Anna Claudelin

CLIMATE CHANGE MITIGATION POTENTIAL OF FINNISH HOUSEHOLDS THROUGH CONSUMPTION CHANGES

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Abstract

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In order to achieve the universal goal of limiting global warming to 1.5 °C above the pre-industrial level, human beings must take action in all sectors. Approximately 70% of global greenhouse gas emissions are related to household consumption. Accordingly, as public awareness regarding climate change has increased, there has been an increase in interest, among both scholars and consumers, in ways that individuals can participate in climate change mitigation.

This doctoral thesis aims increase understanding regarding the potential of these actions through a multimethod approach. Various quantitative methods are used, including calculations based on statistical data, questionnaires, and carbon footprint calculations. The thesis consists of four publications, three of which include carbon footprint calculations. Both the statistical data and data from questionnaires are drawn from the Finnish context. Therefore, there can only be cautious applications of these conclusions to other similar countries.

The average Finnish household could reduce its annual monetary consumption, and simultaneously reduce its greenhouse gas emissions, by approximately 3400€ with moderate changes to their consumption habits. However, reducing consumption might create a rebound effect in which this saved money ends up being spent elsewhere, like on travelling, or invested in an unsustainable cause upon being deposited into a bank account. The saved money should therefore be impact invested, in renewable energy, for example, to avoid this rebound effect; this would lead to further greenhouse gas emission reductions. In this dissertation, a double impact framework is created to assess these potential greenhouse gas emission reductions, and calculations on these reductions are presented.

In the light of this thesis, consumers in developed countries have significant potential to reduce greenhouse gas emissions and can contribute to achieving the 1.5 °C goal. However, despite increasing awareness of climate change mitigation, global greenhouse gas emissions are still increasing. One way to inspire consumers to reduce their impact on the climate could be through an increase in both the confidence of knowledge of mitigation actions and impact investment options.

Keywords: climate change mitigation, household consumption, anti-consumption, impact investing, rebound effects

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Lately, I was told by a stranger that I should have a proper plan for my future. I do not, and I sure am glad I did not have one five years ago either. Otherwise, it would be highly unlikely that this dissertation would have happened.

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Contents

List of publications

This dissertation is based on the following papers. Permission to include them here has been granted by the publishers.

I. Claudelin, A., Järvelä, S., Uusitalo, V., Leino, M., and Linnanen, L. (2018). The Economic Potential to Support Sustainability through Household Consumption Changes. *Sustainability*, 10(11), 3961.
II. Claudelin, A., Uusitalo, V., Hintukainen, I., Kuokkanen, A., Tertsunen, P., Leino, M., and Linnanen, L. (2020). Increasing positive climate impact by combining anti-consumption and consumption changes with impact investing. *Sustainable Development*, 28(6), 1689–1701.
III. Claudelin, A., Uusitalo, V., Pekkola, S., Leino, M., and Konsti-Laakso, S. The Role of Consumers in the Transition toward Low-Carbon Living. (2017). *Sustainability*, 9(6), 958.
IV. Tolppanen, S., Claudelin, A., and Kang, J. (2020). Pre-service Teachers' Knowledge and Perceptions of the Impact of Mitigative Climate Actions and Their Willingness to Act. *Research in Science Education*.

Author's contribution

Anna Claudelin is the first and corresponding author in Publications I–III. In Publication I, she analysed the data with a co-author and wrote the majority of the manuscript. In paper II, she was responsible for the calculations in some of the examples, contributed to the literature research, and wrote the results and conclusions. In Publication III, the co-authors designed the survey while Claudelin analysed the data and wrote the paper. In Publication IV, Dr. Tolppanen was the corresponding author. Anna Claudelin co-designed the survey, was responsible for the carbon footprint calculations on which the survey was heavily dependent, and contributed to the discussion and literature review.

