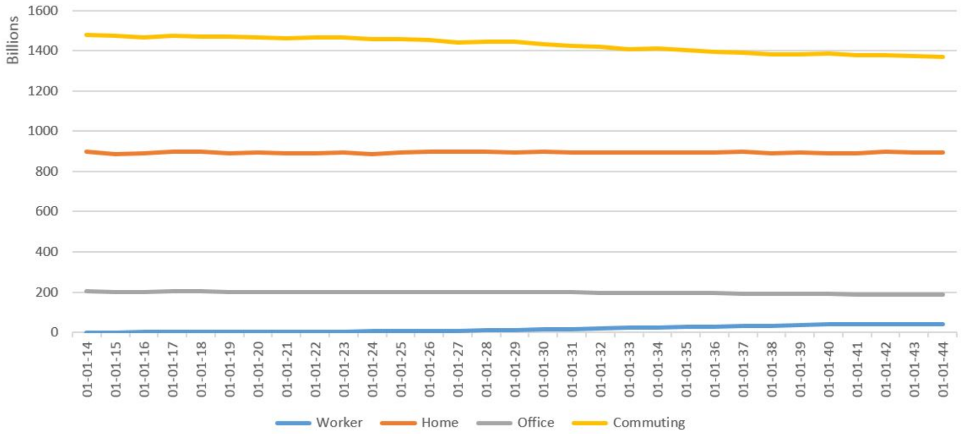


Figure 7.1: Yearly GHG emissions

No TC is the first year of the simulation, 2014, where no one is telecommuting.

TC is the last year of the simulation, 2044, where 20% are telecommuting. No rebound effects are added in.

TC (RE) is the last year of the simulation, 2044, where 20% are telecommuting. Rebound effects are added in.

