Individual carbon footprint calculators in Aalborg to support the transition towards a low-carbon society

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MSc. thesis project
June 8th 2018

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Title:

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Project:

Master thesis

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Editions: 1
Report pages:
Appendix pages:
Completed 08-06-2018

Synopsis:

The international climate treaties have set binding emissions reductions targets of 40% by 2030 (compared with 2005 levels) additionally set at least 27% share of renewable. Accordingly, Aalborg as a Danish city has established ambitious energy targets to ensure a fossil-free energy system by 2030.
In order to ensure stability in the energy system, the individual energy consumption should decrease or should be shift out of the heat demand hours. This research aims to answer the next research question **How can individual carbon footprint calculators (CFC) support the transition towards a fossil-free heating system?** and to solve it literature review, surveys and interviews were performed. The results have evidenced an interest for receiving feedback about the environmental impacts of the energy consumption. As part of the analysis different types of feedback were proposed with the aim of evoking motivational and contextual factors to promote pro-environmental behavior change. Finally a SWOT analysis in presented.

Preface

The current thesis is developed as a requirement for obtaining the Joint European Master Degree in Environmental Studies - Cities Sustainability (JEMES CiSu) organized by Aalborg University (The Faculty of Engineering and Science), Technical University of Hamburg - Harburg (The School of Civil Engineering), Autonomous University of Barcelona (The Faculty of Sciences) and University of Aveiro (The Department of Environment Planning). It is presented as established in the Curriculum for the Joint European Master in Environmental Studies - Cities Sustainability (JEMES CiSu) and under the supervision of the Planning and Geography Study Board of the School of Architecture, Design, and Planning at Aalborg University.

Declaration of Authorship

I hereby declare that the Master Thesis presented here is, to the best of knowledge and belief, original and the result of my own investigation and has not been submitted in part or whole, for a degree at this or any other university. All the information derived from the work of others has been acknowledged in the text and in the list of references.

Reading guide

Through the report, source references are in the form of the Harvard method, and all are listed at the end of the report. References from books, articles will appear with the last name of the author and the year of publication in the form of [Author, Year]. If there is no stated year on a source it will be referred to as: [Author, n.d.]. If the author is a company, a homepage or for other reasons is not stated, the reference is referred to as: [Name, Year], e.g [European Commission, 2014].

Figures and tables in the report are numbered according to the respective chapter. In this way the first figure in chapter 2 has number 2.1, the second number 2.2 and so on. Explanatory text is found under the given figures and tables. Figures without references are composed by the author.

María Camila Rincón Gil
08/June/2018

Acknowledgements

Foremost, I would like to express my sincere gratitude to my supervisors Pierre Vogler-Finck and Martin Lehman for the continuous support of this research, for their patience, the interesting discussions and for helping me to put in place all my ideas.

Besides my supervisors I would like to thank to all the people in Aalborg that who had time for giving me part of their time to solve my questionings during the interviews: Charlotte Bahrendet, Zacharias Brix Madsen, Sven Buch, Ane Sofie Moesner, Christian Jabkobsen, Mette Grosen and Keying Xiang.

During the master, I have had the pleasure to be surrounded by smart, motivated and creative people. Special thanks to my JEMES family, Diana, Marta, Alejandra, Juanita, Erick, Maddalen, Manuel D. and all the amazing people I have met in this journey.

Last but not the least, I am extremely grateful to my family, Maria Helena, Edgar and Andris for their love, patience, unfailing encouragement and support in every step during these two years. Their support has been unwavering and allowed me to push through even during the most difficult times. I owe them much more than a dedication but it will have to do for now.

Abbreviations

CO_2	Carbon dioxide
O_3	Ozone
AAU	Assigned amount units
CDM	Clean Development Mechanism
CER	Certified emissions reduction
CF	Carbon footprint
CFC	Carbon footprint calculator
CH4	Methane
CHP	Combined heat and power
CO_{2e}	Carbon dioxide equivalent
COP	Conference of the Parties
EDGAR	Emissions Database for Global Atmospheric Research
ERU	Emission reduction unit
EU	European Union
EU-ETS	European Union trading system
GDP	Gross domestic product
GHG	Greenhouse Gas
GWP	Global warming potential
HCI	Human-Computer Interaction
IPCC	Intergovernmental Panel on Climate Change
JI	Joint implementation
kWh	Kilowatt hour
LCA	Life cycle assessment
m^3	Cubic meters
NGO	Non-governmental organization
NO_x	Nitrous oxide

ppm Parts per million

RMU Removal unit

TPB Theory of planned behavior

UNFCCC United Nations Framework Convention on Climate Change

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Introduction 1

1.1 Climate Change

The world's population is growing at a startling rate and the need for energy is doing it accordingly. The economic and population growth have led to the highest concentrations of greenhouse gasses (GHG), such as carbon dioxide (CO_2), nitrous oxide (NO_x), water vapour, methane (CH_4), ozone (O_3) and hydrofluorocarbons in at least the last 800,000 years [IPCC, 2014]

This growing process began in the 19th century and has caused a remarkable concentration of people in urban areas, being North America, Latin America & the Caribbean and Europe the most urbanized regions with 82%, 80% and 73%, respectively. Currently, cities only represent around 2-3% of the total land surface, however, half of the world's population lives in there and the number is estimated to increase up to 66% by 2050 [United Nations, 2014a].

Cities utilize approximately 75% of the natural resources [UNEP, 2012], consume 70% of the total produced energy and are responsible for 60-80% of total global GHG emissions [UN-Habitat, 2016]. Consequently, these anthropogenic emissions are considered the dominant cause of the observed global warming since the pre-industrial era, and the reduction of the emissions levels is a priority on most of the political agendas around the world to mitigate climate change [IPCC, 2014].

> *"Climate change means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."[United Nations, 1992]*

According to the Intergovernmental Panel on Climate Change (IPCC [2014]) , the period between 1983 and 2012 was likely the warmest 30 years period of the last 1,400 years in the Northern Hemisphere. The average surface temperature on land and ocean show an increment of 0.85 °C over the period 1880-2012. In addition to the rise on surface and in oceans temperature, other significant aspects of global climate are changing along with it, such as loss of sea ice, rising sea levels, ocean acidification and changes in weather patterns [Wuebbles and Weaver, 2017]. Some of them are presented in figure 1.1

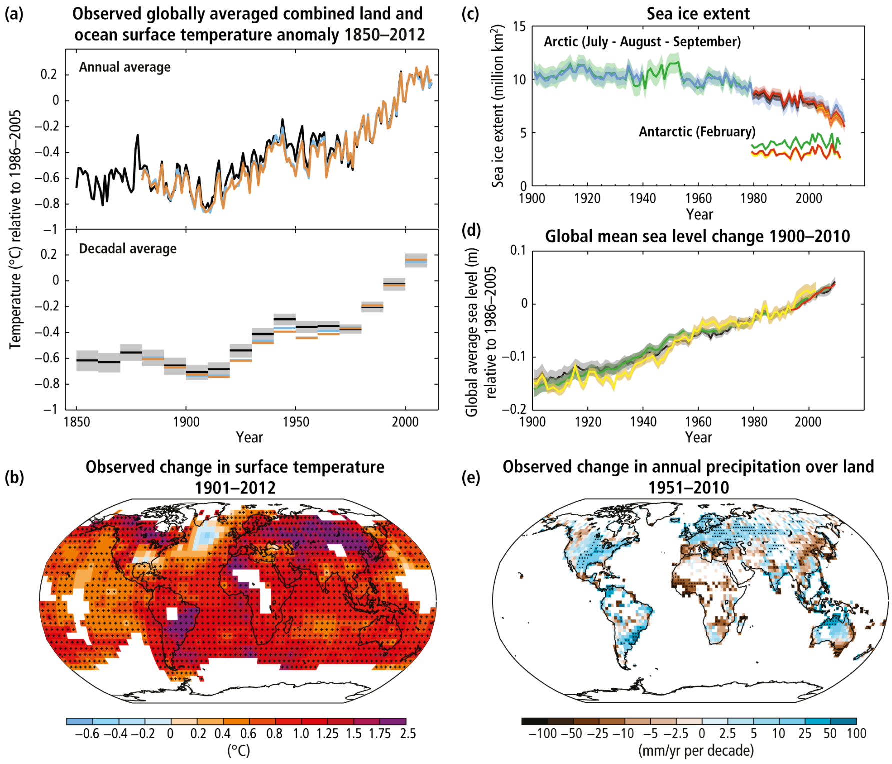

Figure 1.1: Multiple observed indicators of a changing global climate system. (a) Observed globally averaged combined land and ocean surface temperature anomalies between 1850-2012. (b) Map of the observed surface temperature change, from 1901 to 2012. (c) Arctic (July to September average) and Antarctic (February) sea ice extent. (d) Global mean sea level relative to the 1986–2005. (e) Map of observed precipitation change, from 1951 to 2010 [IPCC, 2014]

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As a consequence of the continuous emissions of GHG, the humans and all the ecosystems of the planet will suffer irreversible impacts [IPCC, 2014]. According to the IPCC [2014], the magnitude of climate change in a long term will depend, not only in the amount of GHG emitted globally, but also, in the sensitivity of the Earth's climate to those emissions. In order to limit climate change risks, it is necessary to diminish substantially (and sustainably) the GHG emissions, limiting in this way the global averaged temperature rise to 2ºC (and even to 1.5ºC). Otherwise, having a small reduction in these emissions, the increment in the average global temperature (compared with the pre-industrial era) could reach 5ºC or more by the end of this century [Wuebbles and Weaver, 2017]. Therefore, it has become urgent to address climate change mitigation under different international agreements in order to tackle the problem collectively.

1.2 International agreements

The GHG emissions have global consequences, hence, climate change is a challenge that requires coordinated action by every country on the planet, as stated in the preamble to the United Nations Framework Convention on Climate Change (UNFCCC) : *" The global nature of climate change calls for the widest possible cooperation by all countries and their* *participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions "* [United Nations, 1992].

1.2.1 United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC it is an international environmental treaty which entered into force on 21st March 1994 after being signed in 1992 by the 197 Parties to the convention, which are 196 states and 1 regional economic organization that have ratified the convention.

The overall UNFCC objective is to *"achieve [...] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure food production is not threatened and to enable economic development to proceed in a sustainable manner." [United Nations, 1992]*

The UNFCCC has set the task for every party to establish the annually national GHG inventories specifying GHG emissions and removals.

After signing the UNFCCC treaty, the Parties have met at conferences ("Conferences of the Parties"- COPs), in order to discuss how to achieve the aims proposed in the treaty. During the first COP (COP-1), some discussions about the adequacy of stabilizing the GHG emissions at 1990 levels by the year 2000, have started and have led to the changes made in the Kyoto Protocol [United Nations, 1992].

1.2.2 Kyoto Protocol

After signing the UNFCCC treaty, the Parties realized that stronger actions to reduce emissions were required. Hence, in 1998 they agreed the Kyoto Protocol which sets emission reduction targets, while binding under international law, the 38 developed countries including the 28 member states of the European Union (EU) [European Council, 2017].

The protocol was adopted in 1997 in Kyoto, Japan and the details for its implementation were accepted during the COP-7 in Marrakesh, Morocco. The protocol has two commitment periods, the first one comprised from 2008 - 2012, where the Parties committed to reduce GHG emissions by 5% in comparison with 1990 levels. The second period began in 2013 and will end in 2020. This period is covered by the Doha Amendment which includes the Parties' commitment to reduce GHG emissions levels by 18% below 1990 levels [UNFCCC, n.d]. Additionally, the EU has a more ambitious commitment of 20% of GHG levels reduction compared with 1990 levels [European Council, 2017].

The Kyoto protocol only requires developed countries to take actions, nevertheless, United states signed out to the protocol, Canada pulled out before the end of the first period and New Zealand, Russia & Japan declared that are not joining in the second period of the commitment. Hence, the protocol is currently covering countries that are responsible for the 14% of the world's emissions. Moreover, more than 70 countries including also some developing countries have made non-binding commitments to limit their GHG emissions [European Council, 2017].

The countries must meet the targets first, by implementing national measures, despite the fact that , the Protocol offers three market-based mechanisms to stimulate investments and help the Parties to meet the targets in a cost-effective way. The mechanisms comprises International Emission Trading, Clean Development Mechanism (CDM) and Joint implementation (JI) [UNFCCC, n.d].

International Emission trading: Emissions trading, or also known as "cap and trade", is a market-based approach that aims to limit GHG emissions by giving economic incentives for achieving reduction in the emissions level.

The targets for limiting the emissions reduction are expressed in allowed emissions which are divided to the participant countries into assigned amount units (AAUs) , which is equal to one tonne of CO_2. As it was set up in article 17 of the Kyoto Protocol, the countries are allowed to sell their spare units (emissions assigned but not "used") to other countries that require them (countries that are over their emissions targets) [United Nations, n.db].

The emissions are expressed in carbon dioxide equivalent (CO_{2e}), , which is a metric measure that allows the comparison from different GHG emissions on the basis of their global warming potential (GWP) [Eurostat, 2017], in other words, the CO_{2e} of a mixture of GHG emitted, describes the amount of CO_{2e} that would have the same GWP of the given mixture, and it is generally measured over a timescale of 100 years. Hence, the trading of other GHG are quoted in terms of the CO_{2e} having carbon prices normally quoted in euros per tonne of CO_{2e}.

Therefore, carbon emissions allowances on the form of CO_{2e} can be traded and sold as any other commodity, generally known as "carbon market", in the international market or privately. The UNFCCC is validating every international transfer and when the transfer takes place within the EU, this transfer is additionally validated by the European Commission [UNFCCC, n.d].

Currently there are some emissions trading schemes around the world such as the EU's Emissions Trading System (EU-ETS) , the California Cap-and-Trade Program, the Korean Emissions Trading Scheme and the Tokyo Cap-and-Trade Program, just to mention some of them.

In addition to the AAUs (also known as carbon credits, Kyoto units or carbon credits), there are other units with similar function that also could be transferred under the trading system, but differently to the AAUs, these other units could be earned under different mechanisms that will be addressed in the next paragraphs. For example, the removal unit (RMU) is based on land-use change activities, such as reforestation; the emission reduction unit (ERU) is generated under a joint implementation project; and the certified emission reduction (CER) are generated from a clean development mechanism project activity [United Nations, n.db].

Clean development mechanism (CDM): it allows the implementation of emission-reduction projects in developing countries, by assisting to create sustainable development to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, for being use by the investor. These CERs can be traded and used by the industrialized country to meet their emission reduction targets under the Kyoto Protocol [United Nations, n.da].

Joint implementation (JI): it encourages emissions reductions or emission removal project between industrialized countries. The countries can claim credit for emission reductions as consequence from investment in another industrialized country, resulting in a transfer of equivalent emission reduction units (ERU) between the Parties [United Nations, n.dc].

1.2.3 Paris agreement

The Paris climate conference (COP-21) took place from 30th November to 11th December 2015 and aims to strengthen the global response to climate change. The global agreement presents the goal to limit global warming below 2°C (and even to 1.5°C), which implies keeping the CO_{2e} concentration under 450 parts per million (ppm), in order to strengthen the ability of the countries to mitigate impacts and reduce the risks associated with climate change [UNFCCC, 2015]. Even more, the atmosphere contains 409 ppm CO_2 and the current carbon footprint adds 2 - 3 ppm of CO_2 to the atmosphere per year. This evidences the urgency to phase out fossil fuels before 2050, to live up the Paris agreement.

The agreement recognizes the role of engaging "non-Party stakeholders" in addressing climate change, such as cities, civil society, other sub-national authorities,the private sector and others, by encouraging them to scale-up their actions to reduce emissions, build resilience and decrease vulnerability to the challenges associated with climate change and promoting local, regional and international cooperation [European commission, 2015]. In other words, the agreement is addressing all type of participation, including "non-Party stakeholders" as key contributors on the fight against climate change. Additionally, is promoting the citizens engagement, which are production drivers to change their consumption pattern which will finally impact in the production scale and its GHG emissions levels.

1.3 European Union (EU) and climate change

The EU has ratified the international agreements addressing climate change. Moreover, as part of the Paris agreement implementation, the EU has created the Energy Union strategy, where the priority is to improve energy efficiency, making energy more secure, affordable and sustainable, which has been identified as key elements for encouraging European competitiveness while reducing GHG emissions and securing the energy supply. This strategy promotes low-carbon and environmental friendly economy while allowing a free flow of energy across the borders, to secure the supply for every citizen in the EU territory [European Commission, 2017]. The EU's energy union is characterized by five related and reinforcing areas, which are shown in Figure 1.2.

Policy areas	Description
Security, solidarity and trust	Diversifying Europe's sources of energy and ensuring energy security through solidarity and cooperation between Member states
A fully integrated energy market	Enabling a free flow of energy through the EU
Energy efficiency	While enhancing energy efficiency it will be possible to reduce European dependence on energy imports while reducing emissions
Climate action-decarbonizing the economy	The EU is committed to quick ratification of the Paris Agreement and some of the actions include the EU emissions Trading system (EU ETS), strong national targets for the sectors outside the ETS to cut GHG emissions, a road map towards low-emissions mobility and an energy policy to make EU the world leader in renewables.
Research, innovation and competitiveness	Supporting the transition towards a low-carbon and clean energy by prioritizing research, innovation and competitiveness

Figure 1.2: The energy union policy areas [European Commission, 2017]

1.3.1 Climate strategies and targets

The EU has set targets itself for reducing, in a progressive way, its GHG emissions until 2050. The effort sharing legislation is part of the EU's climate and energy policy framework for 2020 and sets compulsory annual GHG emissions targets for the Member States during the 2013–2020 and 2021–2030. These targets covers the emissions from most sectors that are not included in the EU-ETS, such as households, waste, transport (excluding aviation), and agriculture.

- ***Strategy for 2020***

The national emission targets for 2020 include a 20% reduction of GHG by 2020 (below 2005 levels) for the richest Member States. Additionally, it aims to increase in a 20% the share of renewables; and a 20% improvement in energy efficiency [European Commission, 2018].

The sectors covered by the EU-ETS (such as, aviation, power and industry) which covers around 45% of the EU's GHG emissions, are regulated at EU level and have a target of emissions' reductions of 21% lower than in 2005; in addition the share of renewable energy should be at least 27% of the EU's energy consumption [European Commission, 2018].

- ***Strategy for 2030***

Similarly, the Effort Sharing Regulation was adopted in 2018, as part of the Energy Union strategy and the EU's implementation of the Paris Agreement. This regulation has set binding emissions reduction targets from 2021- 2030 for all Member States, ranging from 0% to 40% compared with 2005 levels, based on the relative wealth of the Member States, which is measured by gross domestic product (GDP) per capita [European Commission, 2018]. Additionally, the 2030 climate and energy framework sets at least 27% share for renewable energy and at least 27% improvement in energy efficiency [European Commission, 2014].

The Member States are responsible for implementing national policies and strategies that aim to limit the level emissions from the sectors covered by the Effort Sharing legislation [European Commission, 2018], such as, supporting schemes for retrofitting buildings, encouraging more efficient heating and cooling systems and adopting renewable energy for heating and cooling, just to mention some examples.

- ***Strategy for 2050***

The low-carbon economy roadmap for 2050 suggests a reduction of 80% of GHG emissions below 1990 levels without relying on international credits; starting with the goal of cutting the emissions levels to 40% by 2030 and 60% by 2040. Hence, in order to achieve this goal, the EU must have a continuous progress towards a low-carbon society where all the sectors need to contribute according to their technological and economic potential, and differences on the amount of reductions of different sectors can be expected as shown in Figure 1.3 [European Commission, 2011]

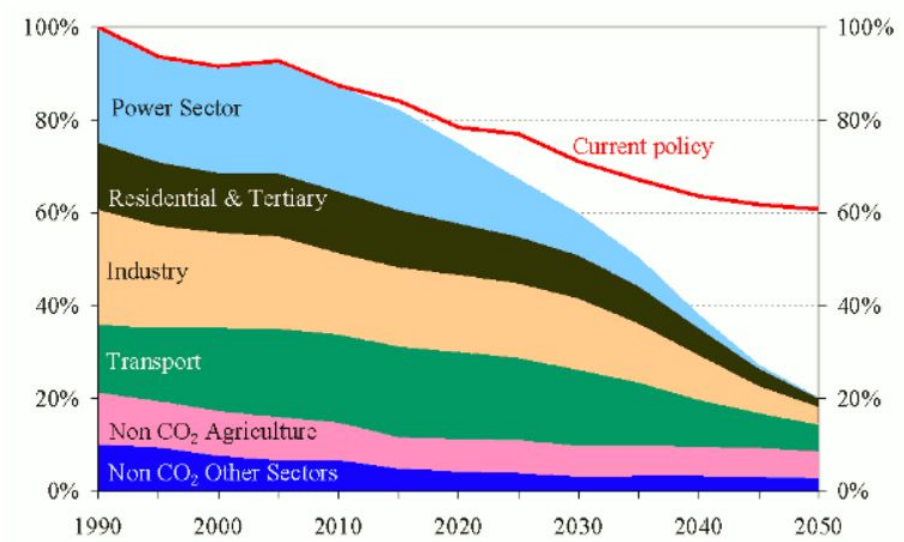


Figure 1.3: EU GHG emissions towards an 80% domestic reduction (100%=1990). [European Commission, 2011]

As it is shown in the Figure 1.3, the power generation sector has the biggest potential in cutting emissions. Hence, to reach the ambitious goals by 2050, the electricity production will be from renewable resources such as solar, water, wind, geothermic, biomass, or others. Moreover, integration of energy systems with one another (power, heating, transport) is expected to be a determinant step in the energy transition towards a fossil-free society.

In addition, emissions from houses and buildings could be cut down in around 90% if its energy performance increase by making investments in passive housing technologies, energy efficiency improvement by refurbishing old buildings, substituting fossil fuels in cooking,heating and cooling for electricity and renewables [European Commission, 2011], and by changing the behavior of the consumers, either to reduce consumption or to utilize energy when the supply of green energy is high (generally, out of the high demand hours).

1.3.2 Energy sector in the European Union

Nowadays, approximately 50% of the EU's annual energy consumption belongs to heating and cooling, 30% comprises transport and the other 20% is used as electricity [European Commission, 2016a].

Addressing heating and cooling because of its greater contribution, 75% of the production comes from fossil fuel, while renewables sources constitute only 18% as shown in Figure 1.4. Therefore, the importance of addressing the heating sector which accounts half of the final energy consumption and currently represents significant GHG emissions.