Nomenclature

Latin alphabet

a_a	anti-consumption or consumption change choice	€
c_i	the money from interest returned to consumption	€
D	the potential double impact (as GWP)	
g_a	life cycle GWP impact of anti-consumption goods or services	gCO_2e/€
g_I	the life cycle GWP impact reduction by investments	gCO_2e/€
g_i	the life cycle GWP impact of consumed goods or services	gCO_2e/€
I	the investment or donation to GWP reduction actions	€

Greek alphabet

Σ	sum

Abbreviations

BAS	business as usual
CBCF	consumption-based carbon footprint
CF	carbon footprint
COICOP	classification of individual consumption by purpose
EE-IN	environmentally extended input-output analysis
EE-MRIO	environmentally extended multi-regional input-output analysis
GHG	greenhouse gas
GWP	global warming potential
HBS	household budget survey
IPCC	Intergovernmental Panel on Climate Change
LCA	life cycle assessment
UBI	universal basic income
UNFCCC	United Nations Framework Convention on Climate Change
PBCF	production-based carbon footprint
PC	post-carbon

1 Introduction

The background for this dissertation is presented in this chapter, followed by the definition of the research gap and the aims and objectives of the study. Finally, the scope and limitations of the dissertation are discussed.

1.1 Research background

Climate change, with its many causes, is threatening the Earth and its inhabitants. Nine planetary boundaries that must not be crossed, lest there be disastrous consequences for humanity, were presented in 2009 by Rockström et al. The study was updated in 2015 by Steffen et al., who found that climate change and biosphere integrity (i.e., biodiversity loss) are the most important planetary boundaries due to their fundamental importance to Earth's system. Even though humanity continues to present itself and planet Earth many environmental risks, this dissertation focuses on global warming and leaves other issues of sustainability out.

The IPCC's goal of limiting global warming to 1.5°C seems to be becoming more and more difficult to achieve. Despite, for example, the EU meeting its goal of reducing its greenhouse gas (GHG) emissions by 20% from 1990 levels by 2020, the future isn't looking bright; when imported carbon is considered, GHG emissions in the EU have remained almost the same as they were in 1990. Similar patterns are occurring in most other developed countries (Peters et al., 2011). In order to limit global warming, far reaching societal changes, especially in the food, transportation, energy, and construction sectors, are needed on all levels, from international legislation to individual action.

It is estimated that approximately 65–72% of global GHG emissions are related to household consumption, whether directly or indirectly; contributing factors include e.g. energy consumption, transportation, and production processes (Hertwich & Peters, 2009; Ivanova et al., 2015). This trend doesn't seem to be changing; according to the World Bank (2021), global household consumption has increased consistently over the last several decades, and McKinsey Global Institute's (2016) report predicts that it will continue to grow. The primary driving factor behind this growth used to be population increase, but it can now be attributed to increased individual spending. It is also worth noticing that the richest 10% of population creates approximately 50% of global GHG emissions, while the poorest half creates only 10% (Oxfam, 2015).

Currently, when both direct impacts and embodied carbon are considered, the average carbon footprint globally is 3.4t CO_2e/capita. In the EU, consumption-based carbon footprints per capita range from Bulgaria's 5.4 tCO_2e to Luxembourg's 18.5t CO_2e. Luxembourg's carbon footprints are among the world's highest, and is on par with those of Australia and the USA (17.7 and 18.6 CO_2e, respectively). On average, only a fifth of global GHG emissions caused by household activities are due to direct combustion of fuels i.e. transport and household fuels. Most of the emissions are embodied in products and services (Ivanova et al., 2015, 2017). This dissertation focuses on Finland, which has a carbon footprint that is among the highest in Europe, at 10.4–13.6t CO_2e/capita (Lettenmeier et al., 2019; Ivanova et al., 2015; Salo & Nissinen, 2017). On average, 24–39% of a Finn's carbon footprint comes from housing, 19–27% from transportation, 16–17% from food, and 26–33% from goods and services (Lettenmeier et al., 2019; Salo & Nissinen, 2017). Individual carbon footprints need to be reduced significantly; according to Lettenmeier et al. (2019) carbon footprints per capita should be reduced globally to 2.5 tCO_2e by 2030 and eventually to 0.7 tCO_2e by 2050 to meet the temperature increase goal of 1.5℃. In developed countries, this would mean an 80–93% decrease by 2050, assuming that the necessary changes would begin immediately. In developing countries, a reduction of 58–76% is required. It has been estimated that, given the extant solutions and technologies, an average individual in developed countries could reduce their carbon footprint by 20–37 % by making changes in the areas of housing, transport, food, and purchased goods and services (Salo & Nissinen, 2017; Jonas & Kammen, 2011).