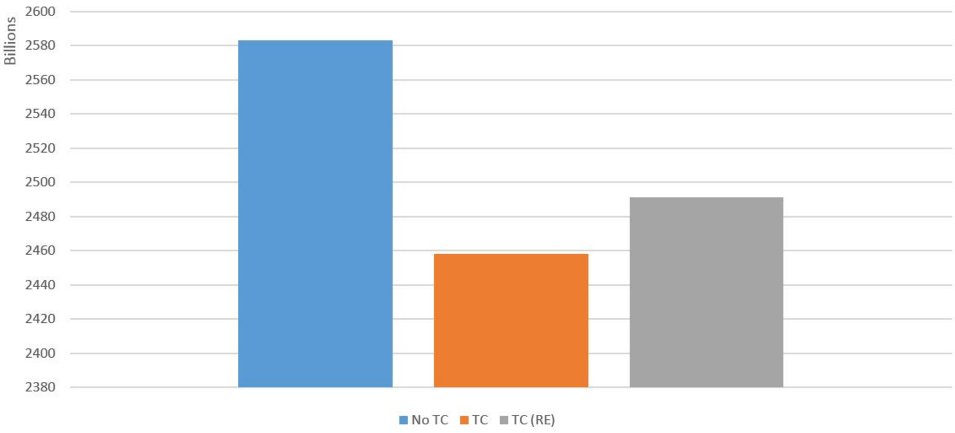


Figure 7.2: Comparing annual GHG emissions for 2014 and 2044

The Rebound Effects in Telecommuting

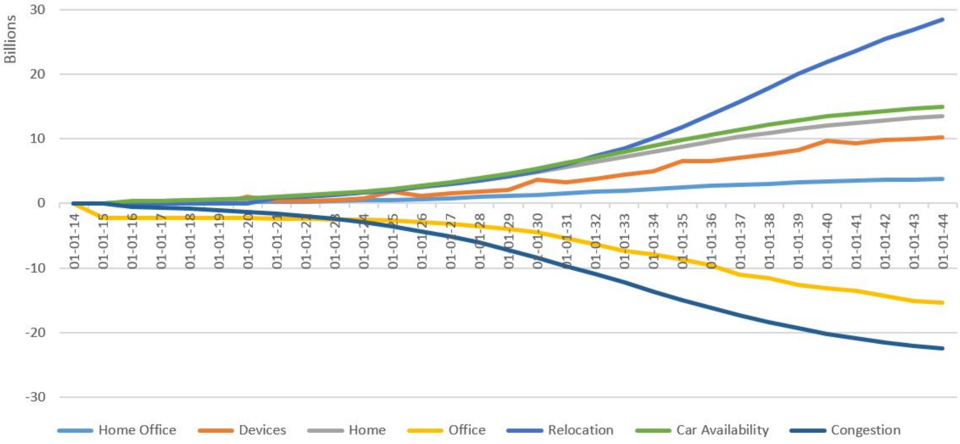


Figure 7.3: Annual GHG emissions associated with the rebound effects

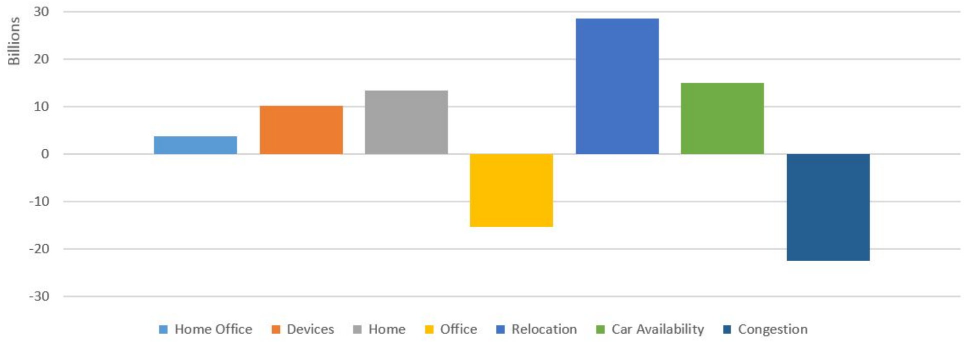


Figure 7.4: The rebound effects of telecommuting in 2044

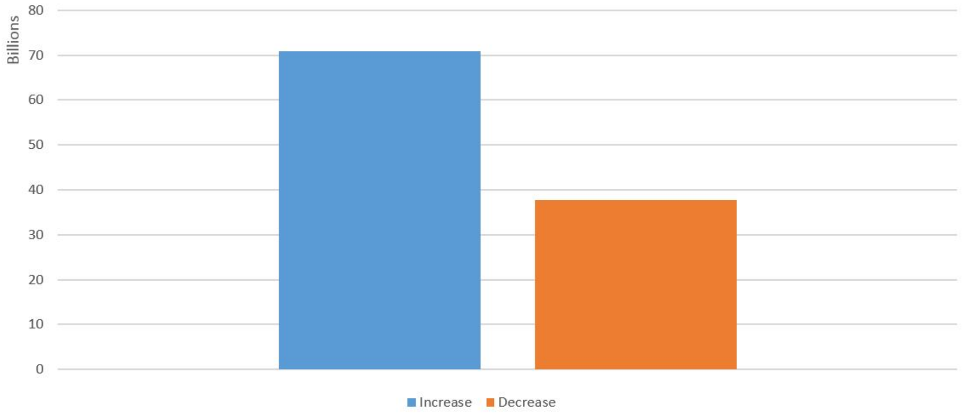


Figure 7.5: The positive and the negative rebound effects of 2044 summed together