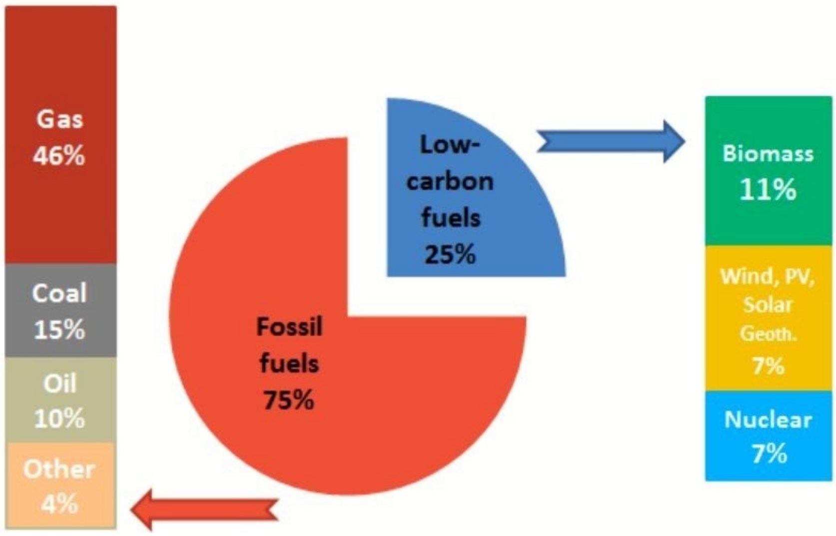


Figure 1.4: Primary energy for heating and cooling [European Commission, 2016a]

According to the European Commission [2016c], 79% of the energy used in households corresponds to heat and hot water, while cooling has a small share of the final energy consumption. However, the cooling demand is increasing during the summer months due to the rise in temperature (this tendency is also linked to global warming and climate change). A similar situation can be found in industry, where 70.6% of energy consumption was used for space heating and industrial process, 26.7% for electricity (such as lighting and motors) and only 2.7% is utilized for cooling [European Commission, 2016c]. Therefore, this project will focus only in energy use for heating purposes in households, due to its great potential to increase energy savings, hence reducing the carbon footprint and supporting the transition to renewable sources in order to achieve the EU's climate and energy goals.

In February 2016, the European Commission proposed a strategy to increase the efficiency of heating sector. This strategy addresses the importance of cutting energy waste in industry in the form of heat, ensuring that the entire EU's heating demand in residential and office buildings can be satisfied by the industrial leaked heat (into the air and in the water) [European Commission, 2016b]. In addition, it promotes synergy between the district heating systems and the electricity system, to support each other in the transition towards a low-carbon economy [European Commission, 2016a]. Consequently, district heating systems might integrate renewable electricity (wind, solar, water), solar collectors, geothermal, biomass and waste-to-energy. Additionally, the implementation of a thermal storage can offer flexibility to the heating system [Marina Galindo, 2016].

Besides the technical proposals to improve energy efficiency in heating and cooling, the strategy also promotes an increment in the consumers power and control in making energy choices. In other words, tenants, owners, housing managers and public authorities will have access to more information on how to improve energy efficiency by renovating and how to implement renewable power, in addition to the benefits of doing so [European Commission, 2016b]. At the same time, the transparency on the billing will increase by having smart-meters which clears the path towards new technologies and services for tracking and controlling energy use.

1.4 Denmark: targets and energy sector

1.4.1 Targets

Denmark as member of the EU is subject to the EU targets to reduce GHG emissions for 2020 and 2030. Additionally, it must contribute to reduce GHG in 2050 by 80-95% compared with 1990 levels. Furthermore, the country has an ambitious national strategy to be a fossil fuel independent society. This strategy comprises different scales of new energy policy initiatives which will start reducing fossil fuel dependence in the short term.

The energy policy goals are:

- The EU energy-targets include a 20% reduction in CO_2 emissions below 1990 levels; a 20% increase in energy efficiency and an increase in the share of renewable to 20% of the energy
- The Government target for 2020 is aiming to reduce the use of fossil fuels in the energy sector by 33% compared with 2009 [The Danish Government, 2011], while having wind powered electricity for 50% of the domestic supply [Energistyrelsen, 2014]
- In the longer term, i.e. 2050, the energy system in Denmark is to be independent of fossil fuels [The Danish Government, 2011].

By 2030, the oil-fired boilers will be replaced with other renewable sources of energy, alongside, the target to have coal-free power stations in Denmark. As a consequence, the combined initiatives will bring a 65% reduction in coal consumption (compared with 2014) and a 50% diminution in the number of oil-fired boilers (compared with 2010), by 2020 [Energistyrelsen, 2014].

Denmark must ensure stability and security for energy supply, hence in order to have a cost-effective transition towards a low-carbon society, and according to The Danish Government [2011] the following elements are considered essential:

- Improving energy efficiency
- Electrification of energy consumption
- Expansion of wind power and other sources of renewable energy
- Efficient use of biomass resources, including biogas, for combined heat and power (CHP) and parts of the transport sector
- Increased district heating and individual renewables based heating
- Increased electricity exchange and a more intelligent energy system.

Denmark has reached a 36% reduction of CO_2 emissions compared with 1990 levels, mainly because the energy conversion (electricity and heat generation) has decreased in a 36% the emissions levels, and the household consumption has achieved 58% reductions on its emissions levels [The Danish Energy Agency, 2015].

These reductions has been possible due to improvements in plants efficiency, increment in the number of CHP plants and almost tripling of energy generated from renewable energy sources [The Danish Energy Agency, 2015]. Moreover, The energy efficiency requirements for new building has increased in a 25% for buildings constructed (or renovated) after 2020 [Danish Energy Agency, 2017] and the energy saving obligations for energy companies has increased by 75% in 2017-2020 [The Danish Government, 2011].

1.4.2 Heating in Denmark

Currently, energy consumption in households corresponds to 30% of total Danish energy consumption. The 83% of the total energy consumption is used for heating purposes, including space heating and domestic hot water, and the remaining 17% is used as electricity [Danish Energy Agency, 2017].

According with the The World Bank [2014], the Co_2 emissions from electricity and heat production represents 49.04 % of the total emissions released by total fuel consumption in 2014. Likewise, the total CO_2 released by fuels is 23,332 kilo tonnes in 2014 [Index mundi, 2014]. Thus, the total emissions from heat and electricity production account in 11,442 kilo tonnes, having 9,497 kilo tonnes from heating and 1,945 kilo tonnes from electricity, following the proportion presented in the last paragraph.

Despite of an increasing number of population and hence on the amount of households, the heating consumption has remained quite at a constant level during the last 15 years, however there have been changes in the energy sources used (Figure 1.5), especially due to the significant reduction in the number of oil-fired boilers.

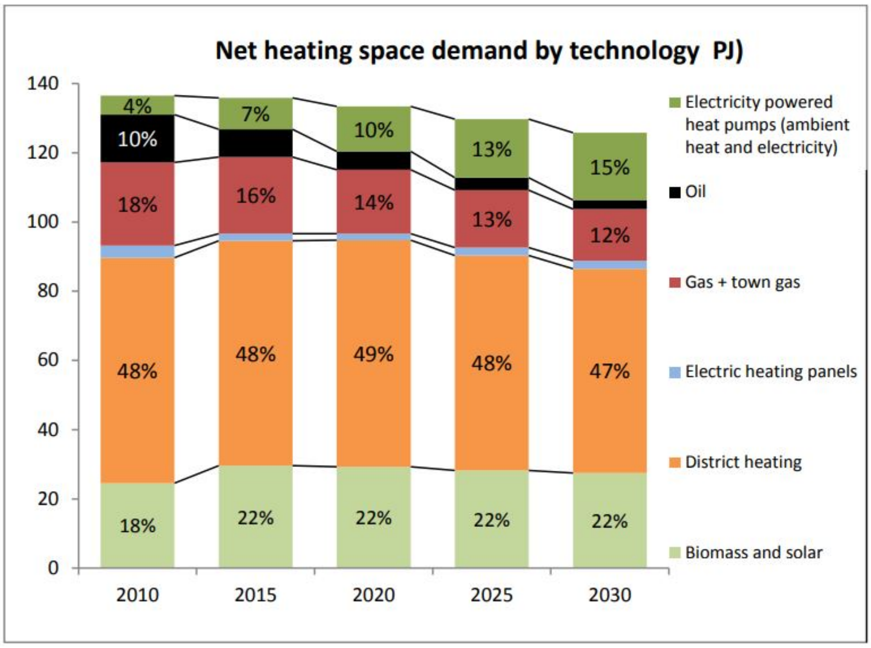


Figure 1.5: The share of technologies supplying the net space heating demand (PJ) [Danish Energy Agency, 2017]

By 2030, a drop of 8% in the space heating demand (compared with the 2015) is expected. The Danish Energy Agency [2017] is accounting with an invariant electric consumption on households, while having a reduction in heating consumption.

The growing population together with an increase in material wealth will led to an increment of 10% in the total heated area as a consequence of the increment in number of homes. Nevertheless, the predicted drop in heating demand will be achieved due to higher energy efficiency in new buildings and even more, due to the improvements in the energy efficiency (or the demolition, when necessary) of the current buildings (see Figure 1.6, where the demand of the buildings increase along the years). Additionally to the expected reduction of the net space hating demand, a 10% decrease between 2015-2030 will be achieved due to the change for more efficient heating sources and additional improvements will also come with the technological advances [Danish Energy Agency, 2017].

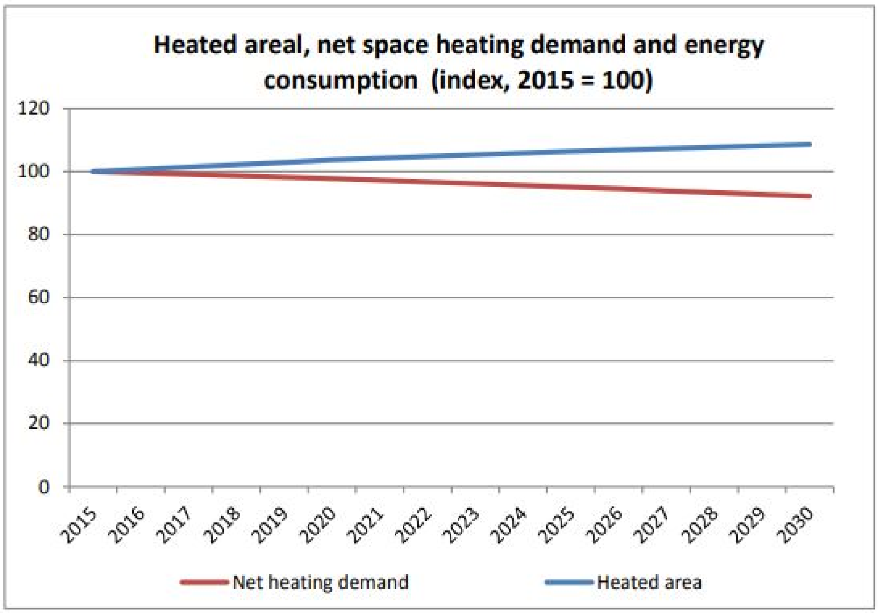


Figure 1.6: increment in the heated area will led to a decrease in the heating demand as a result of more efficient buildings [Danish Energy Agency, 2017]

Regarding district heating, it plays an important role in reaching the energy goals. According to the expectations, a large share of the electricity and heating will come from renewable energy, in that aspect, district heating could offers the required flexibility regarding the technologies.

Some technological implementations can improve the flexibility, such as heat storage, heat pumps, bypass of power turbines and implementing low temperature district heating[Danish Energy Agency, 2015]

1.4.3 Aalborg and its energy targets

As it was introduced in the last section, Denmark is highly committed with its national targets for reducing GHG emissions, however, the different strategies to achieve mentioned targets are implemented in a local scale and are dependant on the scheme proposed by each municipality.

Aalborg is located in the Nordjylland region, it is Denmark's fourth largest city with an urban population of 211,937 (by the 1 January 2017). Additionally, the Aalborg Municipality is the third most populated in the country after Copenhagen and Aarhus [Aalborg Municipality, 2017].

As part of Aalborg's sustainability strategy [Aalborg Kommune, 2016], the 60% of the energy should be from renewable sources by 2030 and by 2050 it should be 100% with 80% of the electricity coming from wind turbines.

In order to achieve this, the municipality has set some targets aligned with the national ones. Therefore, by 2020, the GHG emissions from Aalborg should be reduced by 40%, below 1990 levels. Additionally, the energy consumption in the municipal buildings should be reduced, at least, 2% per year. Furthermore, by 2030 district heating should cover up more than 85% of heat supply in the municipality of Aalborg.

Currently, 99% of the heat demand in the city of Aalborg is covered with district heating, having approximately 40,000 metering points [Bahrendet, 2018]. The system has several sources which are shown in Figure 1.7. Nordjylland coal-based CHP (Nordjyllandsværke) is the main contributor, followed by the waste incinerator plant (Reno-Nord), then the cement factory (Aalborg Portland) and finally, heat generated by other sources including diverse small sources (such as, cremation process, surplus heats in supermarkets, among others) [Aalborg Energikoncern, Aalborg varme A/S, 2016]

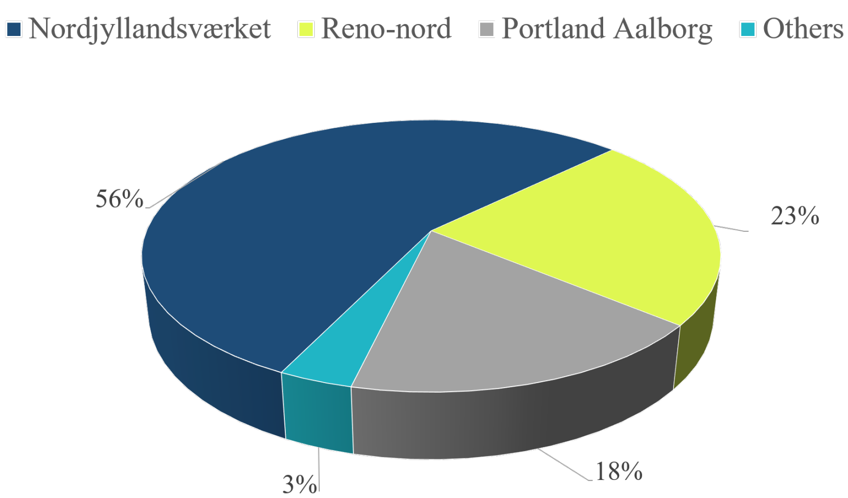


Figure 1.7: District heating sources in Aalborg [Aalborg Energikoncern, Aalborg varme A/S, 2016]

The Municipality has an ambitious goal to have a fossil-free district heating by 2030, hence the CHP plant will be shut-down during the next 10 years and the heat capacity will be replaced with renewable sources, such as wind powered heat pumps and surplus heat from industry [Bahrendet, 2018].

As part of the decarbonization process, the Municipality-owned Aalborg Energy group (Aalborg Forsyning) intends to decrease the current water temperature in the district heating, from 75°C until 60°C, in order to further implement low(er) temperature district heating in the newer households (provided with floor heating). Moreover, it is working on new strategic partnerships with some industries and big supermarkets such as Bilka[Bahrendet, 2018], which were unable to introduce their surplus heat into the system before. Additionally, the energy Group has invested in a 35 MW electric boiler which is expected to reduce annual CO_2 emissions by 15,000 tonnes. With This technology it is possible to produce heat from renewable energy, and at the same time, allows the energy group to sell services on the electricity market when there is an overproduction on the electricity (e.g. from wind turbines) while converting it into heat that can go directly to the district heating [Høstgaard-Jensen, 2017] or that could be saved in the thermal storage for later usage.

The billing for the residential energy consumption happens once a year based on your meter reading (in m3 for heating and in kWh for electricity). However, during the year you need to pay several times on account based on anticipated consumption [Aalborg Kommune, n.d].

2 Problem analysis and statement

2.1 Problem analysis

As said before, Aalborg Municipality is currently doing some efforts to be fossil-fuel independent in the energy system by 2050 (or even earlier). To reach this ambitious goal, the national policy addresses the importance of diminishing energy consumption, together with the implementation of more efficient technologies (e.g. heat pumps and thermal storage), in order to ensure security and stability on the service once having a low-carbon system.

Currently, the policies and strategies promoting reductions of GHG emissions are highly focused on the system level. Thus, the (national and international) proposed targets, and even the financial schemes to support them (e.g. the emissions trading), usually take a territorial production perspective which aims to engage industries and governments in the fight against climate change. As a result, this approach reduces the visibility of the individual's role in the transition process, and the understanding of its influence on achieving the goals of the system level.

Individuals are daily taking several consumption decisions that influence the production of good and services which finally impacts on the amount of GHG emissions of the system level. For instance, if today the citizens of Aalborg consume more energy in their homes than yesterday, likewise, the energy production will increase and also do so the GHG emissions. For this reason, consumption-based emissions modelling and accounting have taken relevance during the last years, and are supported by increasing availability in the data.

Behind the development of new tools that represent consumption-based emissions, is the need to have a better understanding and communication of the impacts of the individual consumption on the environment, with the aim of promoting a change in the current consumption pattern. Therefore, one way of engaging the final consumers is through footprint calculators [1] [West et al., 2015]. This type of tools are gathering strength due to its high potential to present complex information in an understandable way, arising consumption awareness among the citizens and potentially leading to energy savings.

[1] tools for individuals to explore the impacts of their consumption.

2.1.1 Carbon footprint reductions in the energy system

Currently, Aalborg is eliminating the heat input from Nordjyllandsværke and replacing it with renewable sources together with a bigger input of surplus heat from industry. The introduction of renewable energies into the energy system will bring several benefits, including synergy between the district heating and the electric grid, and significant reductions in the carbon footprint. Nevertheless, as the share of renewable resources will increase, so do the challenges. As shown in Figure 2.1, having a system with 100% fossil production, it is not hard to balance the equation because it is possible to predict the demand and then the energy will be produced accordingly.

Figure 2.1: Equation of the energy market

Moreover, adding renewable sources to the equation, it remains as shown in Figure 2.2. The unpredictability is not only in the demand side, but also in the production one, since several renewable resources (e.g. wind and solar) depend from meteorological factors and its prediction is not always accurate.

Figure 2.2: Equation of the transition energy market

The main challenges linked with low-carbon district heating (and the energy sector in general) relies on the difficulty to supply the demand along the day, especially in peak hours[2], when the suppliers may have difficulties providing energy, in case the weather conditions are not favorable, due to the sudden increase in demand.

Moreover, a mistake in forecasting will break the balance of the equation shown in Figure 2.1, having as a consequence high risks of blackouts and an increment in the costs to aligned the actual demand with the production. As an example, Sharp [1986] have evaluated that

[2]specific times when the use of energy by simultaneous domestic activities across the majority of households is concentrated

a 1% increase in forecasting error could cause an increase in operating costs up to £10 million (approx 84.8 Mio DKK).

2.1.2 Individual carbon footprint reductions

Until this point is clear that the implementation of renewable energies bring some challenges, arising the need of having a greater efficiency in the energy system. For this reason is indispensable to diminish energy consumption, together with the implementation of more efficient technologies.

Currently, the strategies applied to reduce consumption are mostly focused in technological and generally costly, implementations (e.g. Smart devices and house retrofitting). While much attention has given to innovation and diffusion of efficient technologies, there is still a need to understand how culture and value systems affect these processes [Armel, 2008]. Or putting it in different words, solving energy problems requires more than just understanding the technical aspect of the problem, it requires also to consider how people perceive the problem and the available solutions.

There is a growing interest on developing human-centered behavioral approach methods where people are supported to explore the impacts of their consumption; especially because people tend to focus on industry and governments as causes of climate change, and just a few people mentioned domestic energy consumption or personal actions as a cause [Whitmarsh, 2009]. For these reasons, dis-aggregation of national level emissions data to small scales (i.e. to households or individuals) allows the development of new tools, such as carbon footprint calculators (CFC) that present consumption-based emissions as a way of engaging consumers to promote a change in the behavior, either to achieve reductions in consumption or to shift it out of the peak hours.

The way how the information is presented to the end-users is taking more and more important in order to not only inform and perhaps raise awareness about consumption and individual contribution to climate change but also to educate and motivate end-users towards having a more sustainable consumption behavior.

In Aalborg a key problem is that people are not able (or do not know how) to evaluate their resource consumption periodically, and only receive a yearly statement with the meter reading in terms of cubic meters (m^3) consumed, in the case of the heating or, in Kilowatt hour for electricity use [Bahrendet, 2018]. Conversely, in the case of the carbon footprint people do not have any type of feedback in terms of emissions, maintaining citizens "blind" about their own impact on the environment. To have a better understanding of this situation, Layne [1994] compared the level of feedback received from energy consumption in the household, stating that this would be like shopping in a grocery store where the only feedback received about the purchase is through a yearly bill that provides one aggregate bill (e.g. “You spent 20000 DKK for 100 food units in 2017”). On the other hand,in the case of GHG, citizens have been shopping items without tag price for many years without having a bill and not even receiving a quantitative yearly feedback as it happens in the case of electricity.

In this sense, CFC is a tool that allows individuals to track their carbon emissions, based on their consumption choices. Nevertheless, without a feedback that involves a mechanism to promote behavioral change, this calculator will have interesting data as output but will do a small contribution to mitigate the environmental and the social problems derived by unsustainable consumption and production.

In its most basic approach, under the scope of this project, feedback is understood as the provision of information about the energy use and the related carbon footprint in a certain period of time.

During the last decade, several studies have explored the influence of receiving constant feedback about energy consumption and the findings suggest that energy savings are about 5 - 20% [Darby, 2010], [Fischer, 2008]. Nevertheless, some authors (based on meta-analyses), have found that the effects are actually smaller [Abrahamse et al., 2005] and stated that the energy monitoring devices are only engaging people who are environmentally motivated [Wallenborn et al.]. Consequently, some doubts have raised about the general conclusion of the potential effects on a local level and the long-term effect of the behavior [Buchanan et al., 2014], especially because according mechanisms of engagement that relies only on information provision are slow and ineffective [Whitmarsh, 2009].

Based on the available literature it is difficult to conclude about the effectiveness of feedback about energy consumption in achieving long-term behavior change and due to they were performed during short-periods of time are expected to be under the "toy effect" particular of every new contextual factor introduced in daily routines; additionally, the potentials of providing feedback about carbon footprint as an add-on of the energy consumption feedback has not been extensively explored yet.

2.2 Problem statement

As it was previously stated, in order to have a successful transition towards a fossil-free heating system targeted by 2030 in Aalborg, it is necessary, among several aspects, to have a decrease in individual energy consumption.

Therefore, one way of engaging the final consumers in Aalborg to achieve this change, is by promoting the use of CFC, as a tool that allow the end-users to visualize their heating consumption and so do to raise awareness about their contribution to climate change by knowing the amount of carbon emitted.