These individual actions could include, for example, insulating outer walls and replacing windows (reduction of 1200 kg CO_2e/a), travelling 1500 km/a less by car and walking instead (reduction of 150 kg CO_2e/a), switching to a vegan diet (total emissions of 700 kg CO_2e/a), extending the lifespan of particular items, and consuming a third less alcohol and tobacco (reduction of 500 kg CO_2e/a) (Salo & Nissinen, 2017). In the EU, Vita et al. (2019) estimated that 9–26% of European GHG emissions could be mitigated by reducing transport, working from home, and switching to walking and biking. Plant-based diets were found to have a mitigation potential of 4–15%, and reducing food waste and surplus were found to have a mitigation potential of 2–5%. Increasing the lifetime of clothing and sharing and repairing household appliances and devices has the potential of a 2–6% reduction. GHG emissions could further decrease by 8% if forestry products were used for current cooking and heating needs, but this would create negative effects in terms of land use. Passive house standards and eco-villages with de-centralized renewable energy systems have 5–14% reduction potential. In the light of findings by Lettenmeier et al. (2019) and Girod et al. (2014), among others, these reductions themselves will not be enough to reduce carbon footprints to target levels.

One way for individuals to decrease their carbon footprints and other sustainability impacts is anti-consumption, literally being against consumption (García-de-Frutos, 2018). Sudbury-Riley and Kohlbacher's (2018) study found two distinct reasons for anti-consumption; the primary reason was social, i.e., avoiding human exploitation, but ecological reasons were seen to be important as well. Sustainability-driven anti-consumption is generally practiced by rejection, reduction, and reuse (Black & Cherrier, 2010).

Anti-consuming and changes in consumption are likely to lead to decreased expenses; people would be able to save money. However, there is a risk of a rebound effect, where the saved money could end up being spent on other consumption options. This, in turn, would create GHG emissions elsewhere. In the worst-case scenario, the added consumption could cause more GHG emissions than the "original" consumption would have. Rebound effect is likely to be caused also when the saved money is invested or deposited into a bank account. Banks use deposited money to fund businesses and projects, through loans and investments, which might contribute to increasing GHG emissions. One way to avoid this rebound effect is to impact invest this money by investing in enterprises that generate environmental or social benefits (Pandit & Tamhane, 2018). In the context of this dissertation, the term is used to imply environmental impact investing. Via impact investing, saved money would further help decrease GHG emissions, in addition to the GHG emissions avoided by anti-consumption. It has been estimated that in Europe a yearly additional investment of 180 billion euros would be needed to achieve the EU's goal of reducing GHG emissions by 40% by 2030 (European Commission, 2018). Although impact investing has received criticism due to lack of clarity on definitions and fiduciary applicability (Hays & McCabe, 2021), it has been studied that when comparing green bond issuers with conventional ones, a decrease in the carbon intensity of the assets is displayed. The emission reduction is found larger in case of green bonds that have gone through external reviews. (Fatica & Panzica, 2021.)

In 2017, Raworth combined planetary boundaries with twelve dimensions of social foundation; health, education, income & work, peace & justice, political voice, social equity, gender equality, housing, networks, energy, water, and food. These dimensions are based on internationally-agreed upon minimum social standards and identified in the Sustainable Development Goals (United Nations, 2018). The social dimensions form a boundary outside of which all humanity should be, and the planetary dimensions form a boundary within which it would be safe to operate. Together, these boundaries form the doughnut of social and planetary boundaries, which can be seen as guideline of future consumption; consumption would be reduced significantly, planetary boundaries would not be risked, and everyone's basic needs would be covered.