Monthly GHG Emissions

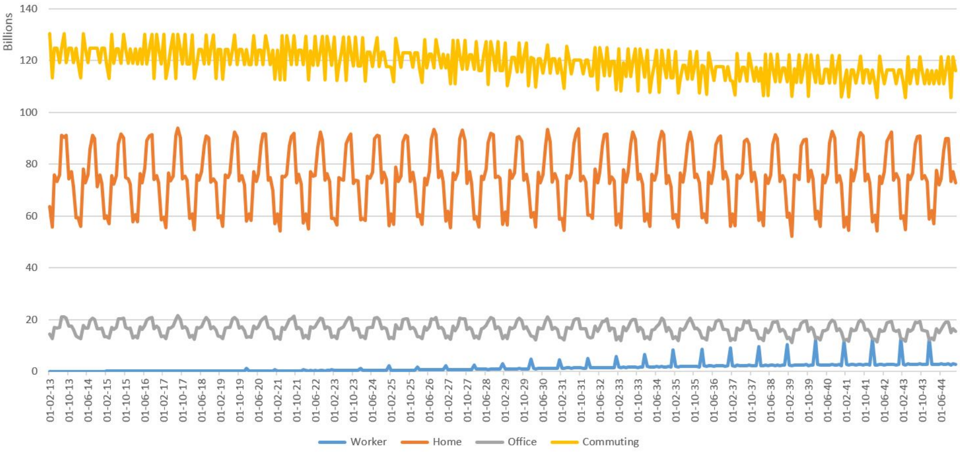


Figure 7.6: Monthly GHG emissions from 2014 to 2044

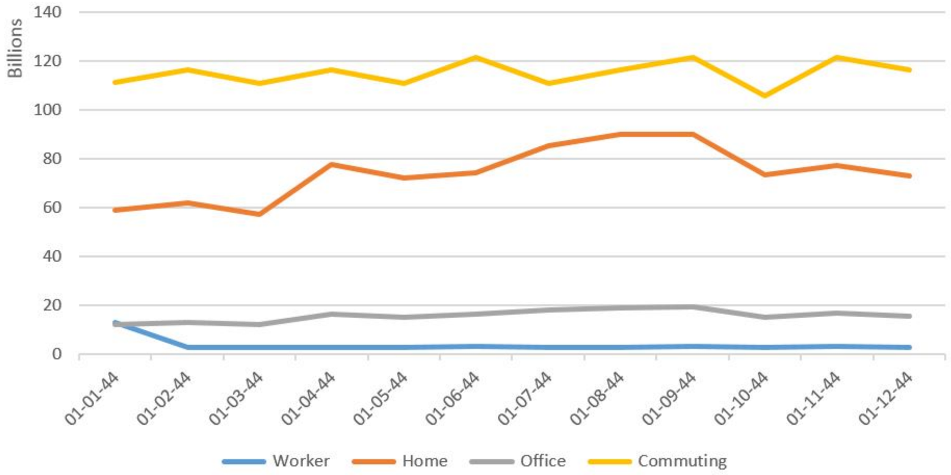


Figure 7.7: Monthly GHG emissions in 2044

Chapter 8

Discussion

In Los Angeles, with one fifth of the workforce telecommuting, 125 metric kilotons of CO_2e could be mitigated by telecommuting. The higher the savings, the better it sounds on paper and easier it will be to convince others that this is a great initiative. However, that is without adding in the rebound effect. The rebound effect is responsible for generating 33 metric kilotons of CO_2e. With the rebound effect added in, only 92 metric kilotons of CO_2e is mitigated from telecommuting.

1 billion gram CO_2e is 1 metric kilotons of CO_2e.

	kt CO_2e emission	Reduction relative to 2014
No TC	2583	0%
TC	2458	5.09%
TC (RE)	2491	3.70%

Table 8.1: Comparison of three different scenarios

Let's explain how the "TC" scenario was derived. The answer is retrieved by looking at the first year of the simulation (2014). In 2014, all the workers are still regular commuters. The difference between the "TC" scenario and the "No TC" scenario is the pollution related to commuting. The vital step is to know what fraction of commuters are still commuting in 2044. In our model, with the given number of telecommuters and the telecommuting frequency probability that was set, the number of workers that stay at home at any given day, Monday through Friday, is 8.5%. The probability is even through the week as the assigned telecommuting days are uniformly distributed. The fraction of current commuters in 2044 (91.5%) is multiplied with the GHG emissions associated with commuting in 2014. That calculated number will be the pollution level associated with commuting in 2044, excluding the rebound effects, of course. After this calculation has been performed, the pollution from the other sectors from 2014 is added in as well. The "TC" scenario is the same as "No TC" but with 8.5% less pollution from commuting.

By knowing these three different scenarios, it is possible to calculate the rebound effect. As explained in 3.9, the rebound effect is usually expressed as a ratio of the lost benefit compared to the expected benefit when holding consumption constant. In table 8.1, the percentage improvement of both scenarios, "TC" and "TC (RE)," are stated. The ratio between these two percentages determine the rebound effect.

Rebound effect $= \frac{5.09\% - 3.70\%}{5.09\%} = 27.4\%$

The Rebound Effects

One of the common misconceptions about the rebound effect is that they are inherently bad. As the figures 7.3 and 7.4 show, there are also rebound effects that are good. These two rebound effects, road congestion and office, are quite large as well. However, the rebound effects associated with an increase of GHG emissions are together bigger than the rebound effects associated with a decrease. Therefore, the sum of the rebound effect still constitutes an increase of GHG emissions.

In the result section, seven rebound effects are presented and illustrated. These seven effects are introduced as a teleworker begins working from home. The sum of these effects constitute whether telecommuting is environmentally friendly or harmful. The seven effects are:

Home Office: Heating and cooling of the home office
Devices: Personal electronic devices
Home: Induced use of lighting, appliance and electronics
Office: Flexible office and office related energy consumption
Relocation: Telecommuters moving further away from work
Car availability: Car available for the household
Congestion: Reduction in travel time due to less commuters

One proposed solution to lower the rebound effects associated with telecommuting is to introduce seasonal telecommuting. As seen by the figure 7.6 and 7.7, the GHG emissions are fluctuating with the seasons. The intent behind this initiative is to encourage teleworkers to telecommute those seasons that require the least amount of energy consumption. In California's case, that is the winter season. However, as this thesis documents, the GHG emissions related to heating and cooling of a home office is the smallest rebound effect. For a greater impact on the environment, it would be better to target one of the other rebound effects.