Moreover, the individual behavior is an important aspect when developing meaningful tools and strategies to promote reductions in the energy consumption. This project is aiming at promoting energy savings in heating that will lead to GHG emissions reductions by exploring the incorporation of motivational aspects to the feedback proportioned by a CFC. The initial hypothesis of the author is that energy savings can be achieved as consequence of the consumption visualization together with an adequate feedback, that evokes extrinsic and intrinsic motivations to promote behavioral change.

The current study addresses the following research question:

How can individual carbon footprint calculators (CFC) support the transition towards a fossil-free heating system?

For analyzing this, the project focuses on identifying:

- *What is the level of awareness of Aalborg residents about their individual contribution to climate change resulting from energy consumption (as the form of heating)?*
- *How to raise awareness about climate impacts as consequence of energy use?*
- *How can feedback promote behavior change?*
- *What is a footprint metric that people understand?*
- *What are the potential benefits linked with CFC uptake?*

2.3 Report structure

The document is divided into six parts: the first one follows a top-down approach to explore the need of decreasing GHG. The national and the local energy targets are presented together with the challenges of having a fossil-free district heating in Aalborg, highlighting the necessity to decrease energy consumption; finally, the research questions and sub-questions are addressed. The second part addresses the methodological framework used on this research project. The third one presents the results and is divided in two chapters: in chapter 4 the results of the literature review are addressed; and chapter 5 described the results of the surveys and the highlight ideas obtained during the interviews. The fourth part is the analysis, the fifth presents the discussion and finally, the last one are the conclusions.

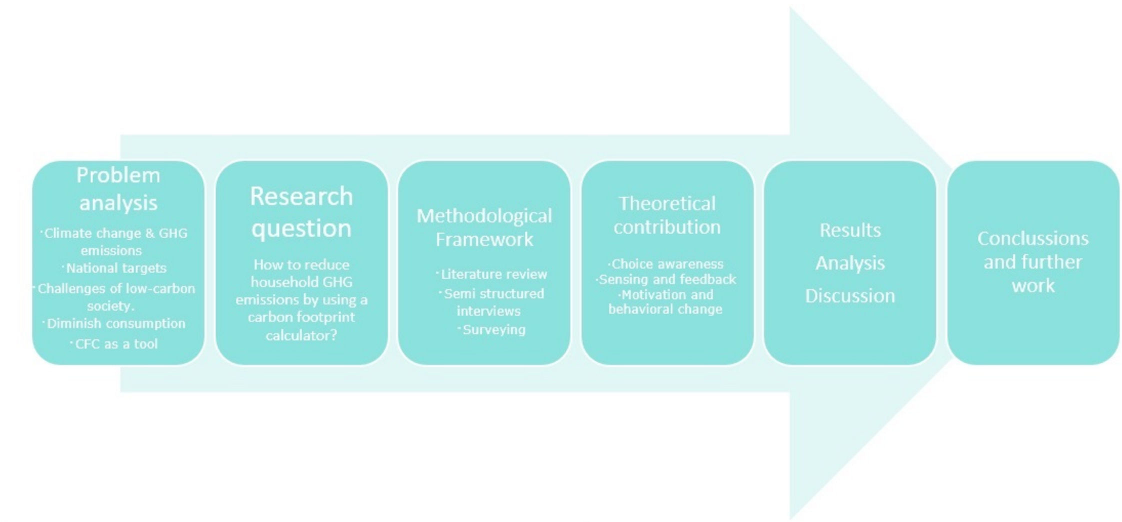


Figure 2.3: Research design

Methodology 3

This chapter presents the different methods used during the research. In order to gain an understanding on how to reduce GHG emissions by using feedback tools like CFC, different sources of information were used to draw information, including literature review, experts opinion, surveys for statistic purposes, local government interviews, and user opinions.

The methodology research is mixed, in other words, it combines qualitative and quantitative research methods, approaches, and theories [Johnson et al., 2007]. Likewise, the qualitative findings are supported with quantitative results.

The table 3.1 presents the method(s) and theory(ies) used in order to answer each research sub-question.

Research sub-question	Method	Theory(ies) used
1. What is the level of awareness of Aalborg residents about their individual contribution to climate change?	• Survey	• The focus theory of normative conduct • Climate paradox
2. How to raise awareness about climate impacts as consequence of energy use?	• Literature review • Survey	• Feedback intervention theory • Informational deficit model
3. How can feedback promote behavioral change?	• Literature review • Interviews • Surveys	• Pro-environmental behavior change • The law-effect • The climate paradox • Norm activation model • Feedback intervention theory
4. What are the potential benefits linked to the potential benefits linked with CFC uptake?	• Literature review • Surveys	• Choice awareness theory • Smart energy system

Figure 3.1: Methodology used to answer research sub-questions

3.1 Literature review

In order to get an understanding of climate change, different scientific reports, international agreements and the Danish commitments, were reviewed. The literature review is mainly used throughout the report to gain understanding about the role of different types of energy feedback in achieving behavioral change; for this purpose, the considered literature are almost exclusively peer-reviewed articles in academic journals, accessed through online databases. Some of the main search queries used were: energy sensing and feedback, carbon footprint calculator, behavioral change and motivational aspects. Additionally, different books were used as a source of information about formal theories.

During the literature review, a basic analysis of the content was made to segregate and filter the information, as the interest of the authors and the year of publication can affect the reliability and pertinence of the information. Thereby, documents published after 2010 were prioritized in the review, this without meaning, that other documents published before the given year were not taken into consideration.

3.2 Interviewing

Semi-structured or semi-standardized interviews were carried out to gain knowledge of the efforts and strategies that different stakeholders are putting in place to achieve energy efficiency in Aalborg, more specifically towards reaching more energy savings in the heating system at the residential level. The list of interviewees can be found in Appendix A.1 and the chosen participants mainly represents Himmerland Housing Association, Aalborg Energy group, Aalborg Municipality and the energy users.

The interviews were conducted in the city of Aalborg and generally covered the duration of 40 minutes. Additionally, the interviewing strategy was based on snowball sampling, In this way an interviewee helped to recruit other participants for the study [Dudovskiy, n.d.].

This type of interviews are characterized by open-ended questions based on semi-standard interview guide [Jamshed, 2014], which is a set of questions and topics to be explored by the researcher. The interview guide was developed in advance and is useful to keep the interview on the desired direction. Despite of having the guide, this type of interviews allows the interviewer to ask follow-up questions based on previous answers, which helps in the deeper understanding of the response [Galletta, 2013].

3.3 Surveying

The surveying is one of the most important research methods of this project, because it constitutes the base for the quantitative analysis. The results will reveal the individual motivations to save energy in form of heating, and the citizens perception of their contribution to climate change. Additionally, this results will be compared with data found in the literature and information provided by the interviewees.

The questionnaire was developed upon self-assessment and was fulfilled between the 9th may and the 23rd may 2018. The original version was in English and a Danish translation was done to facilitate and increase the accessibility. The surveys were mainly composed by closed-questions, however, checklists and one open question is also included. The original English version of the questionnaire is presented in Appendix B.1.

The sampling was based on simple random sampling and the strategies adopted to carry out the survey comprise online access , door-by-door approach in the Vejgaard district, and personal approach to people present in the Østre Anlæg park only during the 10th and 11th May 2018. Because of time constraints, the author managed to complete 190 surveys, in a city with 114,590 households [Aalborg Municipality, 2017].

At the end of every survey, the participants were asked for their contact information in case they will be interested in participate in a personal interview. This interviews followed the same approach as it was mentioned in the interviews section.

Review of the literature 4

This section comprises the findings of the literature review that supports this research project. The general aim is to understand how feedback interventions, such as a CFC, can raise awareness of personal GHG emissions that can lead to a behavioral change. Along the chapter different theories are addressed together with the respective analysis that relates the theory with the current research project. First the theory about pro-environmental behavior change is introduced, later the theories behind the feedback mechanisms are addressed. Due to the feedback in this project is aiming to address climate change concern, the climate paradox is presented together with the barriers of climate communication.

After addressing these theories, finally the carbon footprint calculator is presented as a visualization tool to monitor GHG emissions. Later on, the choice awareness theory and the smart energy system are addressed as is necessary to understand these theories to analyze the benefits evoked by a CFC uptake in the transition towards a fossil-free energy system

Before starting addressing the theories, it is important to introduce some concepts and definitions to contextualize the reader.

4.1 Theory to promote change

The human consumption patterns play an important role in this project, more specifically the environmental behaviour that underlies energy consumption in form of heat. The main purpose of implementing CFC in households is encouraging a pro-environmental behavior change, defined as the behavior that a person seeks deliberately to reduce the negative impact of one's actions on the environment [Kollmuss and Agyeman, 2002]

The type of change this project wants to promote is decreasing the energy consumption by implementing a CFC in order to facilitate the transition towards a low-carbon society.

To promote a pro-environmental behavior change [Steg and Vlek, 2009] suggests the following steps: first, it is necessary to identify the behavior to be changed, then understand the factors influencing this behavior, third design interventions to diminish the environmental impact and finally, assessed the proposed actions.

During this research only the three first steps are considered, because the evaluation stage needs to be addressed once the proposed strategy is implemented.

Before addressing the interventions that can promote energy savings among the residents in the city of Aalborg, it is important first to understand the factors that encourage (or inhibit) such behaviors. These factors can be classify in three groups: Contextual factors, motivational factors and habitual factors [Steg and Vlek, 2009].

4.1.1 Motivational factors

Motivation is defined as *"the reason for a behaviour or a strong internal stimulus around which behaviour is organized"* [Kollmuss and Agyeman, 2002].

Some influential theories that address motivational factors to achieve a pro-environmental behavior are going to be presented, and approach the two types of motivation, the internal motivation (e.g. decreasing consumption because is damaging the environment), or the external (e.g.reducing energy consumption because of a compensation). These two categories of motivation, internal and external, are referred to as *intrinsic* and *extrinsic* motivation in psychology [Deci and Ryan, 1985].

First, the Theory of Planned Behavior (TPB) states that only intentions define behavior [Egmond and Bruel, 2008]. Thus, it assumed that individuals make a reasoning of alternatives and choose the one with highest benefits against lowest costs, such as economic savings, effort needed and social approval. This theory has explained various type of pro-environmental behavior, including the purchasing of energy-saving bulbs, travel mode choice and recycling. [Steg and Vlek, 2009]

Second, some studies have focused on the role of moral and normative concerns. First, the studies have revealed that having higher altruistic values the more likely is the individual to engage in pro-environmental behavior. Similarly occurs to the environmental concern level, thus, higher concern people is associated with acting more pro-environmentally [Steg and Vlek, 2009].

Another line of research is based on the Focus Theory of Normative Conduct, which is focused on the influence of social norms in affecting behavior. The theory distinguish between *injunctive* and *descriptive* social norms. *injunctive* norms refers to what is typically *what "ought" to be done*. While *descriptive* norms refer to *what people actually do*, and involve involve perceptions of which behaviors are typically performed [Cialdini, 2003]. Both types of norms influence behavior, but the level of influence is dependent of the saliency of a particular norm, thus, no matter how pervasive a norm is, it is unlikely that it will affect behavior if the norm is not salient.

As an example of the use of the focus theory of normative, there is the energy conservation program implemented by OPOWER in EEUU. OPOWER mails home energy report letters that compare the energy use of the household with similar neighbors, and also provide energy conservation tips. This comparison provides a *descriptive* social norm, information that induces people that previously used more than the norm to save energy, but would also cause households using less than the norm to use more. This undesired effect is called by social psychologists *"boomerang effect"* [Clee et al., 1980], and it should be avoided if the aim is to promote energy savings. Therefore, to tackle this boomerang effect, OPOWER has included *injunctive* norms, by categorizing the household as "Great", "Good", or "Below Average". The Figure 4.1 illustrate the social comparison (*descriptive norm*) on the left side, and the "efficiency standing" (*injunctive norm*) on the right side.

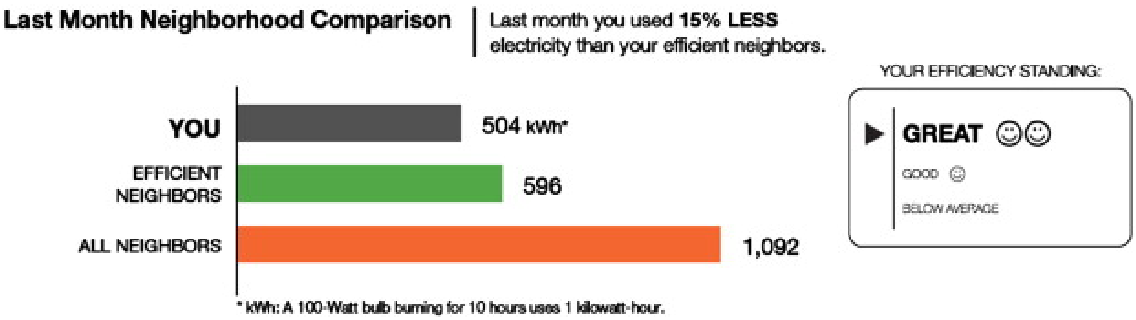


Figure 4.1: Climate change awareness related with individual behavior

The introduction of different injunctive categorizations did not have large differential effects. Conversely, some combination of energy saving tips tailored to different type of households based on historical energy use patterns and demographic characteristics were responsible of mitigating the boomerang effect [Allcott, 2011].

In general, these theoretical perspectives are not mutually exclusive. Different authors have integrated theoretical approaches from different theories, acknowledging that behavior is the result of multiple motivations, including extrinsic and intrinsic. Nevertheless, When using extrinsic motivation as strategy to promote behavior change, is often that once the reward is not offered anymore, the motivation decrease. Thus, promoting rewards or feeling of guilt do not ensure long-term behavioral change if the extrinsic motivation have not been internalized. Therefore, The self-determination theory [Deci and Ryan, 1985] proposes a process that allows to have intrinsic satisfaction as a result from environmentally sustainable behaviors: (1) satisfaction derived from knowing what to do and doing it; (2) satisfaction from not feeling wasteful; and (3) satisfaction from participation in a community (feeling part of a larger effort).

4.1.2 Contextual factors

Human behavior does not depend only in motivations, and many contextual factors facilitate or inhibit not only the environmental behavior, but also influence the individual motivations. Thus, the people's engagement in pro-environmental behaviors in energy consumption depends on the available facilities, the availability of products, technology and products characteristics.

Therefore, the contextual factors may moderate the relationship between motivation and behavior. for example, the availability of different type of bins could result in more positive attitudes towards recycling which will result in higher recycling levels, however, this infrastructure promotes recycling only among those highly environmental concerned (intrinsic motivated)[Steg and Vlek, 2009] and other strategies are required to arise external motivation.

Similarly to the waste management system, this contextual factors are also required in the heating system in order to promote behavioral change. Currently, all energy suppliers in Denmark, in accordance with the Energy Saving Agreement of 2016, shall contribute to the realization of energy savings in end-uses; the purpose is to promote energy efficiency measures and the customers can apply either for advice or for financial support in case they want to retrofit the dwelling to increase energy efficiency [Eniig] [The Danish Energy Agency, 2016]. This strategy addresses the use of motivational factors, in this case economic support that under the theory of planned behavior, plays an important role in the individuals' benefit-cost assessment as part of the decision-making process. Nevertheless, there are some discussions around the strategy, which are going to be addressed in the next paragraphs.

In the first place, the grants are not well known by the citizens, for this reason, its visibility needs to increase, especially, to reach those users that are not internally motivated in reducing energy consumption. This is not a problem for intrinsically motivated users, because all the information regarding the strategy is on the Danish Energy Agency as well as, in every energy supplier's web page in case the individual is seeking for it.

Nevertheless, the strategy is overrating its potential by lacking high visibility among those unmotivated users, due to those individuals could find it as the extrinsic motivational factor needed to take actions that increase their energy efficiency.

On the other hand, the role of the strategy as an extrinsic motivational factor is not completely accomplishing its function due to the low economic value that the grant represents in comparison with the total cost of the retrofitting. Then, individuals intrinsically motivated are going to take the action even if they cannot access the grant. However, the situation is different for the rest, who are making all the process prior the renovation in order to access to the grant; at the end, they will realize that the economic contribution from the government is not significant, and not only will feel unmotivated to take the action but will also lose the trust on the strategies promoted by the government.

4.1.3 Habitual behavior

In the aforementioned theories discussed in 4.1.1 and 4.1.2 has been indicate that individuals make reasoned choices. Nevertheless, in other cases, is an automatic and routine behavior and reasoned weighing is only occurring when the habit is broken. [Steg and Vlek, 2009]

AartsS and Dijksterhuis [2000] define three characteristics of habits. (1) it requires a goal to be aimed. (2) the same action sequence is repeated when the outcomes are satisfactory. (3) habitual responses are mediated by mental processes. Then, when an individual act frequently in the same way under a given situation, that situation will be mentally associated with the goal-directed behavior. Therefore, as the frequency increase, the stronger the association will become, then, it is more likely that the individual act as habitual.

Habitual behaviors generally associate misconceptions and evidence a selective attention, thus, individuals likely focus only on information that confirms their choices and beliefs and neglect information that is not in line with their habitual behavior. Nevertheless, it is possible to break the habit by changing the context. For example Fujii et al. [2001] found that long-term reduction in car use was achieved by forcing car drivers to use alternative travel modes over a short period. This evidenced that habitual car drivers have a modifiable perception of the pros and cons of different transport means. Therefore, in order to design effective strategies to modify habitual behavioral change, it is important to consider how habits are formed and sustained [Steg and Vlek, 2009].

This research is addressing mainly habitual behaviors of heating that are the result of years and years acting in the same way. Habitual behaviors include inappropriate use of radiators and setting temperatures higher than actually needed or preferred. Additionally, some users does not have an active interaction with the appliances and prefer to open the window to cool down the dwelling while having a high temperature settings.

As evidenced in the Fujii et al. [2001] study, in order to break the habit then the context should change. However, in the particular case of this research it is difficult to force consumers to have a drastic change in the context because this will imply a sacrifice on their comfort. Then as an alternative, a nudging strategy could be carried out by informing the users how much they can potentially save in a month by decreasing the set temperature until 21°C and challenging them to set this goal for the next month. Additionally, a reward for the 100 families with higher savings should be offered as an extrinsic motivator factor.

4.2 The importance of feedback

Feedback is defined as the information provided by a (several) external agent(s) regarding some aspect(s) of one's task performance [Avraham N. Kluger, 1996]. Moreover, under the scope of this project,feedback is the provision of information about the amount of carbon released due to heating consumption in a household over certain period (adopted from [Buchanan et al., 2014]).

Feedback has been cataloged as a promoter of behavior change because through it, allows the individuals to monitor, compare and evaluate their performance. The key element for success is that it includes both informational and motivational characteristics, as it was stated by Aitken et al. [1994]: *"it can provide a basis for assessment and action and enable progress towards a goal"*. Nevertheless, the feedback by itself might not be effective but the type of information and the way how this is presented can make a big difference in changing behavior. Feedback programs tailored to increase energy savings in households use different type of feedback methods, starting with the conventional paper-based approach until advanced digital feedback such as CFC and energy display devices. The frequency and resolution of information given by the feedback is highly correlated with the type of technology used. For example, Allcott [2011] presents a positive position of more frequent feedback provided but highlight than from a cost-benefit point of view, the most effective frequency for paper-based feedback is quarterly.

Several studies have assessed the influence of feedback on the energy consumption and have demonstrated reductions between 5% - 20% [Abrahamse et al., 2005] [Darby, 2010] [Fischer, 2008][Roberts and Baker, 2003]. Nevertheless, findings from smart metering trials in the EU present smaller reduction in electricity consumption between 1.5% and 4% Gleerup et al. [2010][Schleich et al., 2013].

Some authors have also noted that the sizes samples where the effects have been evidenced are small [Abrahamse et al., 2005],they have also criticized the short-term duration of the existing studies, being generally under three months, evoking doubts about whether the effects of feedback persist in the long term. In addition, have highlighted the feedback devices are only appealing for those with an environmentalist personality [Wallenborn et al.].

To sum up, studies do confirm a high acceptance rate of feedback for electricity consumption using digital information and communication technologies [Sunderer, 2012], such as energy displays and CFC, but is difficult to ascertain its effectiveness in achieve long-term behavioral change.

4.2.1 How feedback works?

Few studies have analyzed the processes behind the feedback mechanism. In this section, some positions will be presented, together with the theories underlying how feedback works.

In a general way, feedback is based on The Law-effect proposed by Thorndike [1927], which addresses that a positive feedback is related with reinforcement and a negative one with punishment. Thus, reinforcement and punishment facilitate learning and hence improve performance due to a positive one, reinforces the correct behavior and the negative feedback punishes the incorrect behavior [Avraham N. Kluger, 1996].

The most frequent explanation rely on the informational-deficit model [Wilhite and Ling, 1995] assuming that individuals do not receive timely information about their consumption behavior[Buchanan et al., 2014] and the feedback fill the information gap. It is commonly compared with the aforementioned analogy of the supermarket that do not provide customers with an itemized bill. In addition, this explanation assumes that after provided the information, users will gain the required knowledge to learn how to correct their behavior [Froehlich, 2011] and make "better informed choices" [Layne, 1994].

Fischer [2008] introduced a theoretical framework based on The Norm Activation Model, proposed by Sch, which assumes that pro-environment behavior are accomplish once personal and social norms are activated. The activation of the norm arises when the individual feel a personal responsibility after being aware of the problem. Similarly, Fischer [2008] presents that the information given through feedback supports activation of norm in the pre-decisional phase. Therefore, the information of the feedback should be framed on a way as activate norms (e.g. as carbon footprints contributing to climate change) motivating people to decrease carbon footprint by decreasing energy consumption. Similarly, addressing knowledge engagement as part of the feedback by presenting specific saving actions and providing the saving results might positively influence post-actional assessment of individual's goal achievement [Nachreiner et al., 2015].

Karlin et al. [2015] has introduced the Feedback Intervention Theory (proposed by Avraham N. Kluger [1996]) which assumes that feedback will only lead to significant behavioral changes if the individual perceives a difference on the information presented as a feedback and their own expectations, for example when the energy consumption showed in the feedback is higher than thought. Avraham N. Kluger [1996] refers to this as a standard-feedback gap and assumes that raising awareness of it will promote behavioral change only if the gap is meaningful to the individual.

Another frequent explanation addresses feedback as a tool that allow people to see their consumption information, which has been cataloged as "abstract, invisible and untouchable" [Fischer, 2008], into a visible manner in real-time, allowing to understand the link between actions and effects[Chiang et al., 2014] as a way of money expended or as carbon emitted.

4.2.2 Feedback strategies

As it was said at the beginning of this chapter, changing behavior is not simply about the informational content provided in the feedback, but the way how the information is presented is crucial to motivate the consumer into action [Wood and Newborough, 2007].