1.2 Research gap

As indicated by multiple studies (e.g. IPCC, 2018; Lettenmeier et al., 2019; Girod et al., 2014), technical changes alone will not be enough to reduce GHG emissions to the targeted amounts. Changes in households' consumption patterns are critical as well. Consumption-based carbon footprints of different nations, and explanatory factors thereof, have been studied widely (e.g. Ivanova et al., 2015&2017; Harris et al., 2020; Clarke et al., 2017; Lettenmeier at al., 2019), and the knowledge on current levels of household carbon footprints is high. There are also multiple studies on individuals' abilities to lower their carbon footprint (e.g. Salo & Nissinen, 2017; Vita et al., 2019; Wynes & Nicholas, 2017; Girod et al., 2014).

The target carbon footprints for 2050 have been studied by Girod et al. (2014) and Lettenmeier et al. (2019), among others. However, sustainable carbon footprints that would still would cover basic needs in the current situation have not. Kalaniemi et al. (2020) calculated the carbon footprints of people living on a budget that would be enough to cover one's basic needs in Finland, i.e. the carbon footprints of participants in the universal basic income (UBI) experiment. The calculations were based on minimum reference budgets, and can be used as the lowest consumption structure that still covers basic needs in the Finnish context.

Anti-consumption has received increased academic interest, which is generally focused on motivations, attitudes, reasons, and anti-consumption behaviour (García-de-Frutos et al., 2018). Only a few studies combining anti-consumption and environmental impact were found. Touchette and Nepomuceno (2020) evaluated respondents' carbon footprints and presented them with a questionnaire to assess their anti-consumption practises and environmental concerns, and Kropfeld et al. (2018) indicated that anti-consumption lifestyles and environmental concerns are associated with lower ecological impacts, but no studies combining anti-consumption and households' GHG emissions were found.

The rebound effect of improved energy efficiency and reduced and shifted consumption has been studied in different contexts and consumption categories (Chitnis et al., 2013; Druckman et al., 2011, Ottelin et al., 2014; Ottelin 2016). Some studies such as Chitnis et al. (2014) briefly suggested sustainable investments for monetary savings, and Froemelt et al. (2021) brought up the question of what happens to saved money after a household invests in their home's energy efficiency. This dissertation aims to fill the research gap by combining anti-consumption, consumption changes, and impact investing. To support this, a framework for determining the global warming potential (GWP) impact of this combination is presented. In addition, examples of ways households can avoid the rebound effect via impact investing are presented.

Related to anti-consumption and consumption change, this dissertation also investigates whether individuals actually know which actions have the greatest impacts on climate change mitigation, and the magnitude of the achievable reductions in absolute terms. The influence of confidence is studied as well. The rather well-known attitude-action and knowledge-behaviour gaps have been previously discussed by Newton and Meyer (2013) and Kollmuss and Agyeman (2002), among others. Kosak et al. (2020) investigated participants' knowledge of the GHG emissions of daily activities but, in general, the topic has not been studied much.

1.3 Aims and objectives

The main objective of the thesis is to better understand how an individual could mitigate climate change in the current system. Publication I presents estimations on how much an average household would be able to save money with moderate/major changes and reductions in its consumption and presents some possibilities for how the money could be invested in a sustainable way.

Reducing consumption alone does not necessarily ensure GHG emission reduction. Saved money may be directed somewhere else, possibly causing more GHG emissions through the rebound effect than the "original" consumption would have. Therefore, Publication II discusses what should be done with the saved money in order to avoid this. Publication II also presents a framework for combining the impacts of reduced consumption and impact invested money, i.e. double impact, and presents examples thereof.