Residential relocation is the biggest contributor of GHG emissions. In our model, 25% of the telecommuters moved 83.4% further away from the office after five years as a telecommuter. On average, this equals moving all telecommuters 20% further away from the office. This is a much lower percentage than the Finnish and American study concluded. So this rebound effect may have a bigger impact then this thesis presents. Since residential relocation is quite controversial in telecommuting research, it felt natural to be cautious so the importance of it was downplayed. Therefore this justifies using 20% as an average moving distance for telecommuters after five years. For the most effective impact on reducing the GHG emissions, one might shift from focusing on which month to telecommute and rather focus on limiting the urban sprawl of telecommuters.

This idea of taxing away the achieved benefit from an action, like telecommuting, was first introduced by the ecological economists Mathis Wackernagel and William Rees. They claim the only way to sustain a cost saving, like reduction of GHG emissions, is through introducing measurements like green tax, a cap and trade program or higher fuel taxes. This is to try and preserve the achieved benefit and to not let it get re-used on other activities.

Choice of Transportation

In the simulation model, all the workers who commuted to work, did so alone in their own personal vehicles. This is the most polluting way in order to move a worker from their home to the office. If some percentage of the workforce did the commute by public transportation, carpooling or biking, it would indicate a lower GHG emissions associated with that commute. By forcing all the workers in the simulation to commute alone by personal vehicles, the mitigated emissions from telecommuting might be overestimated in this thesis. Therefore, the rebound effect may actually be a much higher than 27.4%.

Chapter 9

Conclusion

This thesis identified several strong rebound effects associated with telecommuting. The rebound effects could all be placed into four separate categories: home, office, commuting and social. The thesis quantified all the known rebound effects associated with telecommuting except for two. The behavioral rebound effects, which are found within the social category, were the ones that proved difficult to quantify. These behavioral rebound effects are therefore not included in the simulation. However, all the other rebound effects are quantified and included in order to calculate the impact it has on the environment.

It was found that the decreased GHG emissions from the offices were offset by the increased GHG emissions from the homes of telecommuters. This is due to the nature of telecommuting. Telecommuters require consumption of electricity in order to perform their job. This is less efficient per person than in an office setting. Telecommuters are also dependent on having personal electronic devices which contributes to the increase of GHG emissions.

The transportation sector is a major contributor of GHG emissions. In the simulation, more than half of the GHG emissions were contributed from commuting. The two strongest rebound effects, residential relocation and road congestion, are both derived from this sector. While the third does not relate to transportation, the fourth strongest rebound effect is the induced driving from having the car available for the household.

The rebound effect of telecommuting was found to be 27.4%. Demonstrating that the majority of the GHG emissions mitigated from telecommuting indeed stay mitigated. This is a strong selling point for telecommuting as a green initiative. However, 27.4% is still a high enough percentage that it makes a substantial dent on the environment. Therefore, the rebound effect should be included in the reduction analysis of GHG emissions. Neglecting the rebound effect will greatly weaken the recommendations of any environmental report.

Chapter 10

Future work

The aim for this paper was to provide a general simulation model for telecommuting that could be adopted into any geographical area. It would be interesting to see this framework applied to a different area than the place chosen in this thesis to see if the rebound effect would still show itself significant. In this thesis, the model was set to represent the telecommuting in Los Angeles. This city has some characteristics that are unique compared to other major cities. Los Angeles is known for its distinctive commuting pattern. This is incorporated into the simulation model. However, if this simulation model were to represent any other area, it would be necessary to incorporate more commuting options into the model. This could be public transport, biking or walking. It is the author's intuition that the rebound effect would be stronger in places where less commuting happened by car. However, this should be further analyzed and research.

As many in the technological community have downplayed the role of the rebound effect for many years, it was the author's goal to try and highlight the importance. The original aim for this thesis was to investigate the rebound effect in multiple sectors that were touched by the new efficiency gains of the Digital Revolution and ICT. However, that scope proved to be too big for a single thesis to cover. This thesis strongly implies that the rebound effect gives a significant impact on the environment and that this should fuel further interest in researching the rebound effect in other sectors.