There are several strategies to motivate consumers to reduce energy use, and they are going to be introduced in the next paragraphs.

Before introducing the strategies, it is important to address that, while using this type of schemes, human-computer interactive tools (such as, home displays and CFC) present a big advantage compared with the traditional ways of feedback (such as, telephone, call, email, letter), because the information has an easy access and updated data (max. one day delayed) is available.

Informational

Informational strategies are aiming at changing perceptions, motivations, knowledge, and norms, without actually changing the external context in which choices are made. Informational strategies target to arise the motivational factors discussed in section 4.1.1.

First, informational strategies can be aimed to increase actors' knowledge and awareness of environmental problems and impacts of their behavior, additionally aims to increase their knowledge of behavioural alternatives and their pros and cons. It is assumed that new knowledge will lead to changes in attitudes, and hence will affect behaviour. Generally, information campaigns hardly result in behaviour changes [Steg and Vlek, 2009].

Basic comparative data

Some authors have addressed the idea to present disaggregated data of heating consumption in different rooms of the household. However, since this type of information can only be obtained after installing sensors in each of the measurement points, (each of the rooms). Likewise, this would lead to a high increase in installation costs that could not be economically viable, from the cost-benefit point of view [Buch, 2018].

There are several options for providing comparative information on carbon footprint, including:

- The savings achieved in self-comparisons of self-historical data. Since the heating use is highly related with the season, it is necessary to have historical data from at least one year to make this type of comparison.
- The comparison rate of use in relation to other household. There is some discussion around what make two households comparable, in one hand households with similar characteristics, such as, area, number of residents and if is possible, level of insulation, can be compared. On the other hand, others prefer the correlation per service

delivered (e.g. total footprint per housing unit) to promote more efficient ways of living.

In order to implement motivational factors, this type of comparison must be always accompanied by injunctive norms as a certain type of qualification, from a happy face to a sad face or other type of measurements that imply a better or worse behavior than the average or than the recommended.

According to Roberts et al. [2004], self-comparisons of historical data is received positively by consumers. On the contrary, comparisons with similar houses seems to be very unpopular, especially because participants has expressed a feeling of skepticism over the ability of suppliers to determine what conditions made them comparable [Roberts et al., 2004][Wood and Newborough, 2003]. Conversely, the aforementioned OPOWER case has obtained energy savings by introducing comparison with others as part of their feedback.

Goal setting as the significant comparison

Relying on motivational factors, people feel a sense of achievement when a target is reached. In this sense, human-computer interface tools, nevertheless the level of the settled target should be considered carefully. If it is too easy, consumers tends to feel bored and demotivated, on the contrary, If it is too difficult, individuals will be frustrated and disappointed for finding it nearly impossible to achieve[G. HARKINS and D. LOWE, 2000]. Additionally, it has been demonstrated by G. HARKINS and D. LOWE [2000] that people has greater confidence in achieving goals assigned by an external entity rather than goals they chose by themselves.

Consumers can set the goal internally. For example a person can set themselves the goal of using less energy than the previous week, or target to use less energy than the consumption in a given period, or to set a maximum budget for heating use during the month. Additionally, the users can introduce their own customized goal or go under relate goals set by external agencies (e.g the 20% reductions goal set by UK Government for CO_2 reduction by 2020, or a reminder for a time-of-use goal set by the utility company to decrease consumption during peak hours).

Similarly, the software can help by suggesting predetermined reductions in a percentage way (e.g. 5%, 10%, 15% or 20%,etc) and according to [McCalley and Midden, 2002] when individuals were asked to set a goal of either 5%, 10%, 15% or 20%, in general , people achieved savings around 20%. Therefore, the interactive tools might be designed with different choices to give the consumer the ability to select .

Rewards

Rewards seems to be the catalyst to have a better performance when reducing greenhouse gas emissions. Not all of the incentives need to be monetary, could also be in the form of emotional rewards (by receiving a "thank you "note, or by making it public in social media or in the dashboard of the building.) [Wood and Newborough, 2007]

Monetary incentives normally are the financial savings as a result of the less consumption. However, this type of incentives can be in a direct payment, for example by promoting a race among the citizens that reward with some money to those with the higher reductions.

4.3 Climate paradox

There is a growing inconsistency between the increasing scientific base about anthropogenic responsibility of the climate change and a decreasing concern and popular support for ambitious and effective climate policies and strategies. There has never been a better understanding of how serious climate change is, however, public concern and prioritization is declining in many countries, particularly wealthy ones [Stokness, 2015].

For several years scientist are bringing facts about climate change, but the messages are not working, sometimes not even for the most receptive audiences. This qualifies as the greatest science communication failure in history: The more facts, the less concern.

The way how the information about climate change is presented, have been condensed by Stokness [2015] into five main defense barriers that keep climate messages away and block the messages from leading to a meaningful response and actions:

- **Distance**: Even though when some people state that global warming is here now, it still feels distant from individuals because the melting glaciers are usually far away, as those places where sea level rise, droughts and other climate disruptions are currently occurring; additionally, the heaviest impacts are perceived as far off in time.
- **Doom**: Usually climate change is illustrated as a disaster that bring losses, cost and sacrifices, creating in this way a wish to avoid the topic.
- **Dissonance**: In most of the people, the global warming message initially evokes alarming feelings, like anxiety, fear or guilt. The more we believe in climate change, the worse we feel, as long as there is not a change in our behavior. Since we fail to act in a different way this creates an internal conflict that can be solved by weakening the climate message to make us feel better about ourselves and the high-carbon lifestyle that we have.
- **Denial**: Denial is a self-defense strategy used to ignore or avoid facts about climate change in order to find refuge from fear and guilt.
- **Identity**: People tend to filter information through their professional and cultural identity. Thereby, people is looking for information that confirm their existing values and notions, and filtering away what challenge them. For example, if a person with conservative values, hear from a liberal that the climate is changing, they are less likely to believe the message. Thus, cultural identity override the facts and people experience resistance to calls for changes in self-identity.

During the last years climate change has been communicated under the the effect of the five barriers, evidencing that is moment to change. Thus, the emerging range of solutions include the use of social networks to promote energy conservation as a social norm, the use of nudging by setting voluntary green energy as the default, hosting pizza parties as a reward for community energy savings and integrating positive communications such as green growth, happiness, well-being and integrated wealth as new indicators of progress in diminishing GHG emissions.

4.4 Carbon footprint calculator

This section presents a brief introduction to the carbon footprint concept and carbon footprint calculators. Moreover, for this project is irrelevant to address in detail the methodology used to calculate the carbon footprint, therefore it will not be presented.

The term carbon footprint has been used for the first time in public media around the year 2000. The term carbon footprint is missing a clear definition and has a wide variety of conceptions that generally address a certain amount of gas emissions relevant to climate change and associated with human production. However, there is not consensus in what gasses should be taken into account and from what type of sources (e.g.direct, indirect) should be included [Wiedmann and Minx, 2008].

In this research, the carbon footprint is defined as "a measure of the amount of GHG indirectly emitted by energy production" [Ellis, 2007]. For the purpose of this project, the measure is limited to the production and consumption of heating for households.

The calculation of the carbon footprint can be approached from two different directions: bottom-up or top-down and both should inform the full life cycle impacts [Wiedmann and Minx, 2008].

Carbon calculators are tools developed by different organizations, including NGOs , commercial companies, government agencies, and universities. There are generally available on internet and the main purpose of this tool is to increase individuals' awareness of the relation between individual consumption patterns and carbon emissions and to give an increase sense of control over the consumption. This tool allows the individual to monitor and receive feedback of their personal carbon footprint. Additionally, CFC has been identified as promoters of energy efficiency and cost reductions at the household level [Pandey et al., 2011], is enabling people to offset their emissions by investing in specific projects, like planting trees [Bottrill, 2007], and in generally is influencing how the people perceive the climate change[Fischer, 2008].

In order to quantify the individual carbon footprint in tonnes CO_2 emitted, the users need to provide some general household information and physical characteristics of the dwelling. Later, more specific inputs with information about home energy, transport means used and type of diet are required. Normally, the carbon emissions of each activity is calculated by translating the data into a quantity of energy and then multiplying it by the corresponding carbon emission factor. Later, the carbon emissions of each activity are added together to obtain a total annual carbon impact.

The calculators use the same emission conversion factors that the national governments use in their reports. Nevertheless, it is common to have variation between calculators, not only because of the variation in the fuel mix for power generation change, the different methodologies to calculate the emissions and also the accuracy depends on the accuracy and type of data required as an input.

Currently, using different calculators can lead to significant differences from one to another. Before promoting the implementation of this type of tools, it is necessary to address the lack of standardization. The challenge relies on establishing which of the available methodologies have fewer uncertainties, in order to define it a standard and hence,having reliable output data. Otherwise, the transparency of the process can be affected because showing an inaccurate result will rise distrust not only related with the accuracy of the tool, but also in the climate change perception in general.

4.5 Choice Awareness Theory

In this section, the description of the Choice Awareness Theory is presented, based on [Lund, 2014]. The importance of this theory in this research relies in CFC raising awareness about personal carbon emissions will open a discussion about the choices that individuals have to contribute towards building a low carbon future.

As the word "choice" plays a key function in the definition of Choice Awareness, it is indispensable to begin this section by contrasting a "true" choice and a "false" choice. In a given situation, a true choice is a selection between two or more options, while a situation with a false choice, the choice is in some way an illusion. For example, when a mother cook soup and let choose her daughter between having the prepared meal or not having any. Hence, in this situation the daughter has apparently free choice, but actually, there is no real alternative, more than choosing the soup; this "false" choice strategy has become popular known as Hobson's Choice.

According to Stokes and Whiteside [1986], every human has a congenital feeling that "we have no choice; and without choice, we have no power". This feeling can led people to lose their individuality, self-worth and the reality of spirit. Nevertheless, these could be counteract by realizing that, even in the most desperate situation the person can still choice "no". Thus, when realizing that saying "no" indeed is a choice, then the person will be able to think better and build real alternatives. In other words, in front of an imminent change in the global temperature, we have no "ability to respond" (reference to the etymology of the word responsibility) and here is where "responsible" behavior starts.

The key factor of Choice awareness is that this perception can also be seen in the collective levels, actually, the Choice Awareness Theory addressed by Lund [2014] focuses on the societal level, addressing that choices are made at the individual level by combining opinions, preferences, interests and motivations with the purpose to achieve a collective decision that lead to social welfare [Endriss, 2011].

The Choice Awareness Theory, generally, addresses how to implement radical technological changes at the societal level, such as the change to fossil-free fuel heating system. The key factor is, that this change will bring significant challenges for the existing institutions, organizations and for the individuals. Furthermore, each of these players have a different perception, interests and level of power, resulting in different mind constructions, approaches and views on what should be done to solve the same problem [Lund, 2014].

The social perception of having a choice or having no choice, is a key fact in decision-making processes; due to some powerful interest groups can pursue to exclude certain choices by eliminating them from the alternatives, and creating a collective perspective of no choice. Therefore, it is indispensable to raise the awareness of the fact that society does have a choice, by promoting different technical alternatives together with feasibility studies that entails society to choose among relevant options [Lund, 2014].

> the decision-making procedures including the definition of alternatives and how these should be assessed are to be seen as a *conflict*. The conflict is a fight between different interests, influences, and discourses, in which well-established organizations seek to not lose power and influence. Furthermore, it is a *process* over time. Developing societal procedures that allow the design of alternatives, proper assessment methodologies, and good public regulation measures take time. It is a process, and in this process, it is not important to win the battle; it is important to win the war" [Lund, 2014]

Currently, the Energy Strategy 2050 has a strong focus on energy efficiency improvements on the societal level by increasing the energy saving obligations of the energy companies and by tightening the energy standards for new buildings. However, the main challenge is to engage individuals as part of the solution, due to relying only on the implementation of more efficient technologies is not enough to face up the challenges linked to a 100% renewable system. Thus, this project addresses the choice awareness on an individual level, because to achieve the societal level targets, the individual choice plays a key role, since the current consumption behavior needs to be changed by decreasing consumption and/or by shifting out of the peak hours.

4.6 Smart Energy System

In a transition towards low-carbon systems, from a technical perspective, changes in the infrastructures together with technological implementations are important aspects in order to increase energy efficiency.

The future of renewable energy systems is a combination of unpredictable energy sources such as wind and solar power, and residual resources such as waste-to-energy and biomass [Lund, 2014].

According to [Lund, 2014], all grids need to use modern information and communication technologies, such as smart-meters, sensors and controllers to accommodate by themselves to the demand while benefiting by the flexibility given by the synergies among the interconnected energy system.

As the introduction of renewable sources will bring challenges for the system to meet the required demand, then district heating plays an important role. The district heating is constituted by a network of pipes interconnecting the whole city, thereby,it can act as a centralized plant or a number of distributed units producing heating. This approach allows the use of any available heat source.[Lund, 2014]

In order to make district heating as an integrated part of smart energy system (i.e. integrated smart electricity, gas and thermal grids), it needs to have a radical change into low-temperature district heating which interacts with low-energy buildings as well as with the smart electricity grids [Lund, 2014].

The importance of the smart energy sector is that should be seen as an overall system and the transition of district heating should be coordinated with the other parts of the system. Additionally, better solutions can arise if the implementation of smart energy systems is coordinated with the individual level [Lund, 2014].

The line diagram of a Smart Energy System is shown on Figure 4.2.

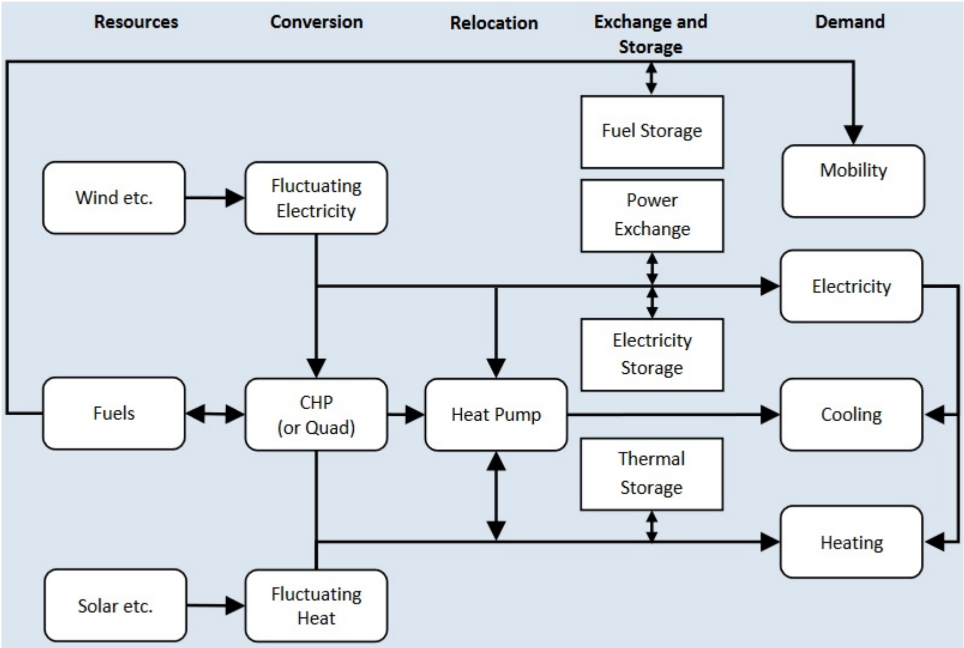


Figure 4.2: Smart Energy System

The choice awareness theory and the smart energy system are highly correlated in this project. As the future is shaped by the introduction of renewable energies, thus the system needs to work towards reaching higher efficiency to satisfy the demand. This is possible by interconnecting the systems and maximizing the synergies among them.

There are diverse challenges related with the coordination and the interoperability of the system. Nevertheless, the focus for the purposes of this project is on the individual level. However, the system and the individual sector are related, so even if the system has the most efficient technology, if there is no support at the individual level, the demand will be impossible to satisfy. Therefore, the individual sector must support the system by decreasing the energy consumption and being an active part of the overall smart system while offering flexibility.

On the other hand, for the individual sector to achieve the reduction in the demand, the system must support this process by offering contextual factors. In this sense, the deployment of smart-meters open the doors to implement new tools that can support the transition, such as CFCs.

Interviews and surveys 5

The main focus of this project is analyze how an individual carbon footprint calculator (CFC) could support reduction of GHG emissions (limited only to heating systems). To achieve this general objective, it is necessary to understand the individual motivations that can led to raise awareness when using energy in heating systems. In addition, the role of smart-meters and visualization tools it is also addressed.

This chapter presents the main results obtained by the surveys. As was mentioned in the last chapter, after each result its respective analysis is presented. In the section 5.1, the demographic characteristics of the sample are presented. Later, in section 5.2, the climate change concern is addressed together with the level of awareness of the individual contribution to climate change. Then, in the next section 5.3, is described the role of the smart-meters in order to develop digital visualization tools(e.g. carbon footprint calculators) as a supporting tool to track and hence, raise awareness of energy consumption, with the aim to promote a change in the consumption behavior. In addition, the motivations and constraints to save energy are presented. Finally, the section 5.4 presents the preferable features of Aalborg residents that should be taken into account when designing an individual CFC.

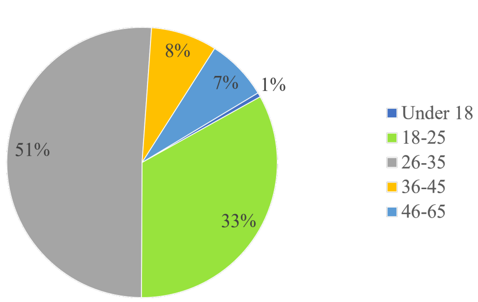
Regarding the survey, the size of the sample is 190, because this is the number of the successfully completed surveys. Having a relatively small sample of 190 and for statistical purposes, it is necessary to determine the margin of error (or also known as confidence interval) of the obtained answers. Hence, the calculation was made using the Survey System online calculator[1]. Taking a typical value of 95% in confidence level, having a sample size of 190 in a population of 114,590 households and a margin of error of 50% due to the choice of supposing a normal Gaussian distribution (bell shaped distribution). The obtained confidence interval is $\pm$7.1%, a value that is within a good confidence interval of $\pm$ 10% [Bryman, 2013]

For those readers who are not familiar with this statistics measurement, an explanatory example is presented, in order to clarify how the confidence interval works. Thus, having an interval of $\pm$7.1, and knowing that 40% of your sample pick a determined answer, then you can be "sure" that between 32.9% (40 -7.1) and 47.1% (40+7.1) of the entire population would pick the same answer.

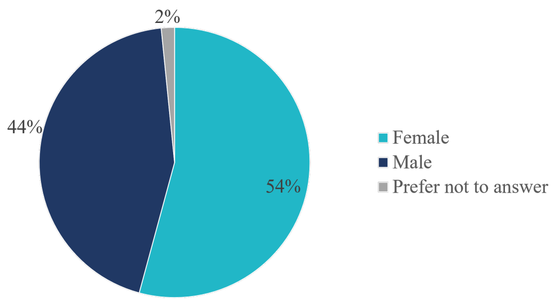
[1] Available in https://www.surveysystem.com/sscalc.htm

5.1 Demographic characteristics of sample population

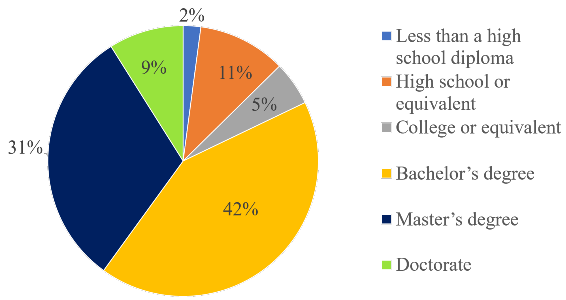
The demographic variables are presented in Figure 5.1, in order to give to the reader an idea of the sample population used in this project.



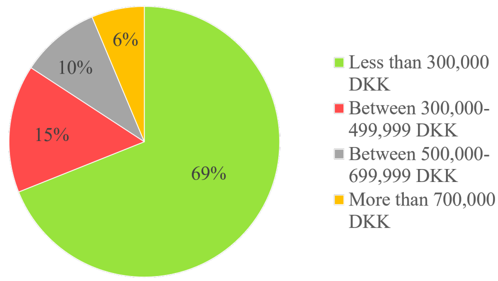
(a) Age



(b) Gender



(c) Education level



(d) Household yearly income

Figure 5.1: Demographic distribution of the sample

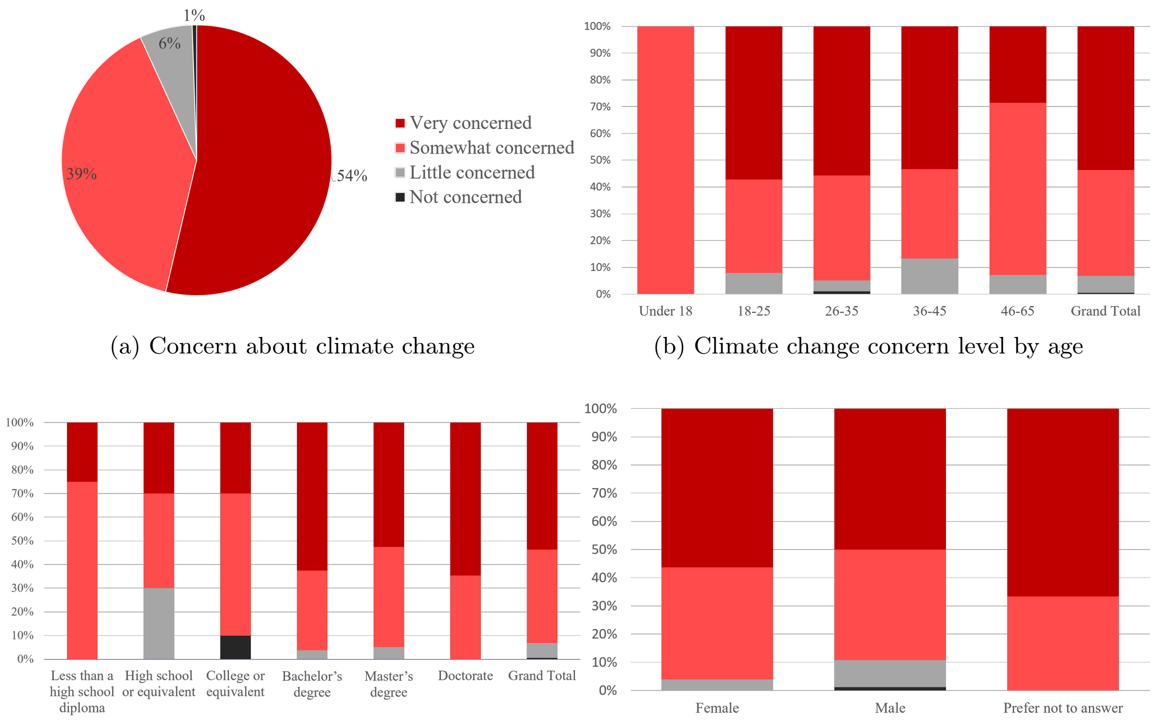
5.2 Climate change concern and awareness

It is widely known that the science behind climate change is being increasingly documented. Nevertheless, public concern is decreasing, not only because of the number of followers of he "climate change denial" movement, but also because of the general lack of act upon tackling global warming. This concept has addressed in the previous chapter under the Climate paradox section.