Together, Publications I, II, and III present some estimations of how much an individual can save money by anti-consumption while simultaneously reducing GHG emissions through both their original actions and impact investing. The household level estimations can be scaled somewhat in the Finnish context; this could also be done, albeit cautiously, in other similar countries.

Publications III and IV present actions that will decrease an individual's GHG emissions. In addition, Publication IV discusses people's knowledge on which consumption decisions have the biggest impacts, and how confidence in these impacts relates to their willingness to act.

Thus, the main research question of this thesis is:

How and how much can Finnish households mitigate climate change by their consumption decisions?

This is supported by the following sub-questions:

a. How much could an average Finnish household reduce its consumption in monetary terms, and how much savings would this create?
b. What is the role of sustainability supporting investments in ensuring that reductions in consumption lead to GHG emission reductions?
c. How much could households mitigate climate change by combining anti-consumption and consumption changes with impact investing? What would this mean in the Finnish context?
d. Do people know which consumption decisions have the largest impacts on GWP mitigation, and how does confidence affects these actions?

The first sub-question is answered by Publication I, the second sub-question by Publications II, I and III, the third sub-question by Publications II and III, and the last sub-question by Publications IV and III. The relations between publications and the primarily used methodologies of this dissertation are presented in Figure 1. To summarize, all publications are related to mitigating climate change by reducing GHG emissions. In addition to emissions, monetary reductions in consumption are discussed in Publications I and II, and statistical analysis is applied. Publications III and IV are partially based on data from questionnaires, and life cycle assessment methods have been applied to calculate the GHG emission reductions of different actions in Publications II–IV.

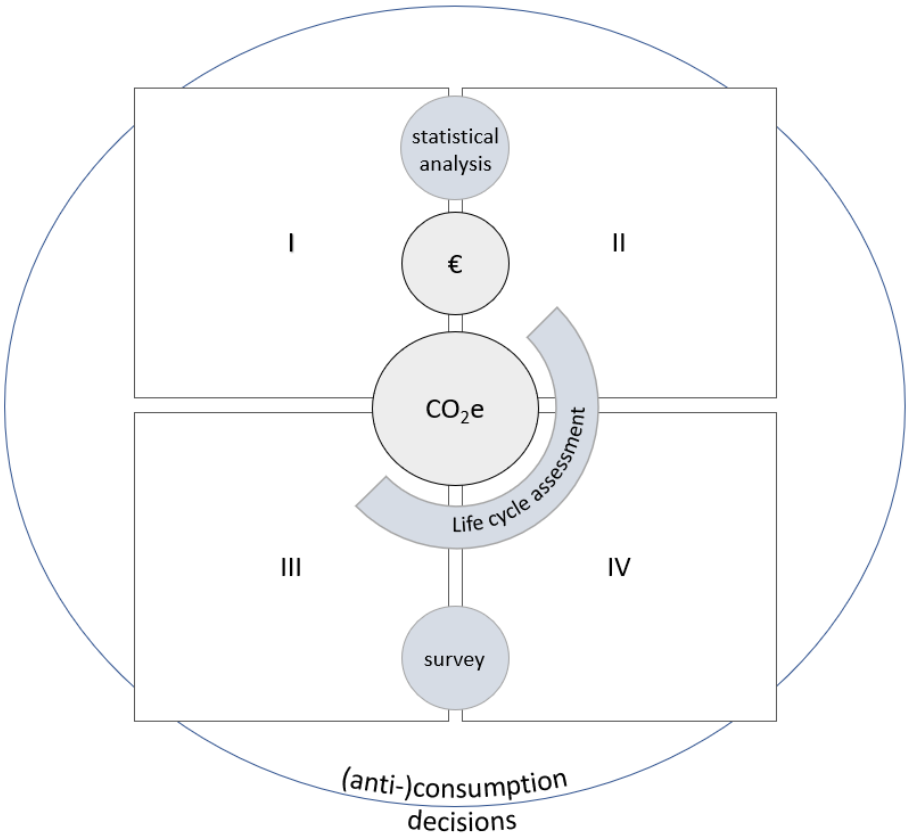

Figure 1. The relations between publications and the primarily used methodologies.