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Chapter A

Global Climate Change Indicators

All the data presented in this chapter is collected from NCDC's own website and can be found at https://www.ncdc.noaa.gov/indicators/.

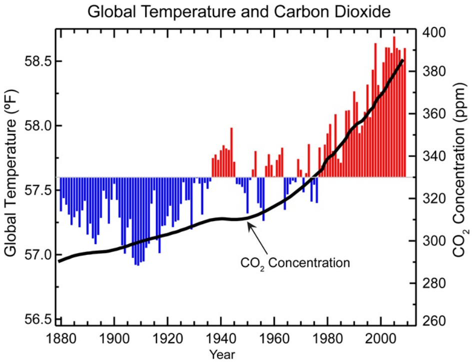
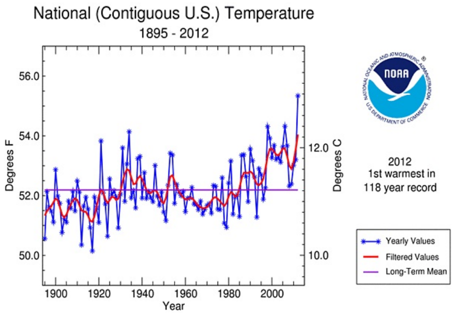


Figure A.1: Global surface temperature



National Climatic Data Center / NESDIS / NOAA

Figure A.2: U.S. surface temperature

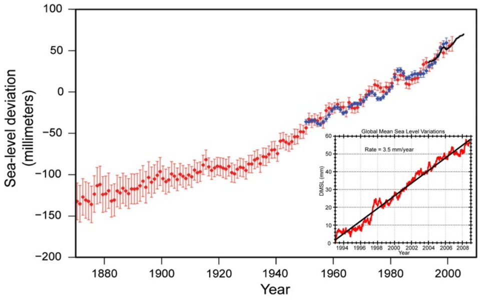


Figure A.3: Sea level

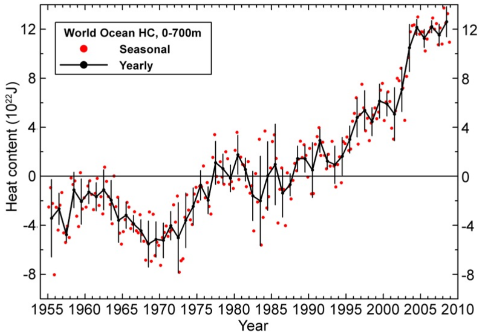


Figure A.4: Global upper ocean heat

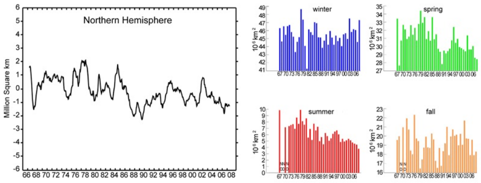


Figure A.5: Northern hemisphere snow cover

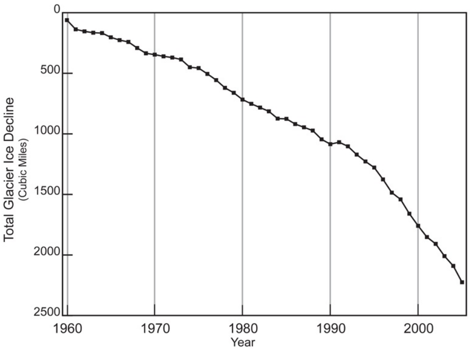


Figure A.6: Glacier volume

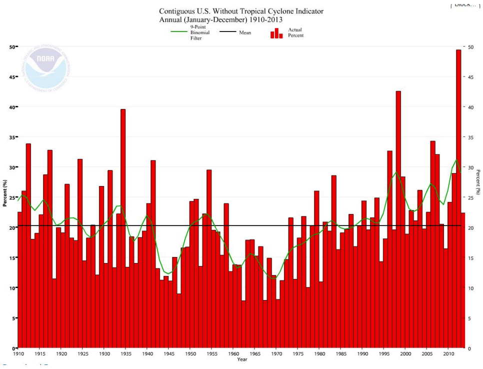


Figure A.7: U.S. climate extremes

Chapter B

Daily Energy Usage Based on Season

In a report prepared for California Energy Commission, an extensive survey of the commercial sector has been executed regarding the end use consumption of energy.