This project is not reviewing the science behind climate change, the fact is rather how people react to such message and not the causing facts. As Stokness [2015] addresses, facts and beliefs are very different things; and if the new facts do not support the individual's beliefs, then the facts go unnoticed. For these, reason the first section of this chapter, addresses the level of concern among people in Aalborg.

In general, the 54% of the sample are very concerned with climate change, 39% are somewhat concerned and only 1% are not concerned, see Figure 5.2(a). Moreover, after analyzing the data and relating it with other demographic variables it is possible to extract important information that is presented below.

In general terms, it exists a concern about climate change in the residents of Aalborg. In



(a) Concern about climate change

(b) Climate change concern level by age

(c) Climate change concern by education level

(d) Climate change concern by gender

Figure 5.2: Climate change awareness of Aalborg residents correlated with some demographic characteristics

Figure 5.2(b), it is possible to appreciate that the highest concern level is among young adults and adults, from 18 until 45 years old. There is clearly an existing target audience for products and/or services that can help them to diminish their contribution to climate change. The big challenge here, is engaging the costumers with these type of products, going beyond the curiosity and becoming into real actions.

It is also valid to mention that 67.4% of people in this group have a yearly household income of less than 300,000 DKK, a 13.2% has an income between 300,000 and 499,999 DKK, and only a 3.2% received more than 700,000 DKK. Even though the majority has the lowest income, their acquisitive power is expected to increase in the upcoming years. As a consequence, it will be possible for them to make bigger investments in high-efficiency devices including smart home appliances, retrofitting, and other emergent technologies to achieve higher energy savings.

On the other hand, regardless the acquisitive power of this target audience, it plays a key role in the communication process of social norms, through their social networks. Cialdini [2003] highlight that imitating others has been efficient during the evolutionary process, thus, when people are uncertain about how to behave, they usually look around to see what their pairs are doing. Therefore, a societal beneficial conduct, like saving energy, needs an adequate communication strategy to be accepted as a social norm.

Social networks are part of the daily life of the young adults and adults, including friends, colleagues, family, neighbors, among other social groups which have a powerful effect on everyone's behavior. Until now, the societal change towards more sustainable behaviors has been slow, but the increase connectivity is making the social web a behavioral support architecture appropriate for developing more sustainable lifestyles.[Krause and Basile, 2014]

Similarly, from 5.2(c), it is possible to appreciate that people with higher level of education, including bachelor's degree, master's degree and doctorate, have the highest concern about the climate issue, therefore as the critical thinking develops during higher levels of education, thus the level of climate awareness also increases. In addition, it is interesting to recognize that the 1% who are not concerned with climate change have a maximum education level of college (or equivalent). However, the general trend shows that currently exists awareness about climate change among the residents of Aalborg.

Finally, based on the results showed in 5.2(d), there is not a big difference drew by gender differences, however, it is possible to recognize that the lower levels of climate change awareness are among the males. This results coincide with other authors, that stated that women tend to be more concerned about climate change effects: 29% of men and 35% of women in the US "worry about global warming a great deal" [McCright, 2010][Tschakert and Machado, 2012]. In addition to the recognition made by UNFCCC in 2008: "the gender dimension of climate change and its impacts are likely to affect men and women differently.", and even when it is not part of the discussion of this project, it is important to highlight the urgency of formulating gender inclusive policy measurements to address climate change and recognizing that women are important actors in tackling climate change [UNFPA, 2009].

After addressing the results of the concern level about climate change among the residents in Aalborg, in the Figure 5.3 is presented the awareness of the individual contribution to climate change. Where 78% is concerned about climate change and it is already taken actions to increase savings and reduce their carbon footprint. Nevertheless, there is a 5% unaware of their contribution to climate change as a result of their energy consumption.

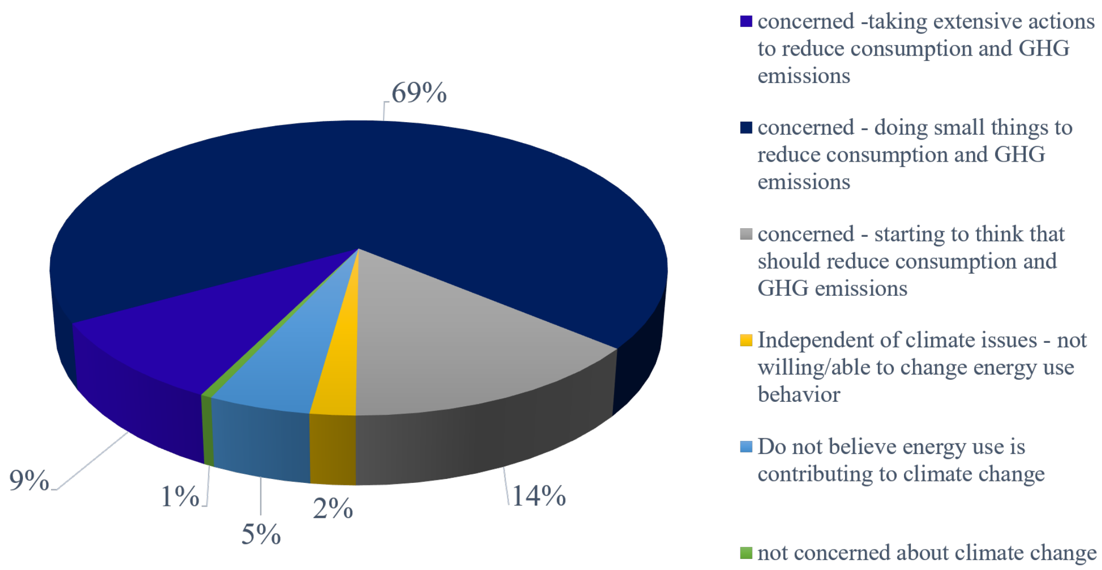


Figure 5.3: Climate change awareness and the energy consumption impact

Moreover, in Figure 5.4, the results of the individual contribution were crossed with the climate change concern. Hence, the people's perception of their own contribution to climate change as consequence of their energy consumption behavior is expressed with different colors, while the climate change concern level is presented in the horizontal axis.

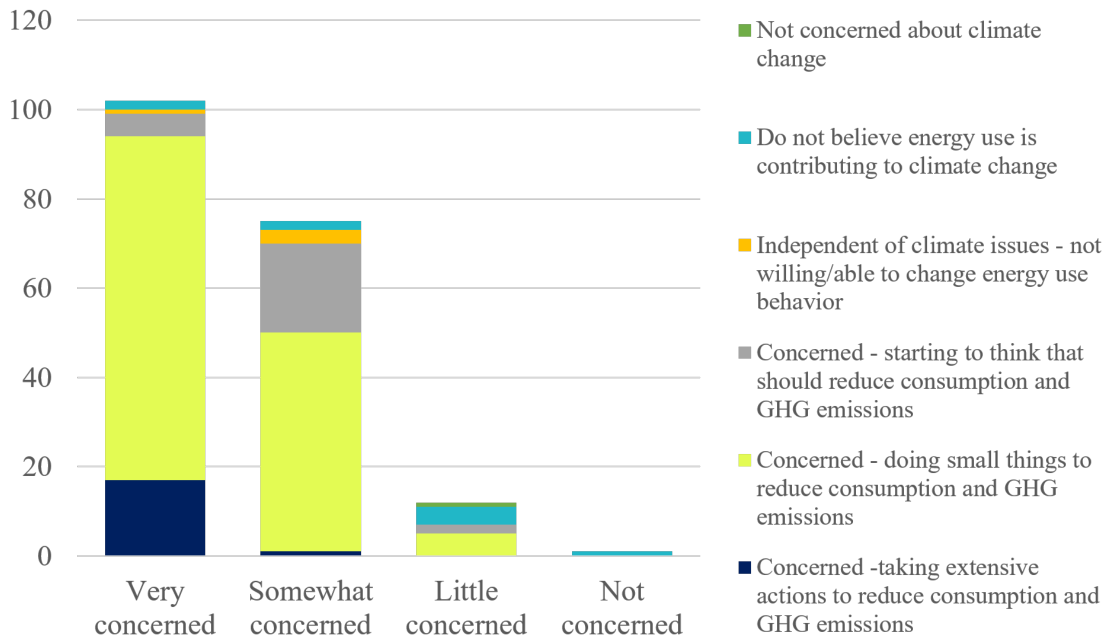


Figure 5.4: Climate change awareness related with individual behavior

In the three first columns, from left to right, an expected result is perceived, as the level of concern regarding climate change decrease, so do the actions to reduce individual contribution. Even though some people has stated to feel "very concerned" or "somewhat concerned", there is still a small percentage unwilling to change their behavior. Independent of the level of concern, there is still a small amount of people that are unaware of their individual contribution to climate change. The results are evidencing a "state of denial", defined by Professor Stanley Cohen as *"The need to be innocent about a troubling recognition"* [Cohen, 2001].

Additionally to these results, the same state of denial was perceived during the personal interviews. For example, one of the participants has stated *"I am very concerned about climate change, but there's nothing I can do about it!, it is the government's responsibility to push all those industries to reduce the emissions level [...]"* [Moesner, 2018].

Consequently, while designing a strategy to decrease individual's contribution to climate change, first, it is necessary to educate and create awareness among the individuals about their responsibility. Once the acceptance is reached, the denial state can be overcome by acting upon it. This transition would result in an emotional shift, and it requires a behavioral change, which would come with a change of lifestyle, ethics and identity. However, there is high uncertainty in addressing to what extent of this individual shift out of denial is required in order to achieve cultural shifts [Stokness, 2015].

5.3 Tracking energy consumption and carbon footprint

5.3.1 Smart-meters in Aalborg

Currently, the Aalborg city is rolling out smart-meters as part of its strategy SMART Aalborg, with the aim of improving the citizens' quality of life by increasing the efficiency in the use of resources. The deployment will send accurate meter readings directly to energy providers and will also allow consumers to monitor and track their energy consumption (both electricity and heating).

Similarly, as part of the interview with Charlotte Bahrendet [2018], from the Energy utility, stated that the smart-meters implementation will bring some benefits to the energy utility, such as to get the consumption data in a more efficient way, to track the water temperature in different points and detecting leakages or frauds in a short period of time. As a consequence of having a better knowledge of their customers, the company can provide timely technical assistance, when the data reflects an anomaly. Additionally, the amount of data could be useful to have a better forecast for heating production, based on real demand.

Accordingly, during the interviews with Sven Buch [2018] from Himmerland Housing Association, and Zacharias Madsen [2018] from Aalborg Municipality, they have highlighted the potential to raise awareness of consumption, the transparency in the billing process and the economic savings as the main benefits for the users. Additionally, both of them together with Charlotte Bahrendet [2018] agree on stating that the smart-meters implementation plays a key role in the development of new tools that allow the consumers to visualize their current consumption. Likewise, it is clearly an implicit expectation from the Energy utility, the housing association and the Municipality that this deployment will provide citizens information to help reduce their overall energy consumption (as presented in [Darby, 2010]), shift out from the peak demand periods and /or increase flexibility to respond in periods with over supply.

Currently, the Aalborg Energy utilities, together with the Municipality are developing a digital application that allow consumers to track and visualize their utilities consumption (electricity, cold and hot water and natural gas), with the aim of increase awareness to improve efficiency and increase savings. However, before developing this type of tools, it is important to analyze if there is already an interest in checking utilities consumption, due to lack of engagement is one of the main challenges related with this type of applications. In the next paragraphs the interest in having access to heat consumption data, together with the main motivations and constraints to save energy are analyzed, in order to determine if there is potential in developing a CFC as a tool to visualize the impact of the energy consumption.

5.3.2 The use of digital tools

As it was mentioned before, the roll out of smart meters has the potential to bring some societal benefits and is opening a pathway to develop digital tools that allow citizens to visualize in a simpler and updated way their consumption.

Currently, there are already commercial applications to track energy consumption, and several CFC that are available on internet. Therefore, some researchers has proven to reach savings up to 20% by implementing the mentioned technologies. However, other authors have reported less efficiency and they have highlighted that an effective communication is one of the main challenges. In other words, the provided information needs to capture the interest of the users, achieve engagement and might be credible and useful for the customers;it is not simply about the content of the feedback, but the way in which information is presented should motivates the consumer into action.

For these reasons, while designing a CFC and/or energy consumption display, it is essential to determine what motivates individuals to diminish their impact to climate change or carbon footprint, either by adopting energy saving behaviors or by shifting out of the peak hours.

In Figure 5.5, is shown the interest of the residents in checking their own energy consumption in "real time", through existing web applications.

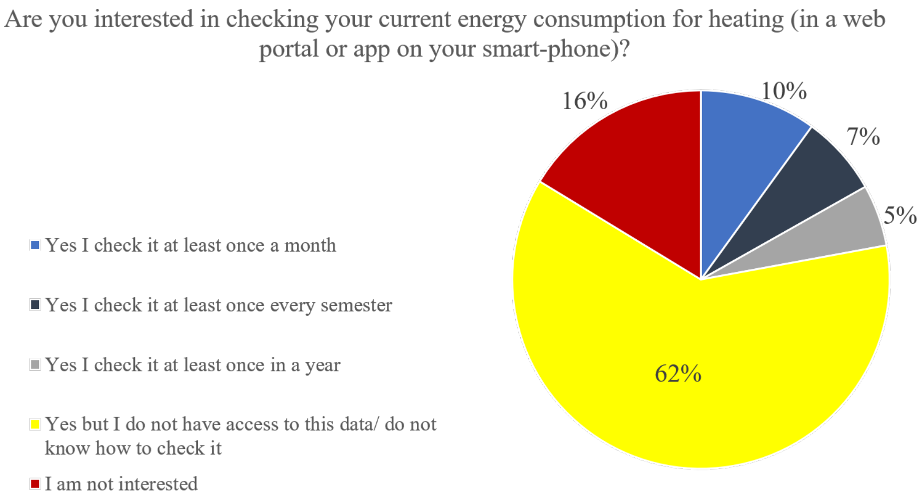


Figure 5.5: Interest in tracking heating consumption through an app or on the smart-phone

From the previous graph, it is necessary to highlight that 16% of the population are not already interested in having access to their detailed and updated data. However, the remaining 84% have already a created interest in this information, with a 17% of population which actually check the consumption at least twice per year.

In Figure 5.6, the results of crossing the information obtained by asking the participants "Do you know how much energy in kilowatt hour (kWh) did you consume for heating during the last year?" and "Are you interested in checking your current energy consumption for heating (in a web portal or app on your smart-phone)?". The interest in checking the consumption is presented in the horizontal axis, while the different colors represent their knowledge about their heating consumption during the last year.

In general, from the "grand total" column in Figure 5.6, it is possible to appreciate that around 62% of the population are not aware of their own consumption. The remaining 40%

are aware of their consumption, either, because they know how much they spent on it, or because they know how much resources they have used in heating. Nonetheless, according to Figure 5.5, 22% of population is checking the heating consumption at least once a year, an as a consequence, only less than 15% actually know how many kWh used (Figure 5.6), showing a lack of understanding from the general public, of the type of measurements, commonly utilized in billing processes, such as kWh.

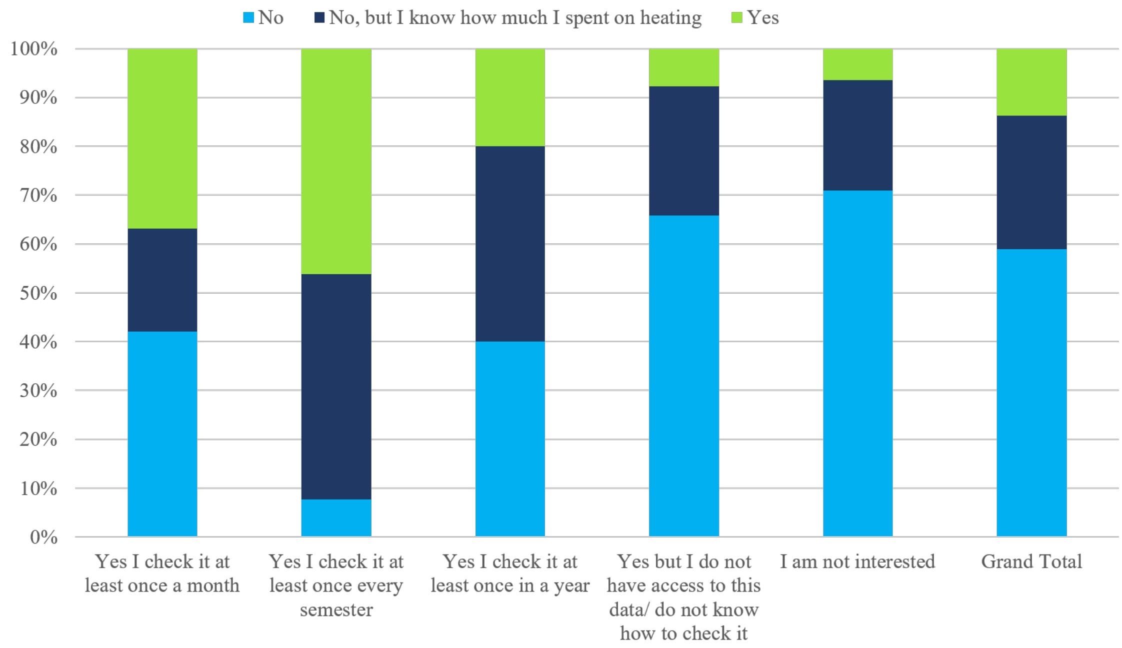


Figure 5.6: Interest in access to data and awareness about last year heating consumption

The 4th column, from left to right, shows the distribution of the awareness about heat consumption of people that are interested in having access to the data, but currently do not access to it. The 5th column , represents the people that are not interested in this data. Both bars have a similar distribution, where at least 65% of the sample do not know their own consumption. However, there is a big difference between these two bars, because the interested people (67%) are potential costumers of digital tools to track consumption and to determine individual carbon footprint, while the 16% are disinterested people, who will need more incentives and stronger strategies to be engaged to decrease consumption and to use the available tools.

Additionally within the survey, the participants were questioned about their interest in knowing how their heating consumption contribute to climate change. The answers are presented in Figure 5.7

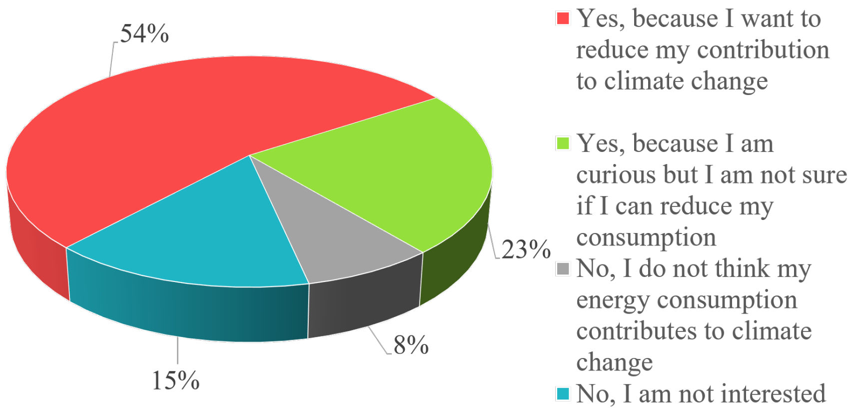


Figure 5.7: Interest in knowing the heat use contribution to climate change

There is a predominant interest in understanding the individual contribution to climate change and comprise the 77% of the total, evidencing a target audience for a CFC based on heating consumption. However, it is clear that what people say and what they do are different things. In this sense, from Figure 5.4, the 78% of population are already acting to reduce their GHG emissions, additionally, to the 14% who is willing to start taking actions, having a total of 92% of people interested in diminish their individual impact. On the contrary Figure 5.7, shows a 23% of disinterested population, evidencing once more time the existence of a state of denial in front of climate change responsibility.

For some of the interviewees Jakobsen [2018][Grosen, 2018][Xiang, 2018] has expressed uncertainty in using a CFC. They have similar approaches by accepting they are concerned about climate change and are interested in decrease their contribution, but also do feel afraid of having bad feelings, like guiltiness, frustration and sadness when realizing their big impacts. Therefore, these type of feelings are evidencing that something is not working in the way how climate change has been communicated.

For several years, climate change has been communicated using words as disaster, cost, uncertainty, destruction and sacrifice. However, these hard confrontations and the negative connotations are not working to motivate people, instead, they are evoking frustration, impotence and sadness causing that people avoid the topic. Hence, it will not help to shift the public to support more ambitious policies.

New ways of communicating climate change are emerging and are using more supportive messages. Therefore, these new approaches aims to introduce messages indicating level of improvement of health conditions and raising well-being as a result of the efforts to diminish GHG emissions. Additionally, this new type of communication is an opportunity to emphasize that households, industries and societies with low emissions are more efficient and competitive, due to the creation of new jobs and the promotion of scientific and economic progress [Stokness, 2015].

Another important aspect that might be causing disinterest in using digital applications to track energy consumption and carbon footprint is that most of the people consider boring to check utility numbers. However, the situation change when the individual receives a tailored feedback that can evoke their interest.

5.3.3 Motivations and constraints to save energy

After addressing the level of interest of the population to know their own consumption and potentially know their own contribution to climate change, it is important to understand what are the main motivations and constraints to change the energy behavior, because understanding these factors is indispensable when designing an effective feedback.

The main motivations identified to save energy are presented in Figure 5.8,

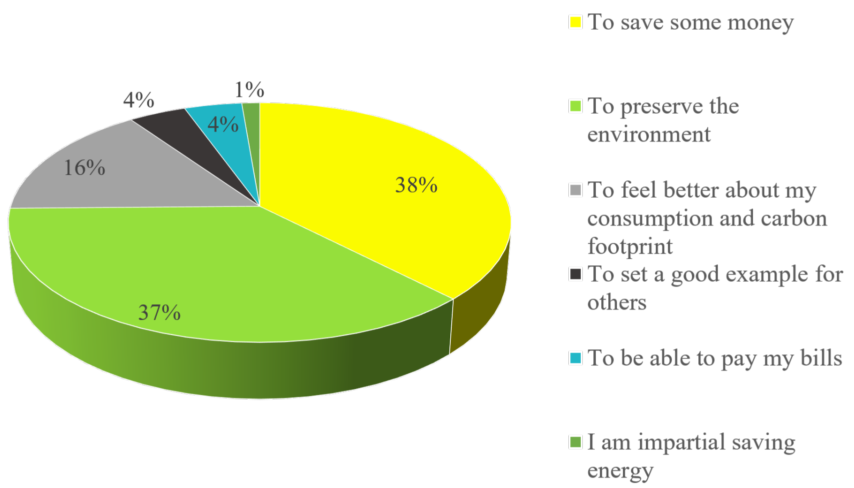


Figure 5.8: Aalborg residents motivations to save energy

As it can be seen in the graph above, the main motivation to save energy is the economic saving, addressed by 38% of the respondents, followed by the environment preservation with a 37%, and a 16% stated that the main motivation was to feel better about their own consumption and their carbon footprint.

On the other hand, Figure 5.9, evidence the main reasons to not save energy. Among the options, the majority (74%) stated that they do not want to be cold. Additionally, a 10% found the economic savings not significant.

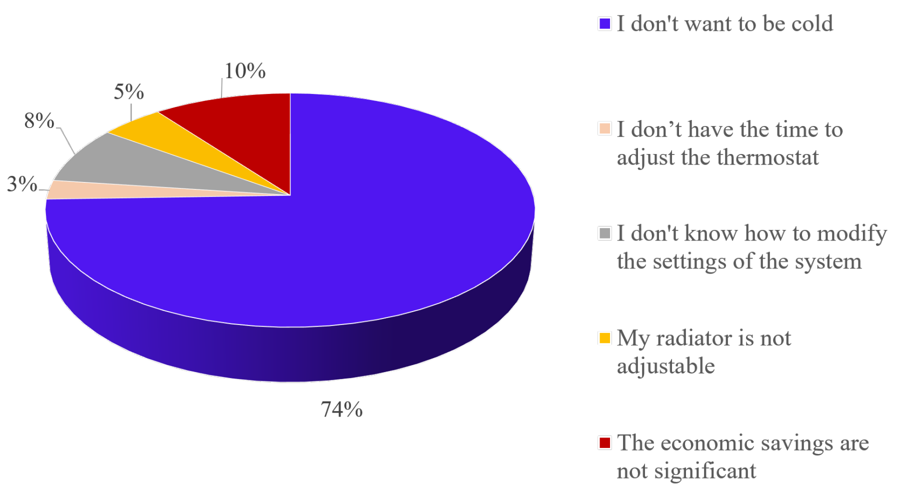


Figure 5.9: The main reasons for Aalborg residents to not save energy

Analyzing both the motivations and constraints to save energy, there is an incongruence [2] in these results. There is clear from the Figure 5.8 that saving money is the predominant motivation to save energy, together with environment preservation. Nevertheless, the results in Figure 5.9, show that people appreciate their own comfort over the economic savings linked with lower consumption.

Bringing back the results from the previous section (Figure 5.3), where 78% of the population are already taking actions to reduce consumption and hence their GHG emissions. Nevertheless, this actions are clearly not related with heating consumption, because as people mentioned in Figure 5.9, they are paying for comfort, and the energy savings are not enough to promote a change in their behavior.

Therefore, in order to raise energy savings, the strategies need to be redefined. The economic savings by decreasing consumption are important, but when the individual feels that is sacrificing its comfort and indirectly it is affecting its happiness, then a greater reward is required.

5.4 Individual carbon footprint calculator

In the previous sections the results related with the interest and motivations to save energy in order to diminish individual carbon footprint, were presented. On the contrary, this section address the design features important in designing a CFC.

5.4.1 Carbon footprint visualization

As it was mentioned in the definitions addressed in chapter 3, a carbon footprint calculator is a tool that allows individuals to monitor and understand their personal emissions and is measured in units of CO_{2e}. Therefore, as its definition has stated, it is important to present the information in an understandable way for the consumer.

[2]Incongruence is defined by Professor Carl Rogers, as having feelings not aligned with your actions

Given that people in general have already a low understanding of their energy bills [Darby, 2010], it is also possible that the presentation of another unit such as kg CO_{2e} result abstract, perhaps confusing and even "meaningless" for some of the people.

In order to determine what type of measurement unit is preferred by the residents of Aalborg, the participants, were requested to choose different ways to illustrate their carbon footprint from a list with given options. In addition, they were also able to add their own proposal. Below in figure 5.10 is presented a simplified version of the results, while the complete list is presented in appendix B.1, addressed in question 19 of the survey, and the detailed results in appendix B.2.

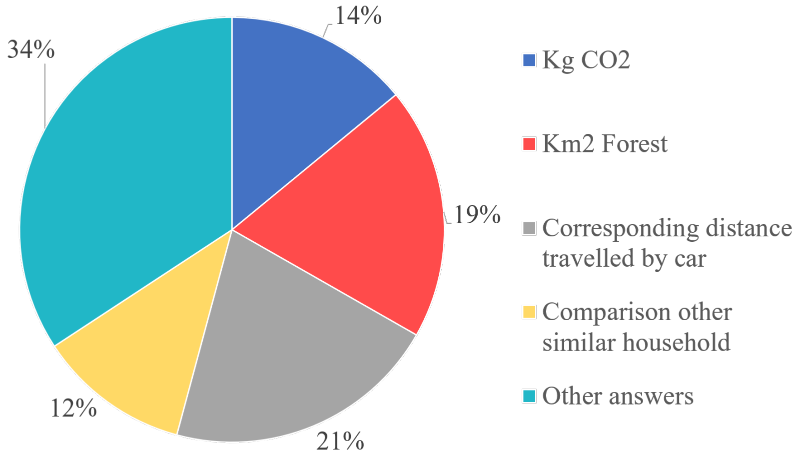


Figure 5.10: The preferred carbon footprint measurement units

In the figure, the other type of illustrative measurements with small number of votes are grouped under "other answers", and the pie chart only shows the 4 most preferable ways to measure carbon footprint. The option with highest number of votes is " the corresponding distance travelled by car", followed by "Km^2 of forest needed to capture/offset the CO2 released". In addition, it is interesting to have found the usual Kg CO_{2e} among the best ranked options, over other options that can contribute to a mental image, such as the corresponding number of flights between Aalborg and Barcelona.

Regarding the proposals made by the participants, the completed list is presented in appendix B.2. Several answers were pointing out to use different types of feedback, such as, comparison with others, therefore they will be addressed in the next section.

As an example of the illustrative measurements proposed by the participants, are:

- Number of planets needed if everyone would have the same carbon footprint as you

  The number of planets is a current measurement unit used by Global Footprint Network [n.d.] and popularized among other popular online calculators. The forests and the oceans of the world are constantly absorbing CO_2, however, currently we are emitting a higher proportion than the planet can absorb. Therefore, the Global Footprint Network organization has calculated how much extra sea and land in the planet would be needed to absorb the current emissions, their estimations are around an extra half planet is needed. Additionally, when an individual calculate their own footprint using the Global Footprint Network's calculator, the result shows how many earth planets would be needed if everyone lived like you. See an example of a result in Figure 5.11.

Figure 5.11: Result in number of planets using the Global Network Organization footprint online calculator [Global Footprint Network, n.d.]

- Number of cows contributing the same amount of CO_2.

  It is an interesting measurement unit, because in the last years it has been an increasing number of publications either scientific and non scientific, addressing the high potential of cows in contributing to climate change, inviting the people to change their diet by decreasing the consumption of meat and dairy products.

  Generally, the literature addressed the 70-120 Kg of CH_4 released per year in the form of farts and belches, especially because the impact on climate change of methane is approximately 23 times higher than the effect of CO_2. Additionally, cattle is responsible for 80% of current deforestation [Nepstad et al., 2014], responsible for the release of 340 million tons of carbon to the atmosphere every year, equivalent to 3.4% of current global emissions [Anderse and Kuhn, n.d.]. As a consequence, livestock and their by-products are responsible for at least 32,000 million tons of CO_2 per year and around 30% of all worldwide GHG emissions [Hyner, 2015]. Having said this, it would be interesting to have an illustrative measurement in "corresponding number of cows" in an individual CFC because is evoking a mental image, an idea or a group of ideas. For example, cows are big, are making large amount of excrement, are associated with milk, meat and during the last years with climate change. An example of how an individual CFC can present this measurement units is shown in Figure 5.12.

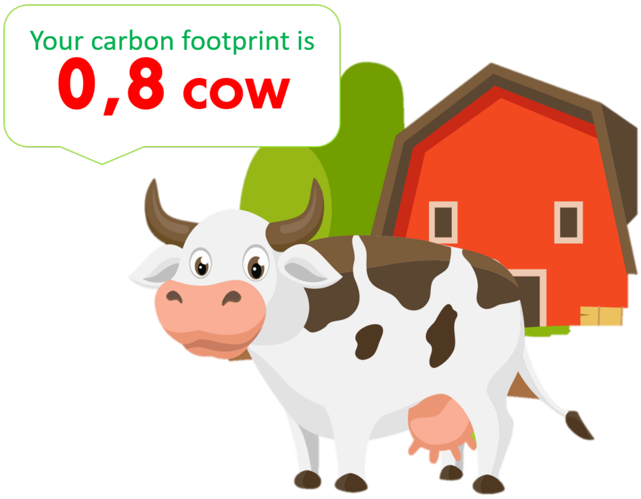


Figure 5.12: Result of your carbon footprint in number of cows

- The fraction of an acceptable yearly emission budget (e.g. 2 tons lifestyle)

Regarding this unit of measurement, it is important to highlight the current average in Denmark. Thus, according to EDGAR [2016] , the average carbon footprint of a Dane in 2016 was 6.66 ton co_2/capita/year. On the contrary, Ivanova et al. [2017], presents an average of 14.5 ton CO_2/capita/year in 2017. It is clear that there is a vast difference between these two cipher, but that discussion is out of the objectives of this research project.

Independently to the number, it is clear that there is still a lot to do in order to achieve the 2 tons CO_2/capita/year lifestyle; this amount is nowadays considered to be the maximum allowed quantity for a sustainable living on earth [Stokness, 2015][Berners-Less, 2010]. Additionally, without having binding international treaty for all the nations, then some countries, including Denmark, are carrying out strategies to decrease GHG emissions, expecting implicitly, that other countries would join in because from an ethical point of view , every nation should do something even if it is not mandatory.

Based on this ethical point of view, Stokness [2015] proposed that this could work better at the individual level. Therefore, each person would get the same right to emit two tonnes per year. Thus, the individual accounting of CO_2 for all the purchases would be required and people would find meaningful to know their own footprint an would be engaged in order to keep it lower as possible. In addition, everyone would find mobile apps like a CFC as an indispensable tool to easily follow the carbon budget.

This idea of personal allowances, which people could use and trade just like money, will raise the choice awareness respect available green energy alternatives and acquiring more efficient infrastructure; this in a general point of view could be seen attractive. Nevertheless, there is still a lot of discussion around it because it is difficult to measure and calculate carbon footprint, especially because the methodology for its calculation is not standardized and the use of different tools (footprint calculators) could lead to distinct results. Moreover, in case of applying this strategy, an access to every aspect of individuals' personal life in order to track not only the purchases but also their behavior, would be needed, making the idea of a personal budget impractical.

Finally, an equal division of carbon allowances would put in evidence social aspects and social classes gaps, which in theory would help to close this gaps due to the richer people, with higher lifestyles would need to buy allowances from the poorer, distributing wealth on a more equitable way. Similarly happened with the carbon trading schemes among the nations signing international climate treaty, nevertheless, this mechanism is encouraging companies to create more GHG and that they can pay to offset them by buying credits through clean development mechanism. Therefore, the offsetting of the emissions allows developed countries to continue emitting into the atmosphere, while removing the possibility to the developing countries to use their carbon allowances to actually develop and to help its populations to get out of poverty.

5.4.2 Most popular types of feedback

In order to determine what is the preferable mean to receive feedback addressing the consumption behavior in heating systems. The participants were questioned which of the given options would choose in case they would be interested in receive personalized tips to decrease their carbon footprint. The results are shown in Figure 5.13

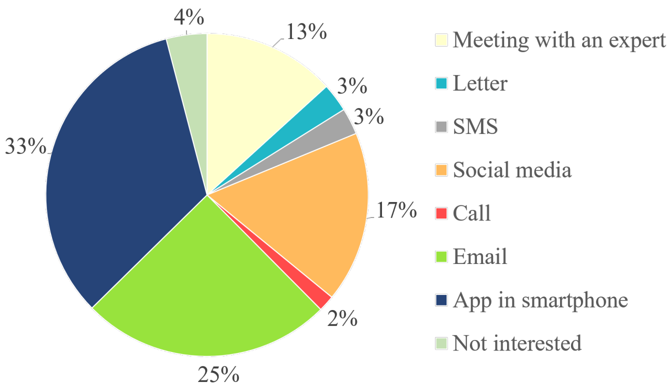


Figure 5.13: means of communication

The 33% of the sample prefer to receive the feedback through an application in their smart-phones, evidencing the potential of developing a digital CFC. Followed by email, social media (such as Facebook, Whatsapp, Instagram) and 13% would like to have a personal meeting with an expert.

The positive aspect is that these 4 most preferable means are not mutually exclusive, on the contrary, they can be adds-on to the CFC, which is actually an application design for display devices, like smart-phones, tablets and laptops.

The application address informational updated feedback about energy consumption and the consequent carbon footprint in a simple and visual way. Different time scales (e.g. daily, weekly, monthly, yearly) might be available to allow self comparison and more accurate forecasts in time.

Additionally, some of the available calculators are aiming to raise awareness of the price linked to carbon offsetting. Therefore, after receiving the feedback, generally they present an option that allow the individual to donate the necessary economic resources to offset the personal carbon footprint. An example of this strategy is presented in 5.14.

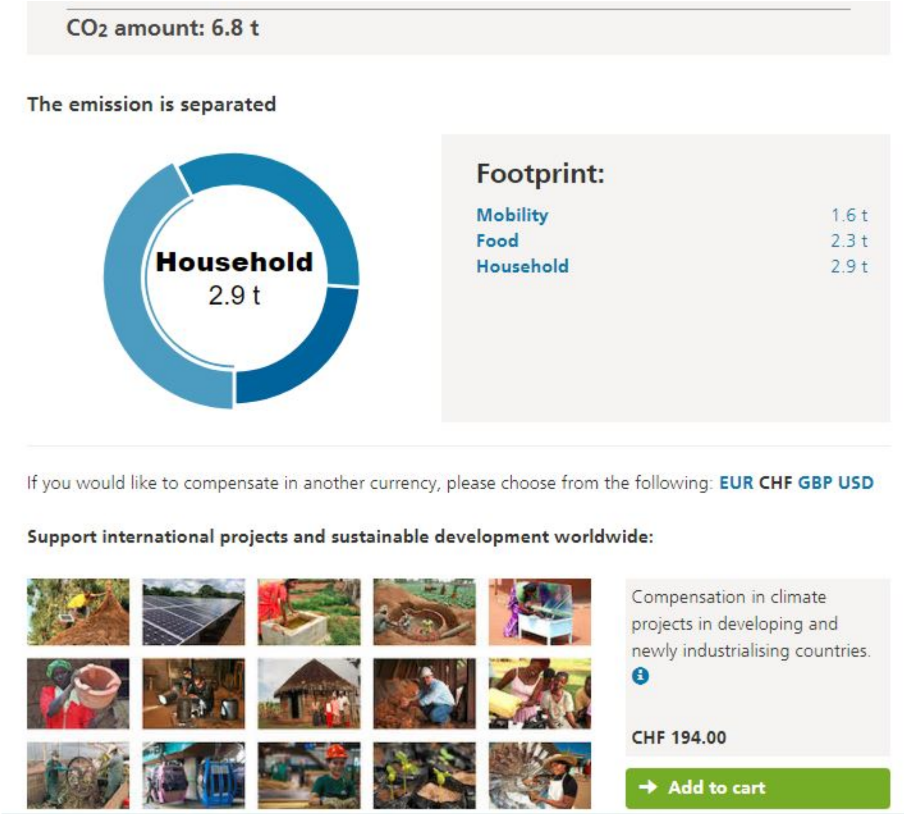


Figure 5.14: Offsetting your personal carbon footprint used by MyCloud [MyCloud, 2018]

The design of the visual aspect of the app plays an important role in achieving its aim of monitor, understand and raise awareness about consumption, for this reason the app should be simple, understandable and intuitive for all different type of users. In order to design it in a way that can be understood by everyone, a co-creation process is expected to be a good option. According to Madsen [2018], Aalborg Municipality has been carrying out a co-creation process with the residents of Sulsted [3] in developing an energy consumption display application. During the workshops different characteristics were approach including the numerical units to be displayed, different methods of visualization, relevant temporally information among other characteristics that the future users have considered relevant.

The app might send an email with the relevant information for the user, including a simple graph with the amount of energy used, the corresponding carbon footprint in Kg CO_2, together with another unit of measurement as "corresponding distance traveled by car". It is clear, that the frequency of this emails could be changed through the application settings, however, by default should have a frequency of once a week. Thus, using the simplest nudging approach that involves the use of default settings the email perhaps act as a reminder to interact with the calculator.

Additionally, the CFC requires a button that allow the users to share their results on social

[3] Sulsted is a town belonging to Aalborg Municipality located approx. 15 km north from Aalborg

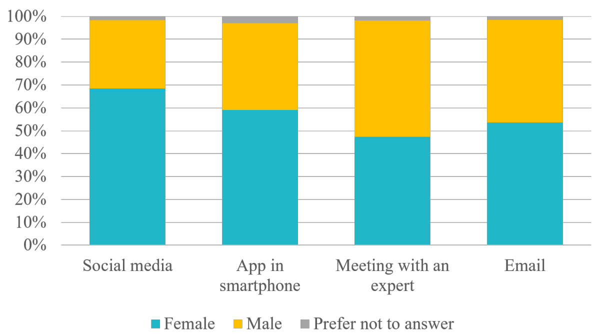
media and an additional button that enables direct communication with technical support, either in case of an emergency or to request a meeting with an expert.

Meeting with an expert is one of the current strategies already used in Aalborg. In case a user want to commit to increasing energy savings, the person is visited by an expert. During the visit, the expert assesses the home and make an inspection of your appliances to determine what type of actions are required to decrease energy consumption.

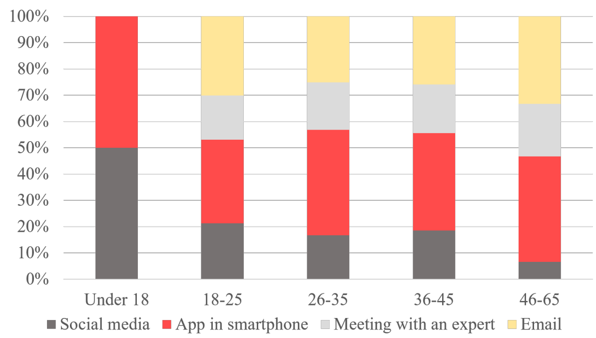
Additionally, the citizens have access to grants offered by the Danish Energy Agency to retrofit the dwelling. Nevertheless, as it was addressed by Bahrendet [2018] during the interview, people generally are uninformed about this grant and in order to be effective, the request should be accepted before you start making the renovation. Additionally, from her perspective, the amount of money offered by the grant does not cover not even a 5% of the total cost, which is not a motivating factor in the decision making process in investing in more efficient technology or retrofitting.

Therefore, the proposed button to contact technical support, might act also as a strategy to promote investments in efficient technologies. However, to obtain good results, it is necessary to redesign the subsidies strategy in order to actually offer support and motivation to the citizens.

Additionally, the 4 most preferable means of communication were correlated with demographic variables as gender and age. The obtained results are shown in Figure 5.15



(a) Preference by gender



(b) Preference by age

Figure 5.15: Preferred feedback means of communication

According to Figure 5.15(a), the preferred mean of communication is not highly related with gender. However, females have a higher preference to post it on social media than males.

Similarly, in Figure 5.15(b), is remarkable that the highest preference for post it on social media is among the youngest participants, and this interest diminish as age increase, having a stability among the young adults and the adults, and the lowest interest is perceived among the oldest people.

Social media have a key role in designing an engaging communication because it allows to have a transparent strategy to promote behavioral change through personal relate experiences while establishing trust and motivating actions [Krause and Basile, 2014].

These characteristics, can make climate communication less universal and more local, demonstrating to their similar that the climate message should not be related with actions and consequences in the distant future, but to practical actions with people and places that they know and care about today [Stokness, 2015].

Social networks keep individuals motivated, in part, because the content is tailored and hence is relevant for each, but also because of the way how they experience events through their smaller and trusted digital world [Krause and Basile, 2014]. Therefore, in order to promote sustainability and different behaviors is necessary to count with active influencers that generates and share activities within their sphere of influence.

The young adults generally have a strong presence in social media and they belong to different social networks while propitiating a comparative environment. Therefore, as it was demonstrated by Cialdini [2003], the comparison with another equal is an emotional inner force stronger than rational self-interest, reason why social media users feel a spark after receiving likes in their content.

Accordingly, it is not motivating enough just reducing heating or saving some money, but being seen and recognized by others for doing it adds enthusiasm.

Human beings have always imitated others, thus, what is needed to communicate climate change and promote more sustainable behaviors as a social norm is to make it as social, interactive and local as possible, because none of us can change the world alone, not even our neighborhood or town. Therefore, we can do more if we can join efforts with others. Thus, the social pressure by itself can not achieve long term and significant changes, additionally it is necessary to combine it with the implementation of other policy tools such as taxes, subsidies and availability of better technology.

5.4.3 Comparison as a feedback

Comparison has widely used in digital energy displays, having as a successful example the OPOWER's case introduced in chapter 3, for this purpose it is necessary to find similarities in the households characteristics to make them comparable (e.g. area, number of occupants, year of construction).

When the participants were questioned regarding their interest in being compared with other households, the results show that only 13% is not interested in others' behavior.