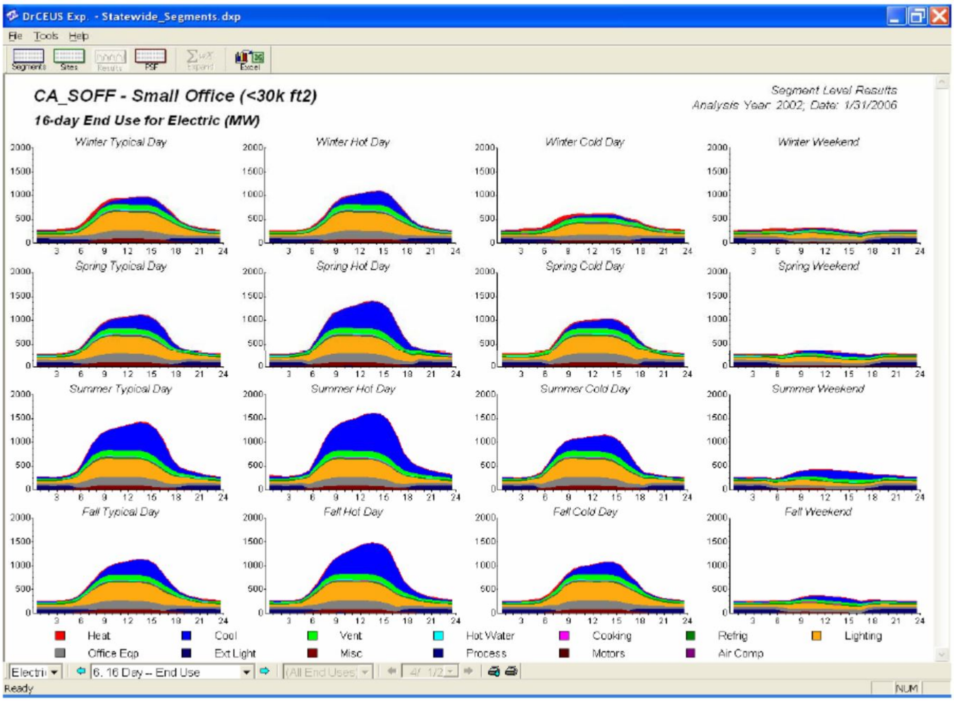


Figure B.1: Small office

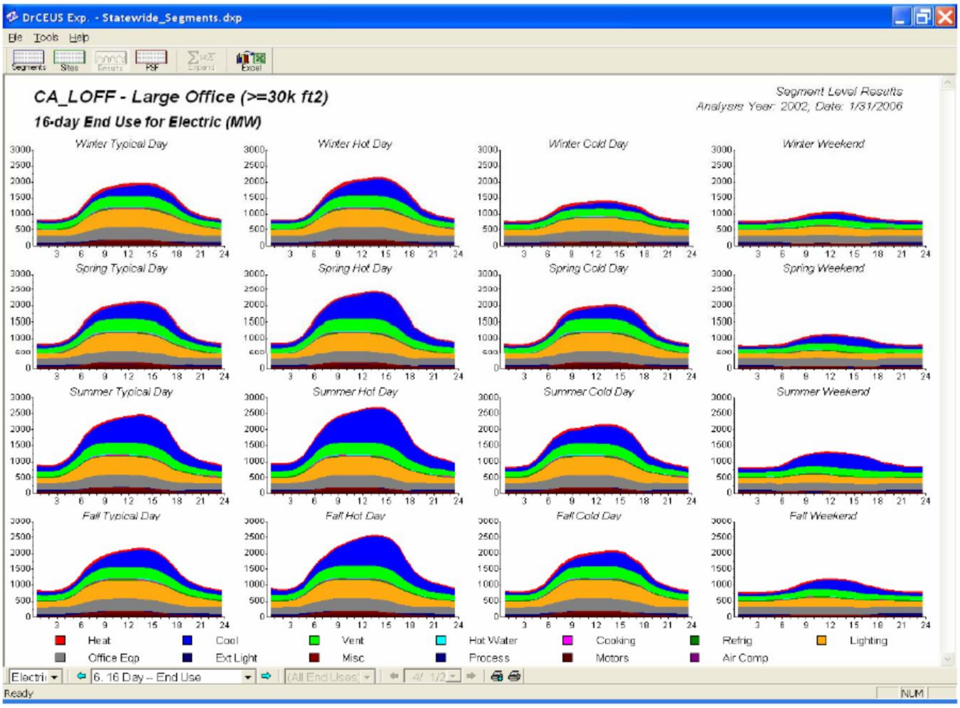


Figure B.2: Large office