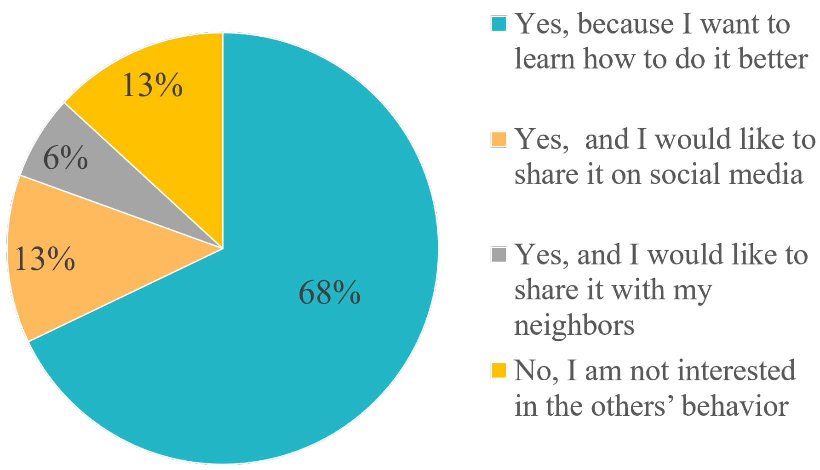


Figure 5.16: Interest in being compared with similar households

The majority want to be compared with others because want to learn how to do it better, therefore, implicitly people are aware that regarding energy consumption they could have a better behavior and they are willing to confront this reality and learn through the feedback how to do it better. Similarly to this idea, Roberts and Baker [2003] state that people are motivated to be compared when the result shows their own consumption "above the average". However, if the comparison shows that their consumption is below the average, they feel that they have done enough and the boomerang effect would conduct to a disengagement in changing behavior, even if there is still potential to improve savings. Thus, one way to overcome this challenge is by giving them rewards; further explanation can be found in the next section.

Additionally to the informational feedback and the comparison with peers, from Figure 5.16 it can be seen that there is an existing interested public in receive a tailored feedback that allows them to improve behavior. This strategy is similar to the OPOWER case explained in chapter 3, where demonstrative norms were introduced through the "Action Steps Module" including energy conservation tips in infrastructure changes but also behavior changes are addressed. These suggestions were targeted to different households based on historical energy use patterns and demographic characteristics.

During the personal interviews, the participants addressed some of this characteristics when they were questioned about the type of visualization and data they would prefer to receive when using a CFC. An example of the outcomes obtained from the interviews with district heating customers is presented in Figure 5.17.

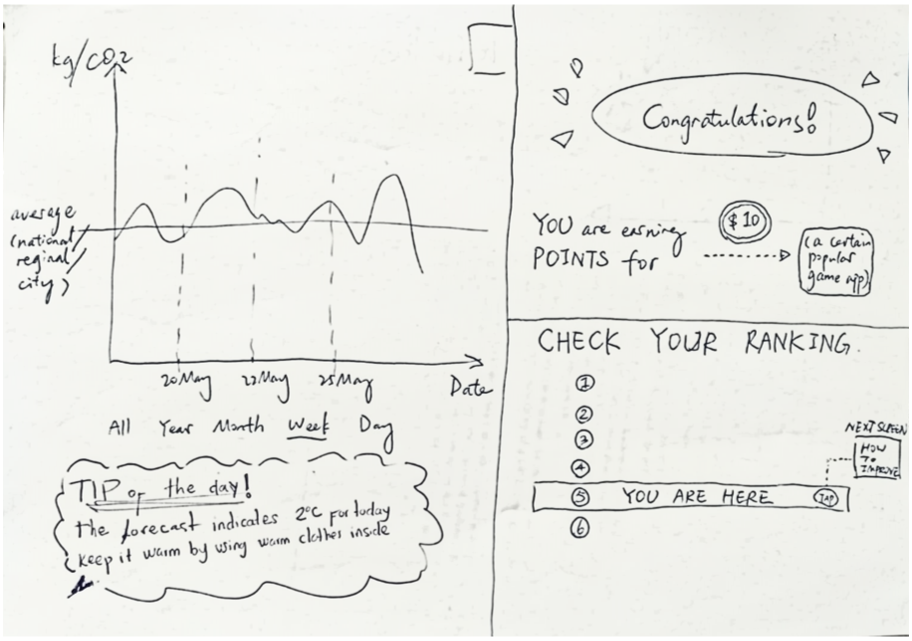


Figure 5.17: Interest in being compared with similar households

This particular sketch has been selected because addresses the informational feedback using a simple an understandable graph that also includes different time scales. Introduce the injunctive and demonstrative norms by proposing comparison with others and assigning a personalize message that gives an account of the performance, in this case is "Congratulations", then can be induced that the carbon footprint was under the average. Moreover, this visual representation is providing the "tip of the day" similar to the "Action steps Module" in the OPOWER's case as a feedback to promote behavior change. Finally, in the right upper zone, the sketch is giving as a reward "10 points to be spent in a certain popular game app".

5.4.4 Rewards

The aim of the CFC is achieving energy savings and consumers may be motivated to save energy if they have an specific goal to aim at. Therefore, as part of the CFC may be a feature to establish energy saving goals, either by being specified for the user or by being suggested for the energy supplier. Additionally, the user should receive advice on how to change their behavior in order to reach the saving aim in the most effective way [Karjalainen, 2011]. After achieving the goal, the users should receive positive feedback and /or rewards for improving their behavior.

The participants have chosen among several given options, the way how to be like rewarded after achieving certain energy aim. The results are presented in Figure 5.18

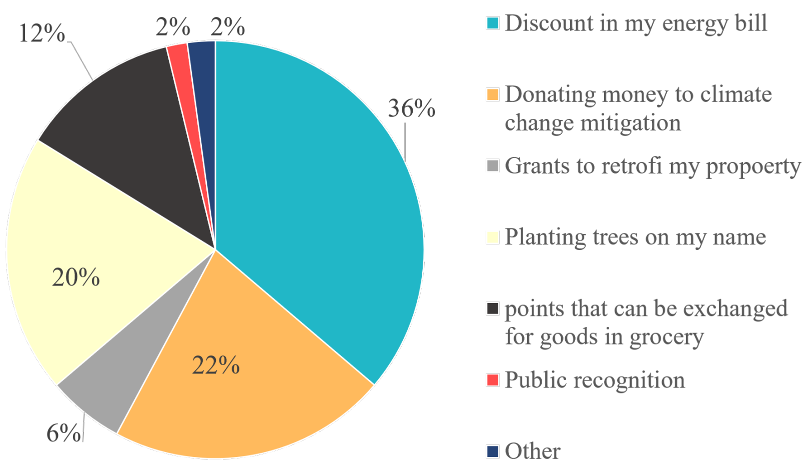


Figure 5.18: Preferred rewards after achieving an energy goal

Again, as it was already mentioned in previous sections, the economic savings are the preferred reward. Conversely, It should be remembered that it was also addressed in the constraints for energy conservation, as the economic savings are not significant.

The options "Donating money to climate change mitigation on my name" and "planting tress on my name" are accounting individually for at least 20% of the total. Nevertheless, when addressing this type of strategies it is necessary to support every action with a certificate that proves the money have been spent following the user desire. Thus, for example, if the money was transferred to support climate change mitigation, the consumer should receive a certificate from the organization who received the money; in the case of planting trees, the user should received a picture of it and a brief description of the type. As the individual cannot control the management of the money, the certificated ensure transparency to the process and reinforces the feeling of trust from the user towards the energy supplier.

Another rewards proposed by the survey participants include:

- Tickets to environmental-friendly activities (e.g. cinema, theater, local events)
- Gamification, based on competition of energy improvement behavior.

    As a good way to overcome disengagement and *boomerang effect* is giving the users a virtual reward, similarly to video games where new levels are unlocked as the person is reaching a more advanced level. Currently, the effectiveness of this virtual rewards in engaging consumers to achieve energy savings, is unknown, but it will worth to implement it, as it has been so effective in engaging gamer.

    During the personal interviews with district heating private users the gamification proposal was recurrent [Xiang, 2018] [Ayala, 2018] [Grosen, 2018] as an engaging feature. Moreover, two specific type of reward were proposed.

    First, the possibility to earn points based on the level of interaction with the application and when a given goal in energy efficiency is reached. The idea is to use these points to unlocking new features in the application such as, more colors and better designs in presenting the historical data, have access to belong to the

VIP group with exclusive competitions and discounts for those who has reach a high level of efficiency, and as an additional feature, they can have access to simulations that allow the user forecast the consequences(in terms of carbon footprint) of an intended change in the behavior (e.g. What would be the carbon footprint if the user decrease the temperature on every radiator of the dwelling by 1°C).

The second "gaming" type reward presents the idea of having a personal virtual world which each user should take care of; based on the strategy applied on the *Forest* app, where the individual plants a tree every time that needs be focused. The tree will grow in the following time and it will be killed in the moment the user leave the app. Each user can keep building its own forest and every single tree represents the time the focused time. In Figure 5.19 an example of a personal forest is presented.

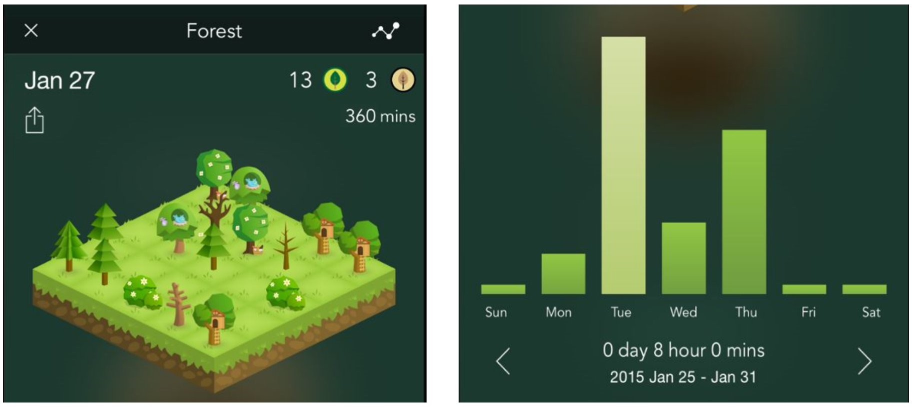


Figure 5.19: Example of personal virtual environment in the *Forest* application [ForestApp, 2018]

Similarly, this concept could be implemented in a CFC as an engaging feature that could arise intrinsic motivations purposely seeking to exploit the maternal or paternal outlook of an individual. Additionally, an interesting add-on to this gaming would be to add a small pre-visualization of the personal virtual world on the main display of the phone. This pre-visualization would act as instantaneous feedback even without entering into the app (e.g. some of the weather forecast apps present this characteristic). As a consequence, when having a damaged virtual ecosystem, the curiosity and exploration (intrinsic factors) are expected to arise, triggering the user to open the app to obtain the adequate feedback.

- Grading system in the app by classifying the household in three different caricatured consumer profiles:

  Family lighthouse, which uses a lot of energy, it is an old construction and lack of good insulation.

  Average family which still have great potential to improve energy savings but has a better performance than *Family light house*.

  Finally, **Family efficiency**, where Mr. Spar and Mr. Heating, had a lot of focus on energy optimization and reducing heat consumption, this type of family has the best performance.

5.5 CFC value-based price

Value-based pricing or customer-oriented pricing is a technique that allows to have an understanding of how much value consumers are willing to pay on the benefits they receive from the product [Kotler and Armstrong, 2010].

As part of the survey, the participants were requested to indicate how much (in DKK) would they be willing to pay for a CFC application in the smart-phone, assuming that they need to make the payment once, the results are shown in Figure 5.20.

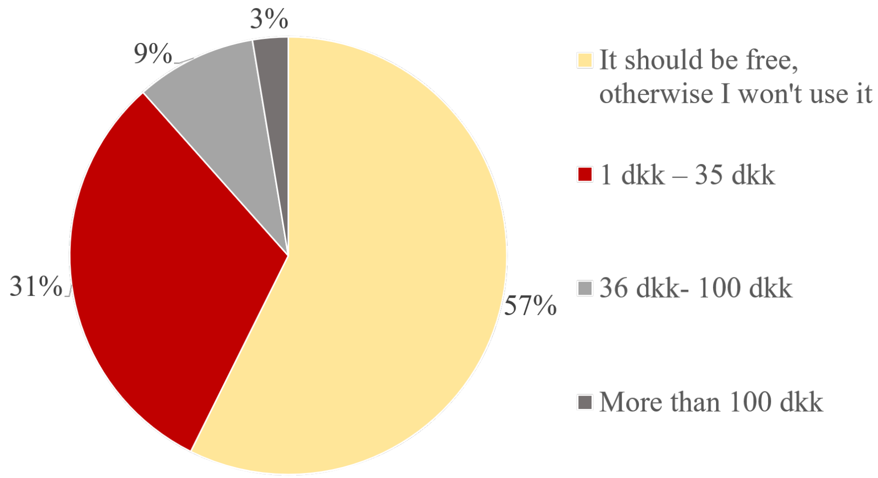


Figure 5.20: Value-based pricing for a CFC

According to the figure 5.20, 57% consider that this tools should be free and 3% would pay more than 100 DKK. to get it. The results were correlated with yearly income level and the results are presented in Figure 5.21. With other demographic variables no correlations were appreciated.

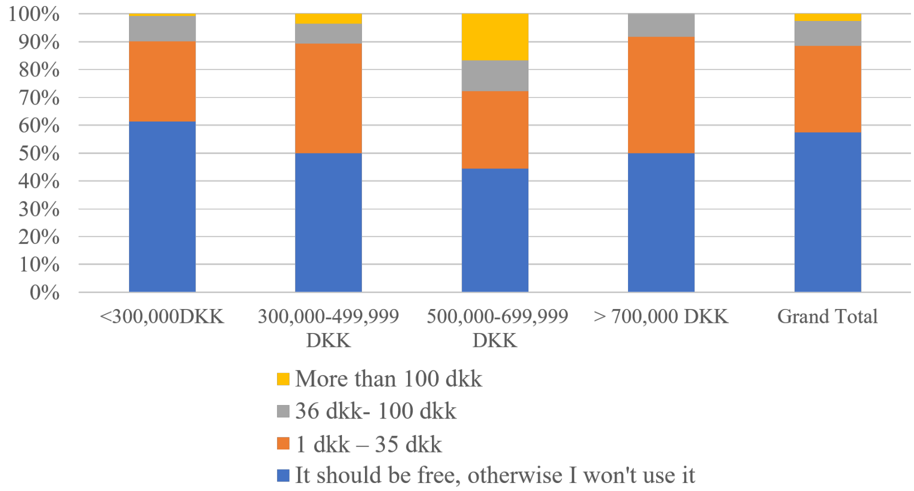


Figure 5.21: Value-based pricing for a CFC distributed by yearly income level

Independently of the level of income the preference among the public is that should be free. Among the groups with incomes between 300,000-499,999 DKK and 500,000-699,999 DKK at least 50% of the respondents consider the app should not be free. Additionally, in these two groups there are few people that would be willing to pay more than 35 DKK.

These findings imply that should have a free version supported by ads or another type of sponsorship but also there is a public willing to get a paid version with perhaps some better features.

Analysis 6

As the analysis was done as the results were presented, this chapter aims to present a SWOT analysis in order to determine y strengths, weaknesses, opportunities and threats related to a project or product, in this case, related to a CFC.

6.1 SWOT analysis

The results addressed in this research can be summarized by using a SWOT analysis defined as a strategic planning technique used to help in the identification of Strengths, Weaknesses, Opportunities and Threats related to a project, in this case related to the implementation of CFC.

6.1.1 Strengths

Easy to understand: The CFC measures the amount of GHG indirectly emitted by the production and consumption of energy (in form of heating). Generally, the carbon footprint (CF) is expressed in $kgCO_{2e}$, however, this unit could result abstract for a general public, hence in this research, another units of measurement have been proposed to facilitate its understanding. The preferred units chosen by Aalborg residents are: "corresponding distance traveled by car", followed by "Km^2 of forest needed to capture/offset the CO2 released".

There is a potential to move society towards EU's target of 40% GHG reductions if individuals start taking actions in reducing their consumption patterns

Inclusion of all direct and indirect GHG emissions: The CF quantifies all direct and indirect GHG emitted both, in the production and in the consumption, allowing the tracking of GHG emissions along the entire supply chain.

Raise consumption awareness: The current billing scheme give feedback about consumption on a yearly based and do not allow the individual to assess the environmental impact resulting from their consumption, while using a CFC the user have full access to its personal contribution to climate change. The raise in the consumption awareness is based on the informational-deficit model because currently exists and informational gap to assess in a constant basis the individual performance. Based on the survey results, Figure 5.5 shown 62% of respondents are interested in tracking their own consumption but they do not have access or do not know hot to do it and 22% stated that is already doing it through an application, evidencing there is an existing interested public for implementing this type of digital tools.

Raise awareness of the environmental impacts derived from energy use: It is important to provide people with information about climate change because some studies have shown that general public have many misconceptions bout the causes [Whitmarsh, 2009]. As it was mentioned in the previous paragraph, the current available feedback only accounts for the m^3 used (in the specific case of heating) and there is a lack of information about the environmental impacts caused by the mentioned consumption. As part of the surveys results, has been shown (5.4) that 5% of the population believe that energy use do not contribute to climate change. Additionally, in the respondents' proposed alternative units of measure of carbon footprint (B.2), there is one referring to the impacts in the deterioration of the ozone layer, evidencing once more time the misconception about global warming causes. However, strategies based on the informational-deficit model that only provides information assuming that filling the information gap would promote behavioral change tend to result in slow engagement [Kellett, 2007] and have not been particularly effective in reducing emissions [Lorenzoni et al., 2007].

Robust methodology: Even though when it was not part of this research project to discuss in details the available methodologies to calculate CF, this assessment is often called as environmental life cycle assessment (LCA) and for CF determination purpose allows the GHG accounting. Different standards and guidance are provided including GHG protocol of World Resource Institute/ World Business Council on Sustainable Development, ISO standards 14064, 14025 and 14067, the freely available standard PAS2050, and others. Additionally some countries have developed their own guidelines such as Department of Food and Rural Affair (DEFRA), carbon trust in United Kingdom and Environmental Protection Agency (EPA) in USA, evidencing the robust methodology behind the CF calculations[Pandey et al., 2011].

Data availability: Different data sets collected by different organizations and governements with an open access to calculate the CF. The national environmental accounts are generally updating the data sets on a yearly basis and the EUREAPA tool is updating it every three years [OPEN:EU, 2010]. As an example, international organization World Resource Institute and World Business Council on Sustainable Development offer large relevant information

Applicable at various levels: The methodology of CFC allows the GHG accounting in an individual level. Therefore, the methodology can also be applied in local and regional levels.

Raise awareness of the cost of offsetting carbon emissions: Using a CFC allows the individual to have an economic idea of how much cost to offset their personal emissions, as the example shown in 5.14 even without having binding effects, the strategy is expected to raise awareness and to collect funds to execute offsetting actions.

6.1.2 Weaknesses

Inaccuracy of the results: Due to there are different methodologies to carry out the calculation, the LCA bring some differences even when using the same data input, because of the considered emissions, the cut-off criteria, selection of the system boundaries, the inclusion of offset mechanisms and the consideration of emissions from land use change, lead to increase the differences [Finkbeiner, 2009].Therefore, distinct CFC could lead to significant differences in the results, giving to the process a lack of transparency that needs to be addressed before implementing CFC as a measurement strategy.

lack of link with policy changes: Even though the input data is updated in a national level every year, the outputs are nor necessarily updated at the same speed. The CF indicator cannot tack short-term changes, therefore it cannot be link to policy changes, conversely, it should be addressed as a long-term indicator [OPEN:EU, 2010].

Only considers impact on climate change: The effectiveness of the environmental assessment is restricted by considering climate change as the only category impact while possibly neglecting other impacts such as acidification in land and sea, health consequences due to particulate matter pollution, ad so on.

lack of evidence in achieving long-term behavioral change: The communication and feedback strategies presented in this research are mainly based in empirical features that have achieved behavioral change in energy display users. Nevertheless, the literature studies do confirm a high acceptance rate of feedback by using digital feedback tools, such as energy displays and CFC, but is difficult to ascertain its effectiveness in achieve long-term behavioral change, mainly because vast results presented in the literature have been carried out in short periods of time (under 3 months).

Communication strategy as the core of a successful engagement: Since a CFC rely on users engagement, the communication strategy used plays an important role in achieving its purpose to monitor, communicate and raise awareness about the personal carbon footprint. The communication when addressing climate change should be based on avoiding the five barriers presented under the climate paradox theory, in order to avoid the unintended effect of disinterest.

6.1.3 Opportunities

Better understanding of the consumers: The energy supplier company is seeking to have a better knowledge and understanding of their users in order to design tailored strategies promoting energy efficiency improvement in the households as a way to reach their reduction obligations (established by the national energy targets).

The target to have a low-carbon energy system: The implementation of CFC could help the Municipality and the Energy group to achieve environmental savings related to a more efficient use of the energy (either by decreasing consumption/ shifting out from the peak hours or by implementing more efficient infrastructure).

Increasing climate change concern among the citizens: As shown in Figure 93% of the population is concerned about climate change, additionally, (from Figure) 54% of the population is interested in understanding their individual environmental climate because they "want to learn how to do it better". These figures evidence an existing target audience for the CFC.

Generation of emissions data: Accounting GHG emissions in an individual level allows to generate a bottom-up approach of emissions inventory. This information is useful in case the CF calculations are audited by independent or external agencies, allowing the CFC to be a cost-effective measure to deal with some mistrusts about the underestimation of the emissions [McKinnon, 2010].

Progress measurement: The implementation of CFC gives the opportunity to integrate CF as a new indicator to see and give feedback on progress (e.g. green growth, happiness, well-being and integrated wealth, ecosystem health and nature index, and so on) [Stokness, 2015].

6.1.4 Threats

Lack of standardization: The definition of the system boundaries and other criteria to be defined in the assessment vary subjectively with each analyst, compromising the consistency and comparability of results. Therefore, the successful adoption of the CFC could be inhibited if standard and transparent methodology is not fully developed.

Risk of disengagement: Additionally to the aforementioned lack of evidence in achieving long-term behavioral change, Wallenborn et al. have highlighted the fact that environmental feedback devices, such as CFC are only appealing for those with an environmentalist personality (intrinsic motivated) users, leading a significant probability of having a "toy effect" characterized by high level of interest and engagement while the device is still a novelty in the users life and leading to disengagement in time by those that lack of intrinsic motivation.

Privacy data issues: The base of the CFC development is the smart-meters deployment which might ensure data encryption of the data from end-to-end in order to avoid a cybernetic attack that can modify the consumption data.

The value-based price is low: The results obtained from the survey evidence that 57% of the population consider that a CFC should be free, otherwise they will not use it. Therefore, it has been recommended to launch a basic free version supported by ads or other type of sponsorship, and also a paid version with better features.

The summary of the SWOT analysis is presented in Figure 6.1

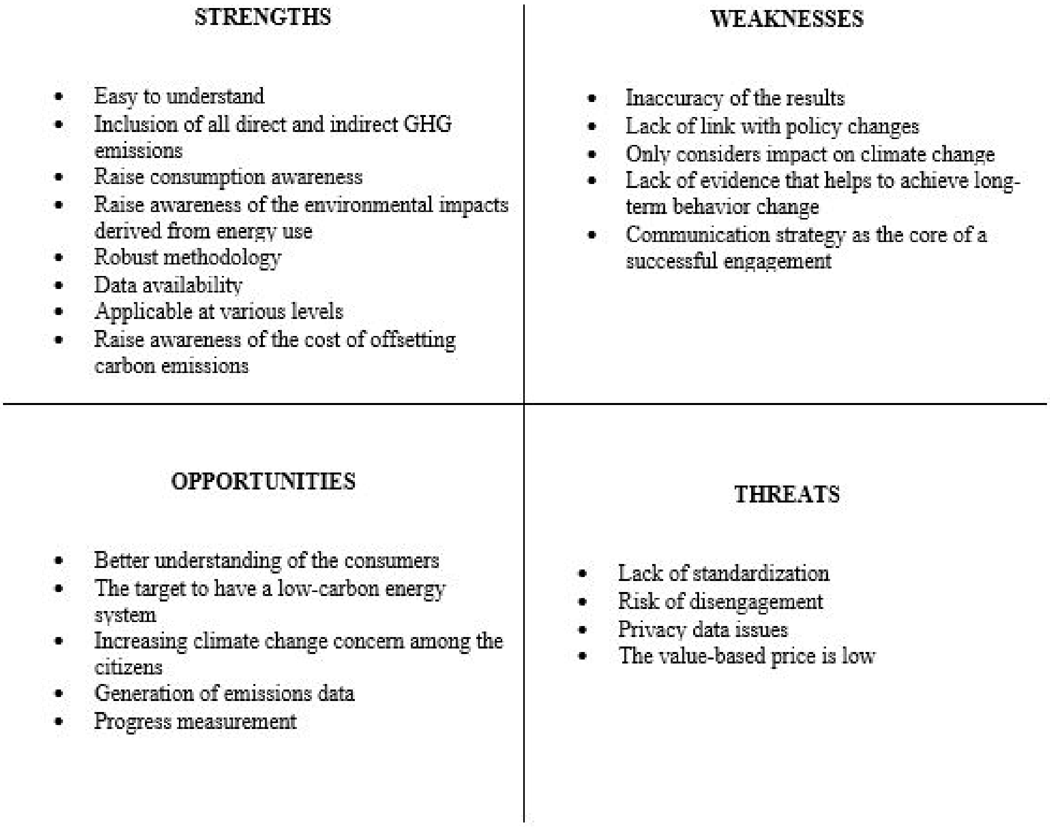


Figure 6.1: Analysis SWOT

6.2 Analysis

It is widely believed that it is possible to reduce CO2 emissions sufficiently to achieve the 2 °C target without destabilizing the global economy by implementing strong policy choices. In Denmark the targets and the strategies to decrease GHG are strongly focused on promoting technological improvements leading towards an energy smart system, as a solution for the challenges of the renewable sources.

Even when the individuals are not addressed directly under the strategies, the system and the individual sector are related, so even if the system has the most efficient technology, if there is no support at the individual level, the demand will be impossible to satisfy when the share of renewables increase. Therefore, the individual sector must support the system by decreasing the energy consumption and being an active part of the overall smart system while offering flexibility.

On the other hand, for the individual sector to achieve the reduction in the demand, the system must support this process by offering contextual factors. In this sense, the deployment of smart-meters open the doors to develop and implement new tools that can support the transition, such as CFCs. Currently, the billing process is based upon estimates and the bill with the actual consumption is received on a yearly basis, reason why is difficult to have an idea of the amount of energy consumed additionally, there is an informational gap regarding the environmental impact linked with consumption patterns.

The CFC as a visualization tool, together with feedback strategies presented in this project, are expected to allow the individual to monitor and raise awareness of the carbon footprint derived from the heating use.

In a broader perspective, the benefits of the CFC implementation in an individual level in a big sense relies in achieving higher energy efficiency, reductions in the demand and shifting out of the peak hours in order to ensure security and stability in the energy system. Therefore, since not only less energy needs to be produced in order to satisfy the system, but also less GHG emissions are released, the societal benefit will be link with the savings achieve by the societal cost of carbon and by the price of carbon itself. Therefore, it would be valuable to present through the CFC an approximate economic value needed to offset that amount of carbon equivalent released. This price has a lack of consensus, for example the social cost of carbon generally used in the US addresses that an additional ton of carbon dioxide (emitted in 2015) would cause $37 USD worth of economic damages [Hay, 2016], however, the Stern Review commissioned by the UK government [Stern, 2007] had estimated the social cost of carbon to be 86 USD per tonne of emissions, and according to **?** have estimate that the social cost of carbon is not $37 per ton, as previously estimated, but $220 per ton. In this sense if the value is as high as $220 per tonne, the countries and hence the individuals may want to increase their efforts to limit greenhouse gas emissions.

This idea addresses the main motivational factor identified in this project, that it was the money and is seeking to counteract the people's main motivations to not save energy that were "I don't want to be cold" and "the economic savings are not significant". This two motivations are evidencing an implicit assumption of having a low price of electricity reason why does not worth to make the effort just to save a couple of kroner.

The use of CFCs is the first step towards a more efficient system because through raising awareness of consumption and environmental impact, the achievement of reductions in demand is expected. The big questions that arise are if the behavior change will remain long-term and second if the achieved change in the demand will contribute to ensuring security to have a successful transition to the fossil-free energy system.

The level of uncertainty to address these two issues are very high and limited by the purpose of this research, nevertheless, brings the possibility to discuss what are the benefits of the CFC uptake.

Besides the already mentioned purpose to raise awareness of environmental impacts and promote behavior change, the CFC up-taking would also bring other benefits. Since the tool is constantly monitoring the performance of dwellings, after a certain period of time and by managing the data in an appropriate way, it would be possible to determine if the energy performance is mainly consequence of the infrastructure characteristics of the dwelling or by behavioral attitudes. This type of assessment would allow landlords to track the value of its asset based on its energy performance preventing it to become in a *stranded asset.*

Kerkhof et al. [2009] has found exceptions in Sweden and Norway of the general pattern of low income households having greater carbon emissions from direct energy use than higher income households. This exception is mainly attributed to the vast use of district heating. Due to Aalborg also present a large coverage of district heating would be expected to have a similar trend that Sweden and Norway. Therefore, literature have demonstrated that user behavior can increase the efficiency of the energy used in the building [Paone and Bacher, 2018]. Likewise, a house with high efficiency but with residents with an inappropriate behavior will lead to have the same performance as a less efficiency house. In this case, the benefit of the CFC would be in identifying the reasons of the poor performance and giving feedback accordingly to promote corrections. The benefits for housing associations, building owners and the energy supplier are linked to identifying leakages, inappropriate uses and inefficient appliances that are affecting a larger scale housing unit, such as a buildings. In this case, the CFC provide relevant information of energy performance allowing the identification of the leakage in order to take actions due to its affecting the whole building unit and hence, is promoting higher energy uses.

A recent study demonstrate that by achieving the 1.5ºC target could increase global gross domestic product by 3% to 4 % by 2100. That equates to around $30 trillion in current dollars, or about 20%percent of current global GDP. Although the several challenges of reducing emissions to achieve the targets set out by the Paris Agreement the economic gains may well be worth the pursuit.

7 Discussion

The individual behavior is difficult to quantify as the human decision-making process is complex and different factors intervene; thus, factors influencing behavior are numerous and varied and this research only addressed some intrinsic and extrinsic motivational factors linked with energy, however, there are other several aspects that were not taken into account which perhaps could have an important impact in the decision-making process, such as perception of energy prices or willingness to pay a tax in case of not reducing consumption.

Another limitation of the project is relying on the heterogeneity of the sample, even though when the method to choose was *random sample*, the final result shows that mostly international residents are part of the sample, thus, mostly of the people are not living in their own house, this phenomena is considering as a limitation in the sample.

During the project the author realized that the Aalborg Municipality is already developing a similar digital application, nevertheless, for their tool, the GHG and the environmental contribution was not a factor taken into account as it was on this research.Consequently, the findings of this project could be useful additions to the Aalborg Municipality in case of interest.

The literature review revealed a common agreement that behavioral changes are required to increase energy efficiency levels, and despite of the different interventions tested during the last years, some of the authors have consider them as ineffective and have not achieved significant changes in the behavior , however, studies do confirm a high acceptance rate of feedback for electricity consumption using digital information and communication technologies.

The feedback strategies proposed in this project are based on empirical similar studies, but due to they have not been tested yet, it effectiveness in engaging users and raising awareness of climate change impacts linked with energy consumption was not determined, which can be part of the future work.

For the future work, a PEST analysis would be valuable in order to understand from a multilevel perspective, the future implications of up-taking CFC in an individual level, additionally, detailed policy analysis and recommendations could be conducted.

Conclusions 8

This chapter aims to summarize the main ideas resulting from this project:

- From the results it was evidenced that most of Aalborg's residents are concerned about climate change, and even when they are currently taking actions to diminish their individual contribution, a CFC would provide feedback about environmental impacts related with energy consumption which currently is a "hidden" measurement.
-
- Inconsistent results were found while determining the main motivations and constraints to save energy. Money has been chosen as the main motivational factor to save energy but was also addressed in the constraints in the way " economic savings are not significant".
- From the surveys it was possible to appreciate an already existing target-audience for developing a CFC, due to 77% of the population are concerned in knowing their environmental impact, nevertheless, there is still a 5% unaware about the environmental impacts linked with energy use.
- The recommendations addressed to promote behavior change involve changing the way hot climate change is communicated by introducing more supportive messages indicating level of improvement of health conditions and raising well-being as a result of the efforts to diminish GHG emissions. Additionally, is an opportunity to emphasize that households, industries and societies with low emissions are more efficient and competitive, due to the creation of new jobs and the promotion of scientific and economic progress. The strategy to raise awareness about climate impacts as consequence of energy use is through the implementation of a CFC that allows the individual to monitor, understand and raise awareness about consumption, the app is suggested to be designed as simple, understandable and intuitive for all different type of users. Moreover, social media have a key role in designing an engaging communication reason why is important to have a featured allowing to share results on social media.
- The informational feedback of carbon footprint should be carry out by using a simple an understandable graph including different time scales. The introduction of injunctive and demonstrative norms by proposing comparison with others and assigning a personalize message that gives an account of the performance. Additionally, to customized personal tips to improve energy conservation.
- Most of the participants has chosen " discount on my energy bill" as the preferred reward. In addition, gamification was proposed as an engaging characteristic.
- The preferred unit of measurement of the CF for the Aalborg residents was "corresponding travelled by car".

- The main benefits linked to the CFC uptaking rely on the assumption that a raise in the environmental impacts caused by energy use and understanding of the carbon footprint are expected to lead to a behavioral change i. Some of the benefits are the follows: on a national context, savings by avoiding social cost of carbon and carbon price are expected; allow landlords to track value of the assets and take actions when required; the benefits for housing associations,building owners and the energy supplier are linked to identifying leakages, inappropriate uses and inefficient appliances that are affecting a larger scale housing unit.
- Although the several challenges of reducing emissions to achieve the targets set out by the Paris Agreement the economic gains may well be worth the pursuit.

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Appendix A

A.1 List of interviewees

Interviewee	Occupation	Interview location	Company	Interview date
Charlotte Behrendt	Manager, Sales & Service	Rendsburggade 14, 9000 Aalborg	Aalborg Energy group	19th April 2018
Zacharias Brix Madsen	Green Agent	Stigsborg Brygge 5, 9400 Nørresundby	Environment and Energy Administration, Aalborg Municipality	14th May 2018
Sven Buch	Development manager	Rendsburggade 22, 9000 Aalborg	Himmerland Housing Association	9th May 2018
Ane Sofie Moesner	District heating customer	Private home 9000 Aalborg		10th May 2018
Christian Jabkobsen	District heating customer	Private home 9000 Aalborg		10th May 2018
Keying Xiang	District heating customer	Private home 9000 Aalborg		25th May 2018
Maddalen Ayala	District heating customer	Private home 9000 Aalborg		25th May 2018
Mette Grosen	District heating customer	Private home 9000 Aalborg		1st Jun 2018

Appendix B

B.1 Survey

In this section the English version of the survey is presented and could be found from the next page. As it was mention in chapter 3, the questionnaire was distributed through different means, including personal approach, and the online versions are available in `https://goo.gl/forms/mgRReNp7RV6Sx67o2` (English version) and `https://goo.gl/forms/s0bwfxH1gVqmNzSe2` (Danish version).

“Understanding the heating consumption habits of Aalborg’s residents”

Thank you for taking the time to participate in this research project and the enclosed survey! Your input is very valuable. I am a master student from Aalborg University and I am carrying out a thesis in the Cities & Sustainability programme (JEMES CiSu:http://www.jemes-cisu.eu/). The following survey aims to have a better understanding of the heating consumption habits of Aalborg’s residents, knowledge of climate change, and motivations that influence their consumption behavior, in order to develop a smartphone application.

The survey is divided in two parts and will take you approximately 5 minutes to answer, participaton is completely anonymous and no personal information will be collected other than your answers. Part 1 covers questions for statistical and data sorting purposes, and part 2 covers questions related to habits, understanding of climate change, and motivations to their habits.

PART I - Demographics

1. What is your gender?

O Female O Male O Prefer not to answer

2. What is your age?

O Under 18
O 18-25
O 26-35
O 46-65
O Over 66

3. What is your nationality?

O Danish O Other

4. What is your highest level of completed education?

O Less than a high school diploma
O High school or equivalent
O College or equivalent
O Bachelor’s degree
O Master’s degree
O Doctorate

5. What is your current employment status?

O Student
O Employed
O Self-employed
O Househusband/Housewife
O Unemployed
O Retired

6. What is your approximate yearly household income?

O Less than 300,000 DKK
O Between 300,000-499,999 DKK
O Between 500,000-699,999 DKK
O More than 700,000 DKK

7. Regarding the place where you live, you are the

O Owner
O Tenant

8. Do you live with other people (e.g. partner, children, flatmates, etc)?

- ○ Yes, I share with others
- ○ No, I live alone

PART II- Heating Behavior and climate

9. How concerned are you about global warming and climate change?

- ○ Very concerned
- ○ Somewhat concerned
- ○ Little concerned
- ○ Not concerned

10. Do you know how much energy in kilowatt hour (kWh) did you consume for heating during the last year?

- ○ Yes
- ○ No
- ○ No, but I know how much I spent on heating

11. What would be the main motivation for you to save energy? (Please choose maximum 2 options)

- ☐ To save some money
- ☐ To preserve the environment
- ☐ To be able to pay my bills
- ☐ To set a good example for others
- ☐ To feel better about my consumption and carbon footprint
- ☐ I am impartial to saving energy

12. What would be the main reasons for you to not save energy? (Please choose max. 2)

- ☐ I don't want to be cold
- ☐ I don't have the time to adjust the thermostat
- ☐ My radiator is not adjustable
- ☐ I don't know how to modify the settings of the system (in case you have an automated system/ smart appliance)
- ☐ The economic savings are not significant

13. Which of the following statements best reflects how you feel?

- ○ I am concerned by the contribution of my energy use to climate change, and I am taking extensive action to reduce my consumption and my greenhouse gas emissions.
- ○ I am concerned by the contribution of my energy use to climate change, and I am doing small things to reduce my consumption and my greenhouse gas emissions
- ○ I am concerned by the contribution of my energy use to climate change, and I am starting to think that I should do something to reduce my consumption and my greenhouse gas emissions
- ○ I don't believe my energy use is contributing to climate change and I'm not willing or able to change my behavior
- ○ Whether there are climate change issues or not, I am not willing or able to change my behavior regarding my energy use
- ○ I Don't know what climate change is

14. How often (during winter time) have you adjusted the heating temperature on the radiators?

- ○ At least once a day
- ○ At least once a week
- ○ At least once per month
- ○ I don't adjust it
- ○ I am unable to adjust it

15. Are your radiators currently completely off?
- O Yes, all the radiators at home are off
- O Not all of them
- O None of them

16. How do YOU feel with the following statements (Please answer if you share your home)

	Always true	**usually true**	**Neutral**	**Rarely true**	**Never true**
I would like to have a different indoor temperature than the people I live with.	O	O	O	O	O
I am more careful to save energy than the people I live with.	O	O	O	O	O
I regulate the heat more often than the people I live with	O	O	O	O	O
I usually wear warmer (indoors) clothes than the people I live with.	O	O	O	O	O

17. Are you interested in checking your current energy consumption for heating (in a web portal or app on your smartphone)?
- O I am not interested
- O Yes but I do not have access to this data/ I do not know how to check it
- O Yes I check it at least once a month
- O Yes I check it at least once every three months
- O Yes I check it at least once every semester
- O Yes I check it at least once in a year

18. Would you be interested in knowing how much your heating consumption is contributing to climate change?
- O Yes, because I would like to reduce my contribution to climate change
- O Yes, because I am curious, but I am not sure if I am able to reduce my consumption
- O No, I am not interested
- O No, I don’t think that my energy consumption contributes to climate change.

19. Which of the following options would you prefer if your energy consumption for heating and its influence on climate change could be illustrated?
- ☐ The usual Kg CO2equivalent (carbon footprint) itself is meaningful for me
- ☐ km^2 of forest needed to capture/offset the CO2 released
- ☐ The corresponding distance you can travel by car
- ☐ The corresponding liters of gasoline burnt
- ☐ The corresponding cheeseburgers produced and eaten
- ☐ The corresponding hours with Tv on
- ☐ The corresponding number of pair of shoes produced
- ☐ The corresponding number of trips Aalborg-Barcelona
- ☐ Number of Olympic pools that could be filled up with that Co2 emitted
- ☐ Your emission level compared to other similar persons/households

Please suggest other comparison that it would be meaningful/interesting for you:

____

20. If you were interested in receiving personalized tips to decrease your carbon emissions which of the following options would you choose? (choose max. 2):

- ☐ Meeting with an expert
- ☐ Email
- ☐ Sms
- ☐ Social media (Whatsapp, Facebook, Instagram, etc)
- ☐ Phone call
- ☐ Letter
- ☐ Through an App in your phone
- ☐ I am not interested in this information

21. How much would you be willing to pay, assuming you would only pay once, for a smartphone application that shows your contribution to climate change (due to the heating used in your house)?

- ○ It should be free
- ○ 1 dkk – 35 dkk
- ○ 36 dkk- 100 dkk
- ○ More than 100 dkk

22. In this application, Would you be interested in knowing how are your carbon emissions compared with other similar households?

- ○ Yes, and I would like to share it on social media
- ○ Yes, and I would like to share it with my neighbors
- ○ Yes, because I want to learn how to do it better
- ○ No, I am not interested in the others' behavior

23. If this application had a reward system, how would you like to be rewarded for reaching a certain energy efficiency? (Choose max. 3)

- ☐ Discount in my energy bill
- ☐ Grants to retrofit my property
- ☐ Points to exchange for goods in grocery shop
- ☐ Public recognition (social media/ dashboard in my building/ app)
- ☐ Donating some money to climate change mitigation on my name
- ☐ Planting trees on my name
- ☐ Other:____

If you have further suggestions to help me to create this app, do not hesitate in giving me your comments and ideas in the space below, and if you are interested in helping me a little bit more through a short (phone/personal) interview, please leave your email below and I would be happy to get in contact with you.

Thank you for your participation! with your answers you have contributed a lot to my thesis project :)

B.2 Carbon footprint measurements

In this section, the results of the preferred measurements to illustrate individual carbon footprint, are presented. The participants of the survey were request in question 19, to choose some meaningful ways to illustrate their contribution to climate change. The results are shown in Figure B.1

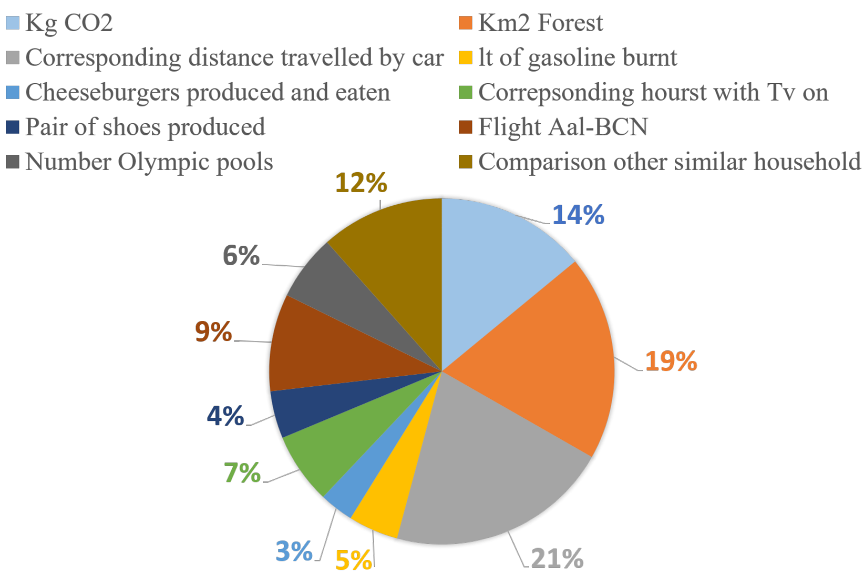

Figure B.1: The preferred carbon footprint measurement units

Below are presented the options proposed by the participants.

- " Planets needed if everyone would have the same carbon footprint as you"
- "Number of species endangered due to my habits "
- "Area of installed PV panels (250W/each) required to offset the energy consumed"
- "Area of sea affected by acidification due to the amount of CO2 emitted"
- "Comparison with households in other (less developed) countries"
- "Number of balloons that could be pump up"
- "The total difference in CO2 emissions if all Danes used 10% less heat and what effect it would have on the deterioration of the ozone layer"
- "Pizza - with and without box"
- "Kg CO2 compared with the average Dane"
- "Your projected total cost in carbon prices"
- "number of cows releasing the same amount of CO_2"
- "The percentage used regarding your historical emissions"
- "Comparison with the average emission of a same size house"
- "The fraction of an acceptable yearly emission budget (e.g. 2 tons lifestyle"
- "My emissions in terms of an average in DK, specifying how much it should decrease in order to reach the climate targets"
- "You could make 3 different, easily-caricated consumer profiles. Profile 1 could be the 'family lighthouse', which uses a lot of energy, has a high consumption and an old residence. This could be lower baseline. Profile 3 could be 'Family Save Heating', where Mr. Spar Mrs. Heating, had a lot of focus on energy optimization and

reduced heat consumption. This should then be the upper baseline. And then you could possibly. Try to define an average Danish family in 2018, with consumption in the middle of. So you could compare consumption by being placed on this scale between consumer profiles. I think that would be a very understandable (albeit slightly over-educational), for Mr. and Mrs. Denmark - and their children."