1.4 Scope and limitations

This dissertation focuses on anti-consumption decisions, consumption changes, impact investing, and the GWP impacts of households. Thus, the calculations are made on the microeconomic level and the calculations do not take macroeconomic changes that might occur over time or due to changes at the microeconomic level into consideration. The results are discussed on a microeconomic level, though macroeconomics is acknowledged.

The studies are based on data collected in Finland, which therefore represents Finnish households. The results can be cautiously applied to other similar countries and their households, though some carbon footprints are region-specific, mainly because of variation in region-specific emission factors. There are also limitations in the data found in Publications III and IV. In Publication III, the questionnaire is distributed to an area, where dwellings are newer than the Finnish average. In Publication IV, the respondents were pre-service teachers attending a sustainability class, and thus the sample did not represent the entire population. However, the questionnaire was answered before any lectures took place, and so the respondents did not have any prior formal education on the subject.

Human activities cause many other sustainability impacts in addition to climate change. This dissertation focuses solely on GWP mitigation; other environmental impacts are not considered. It is important to note that some GWP-mitigative actions might cause additional pressure to other environmental and sustainability areas.

2 Theoretical background

The theoretical background for this dissertation is presented in this chapter.

2.1 Consumption-based carbon footprint

Making a distinction between territorial GHG emissions and consumption-based GHG emissions is necessary before exploring consumption-based carbon footprints. When countries report their GHG emissions, to the UNFCCC, for example, they report their national emissions. That is, emissions released from transportation, heat production, and factories' production processes. This national accounting does not consider emissions embodied in products exported from the country, nor does it consider the emissions imported to the country in question. Thus, national accounting does not take into consideration, who benefits from the products and services. Emission reduction targets are based on national accounting, and so it seems that GHG emissions are steadily decreasing in many developed countries. However, when the imported carbon is considered, there is often very little or no decrease in emission levels (Peters et al., 2011).

The most prevalent way to assess consumption-based carbon footprints (CBCF) is the use of various databases (Eora, EXIOBASE) based on (environmentally extended) multi-regional input-output (MRIO) analysis. Often, MRIO databases are linked with household expenditure surveys and other subnational information used for assessing environmental footprints. MRIOs can also be used to assess environmental impacts other than GHG emissions. Giljum et al. (2014), for example, studied material footprints using a MRIO. The studies discussed in this chapter are based on MRIO analysis, or similar but more regional environmentally extended input-output (EE-IO) analysis, unless otherwise noted. MRIO modelling is briefly discussed in Chapter 3.2.

Ivanova et al. (2015) analysed the global GHG emissions from household consumption in various countries. In the reference year 2007, 65% of generated GHG emissions came from household consumption. Wilting et al. (2021) found the corresponding number in the EU to be 75% for the reference year of 2010. On the global and EU levels, approximately 20% of households' GHG emissions were from activities involving fuel combustion. The majority of these emissions were tailpipe emissions from private vehicles and the rest were from the use of household fuels, such as gas. (Ivanova et al., 2015; Ivanova et al., 2017.) Globally, percentages of household GHG emissions from various activities were as follows: consumption of services, 27%, shelter, 25%, manufactured products, 17%, mobility, 15%, and food, 13% (Ivanova et al., 2015). In comparison, the shares in the EU were as follows: services, 14%, shelter, 22%, manufactured products, 17%, mobility, 30% and food, 17% (Ivanova et al., 2017). In the EU context, the top decile (10% of population producing the most emissions) emitted 15% of the total EU GHG emissions, with CBCFs of 16–22 tCO_2/capita. The lowest decile emitted 5%, with carbon footprints of 5–7 tCO_2/capita. (Ivanova et al., 2017.) The global difference between CBCFs is huge, which is also implied by the fact that the richest

10% of the population produces approximately 50% of global GHG emissions, while the poorest 50% creates only 10% (Oxfam, 2015).

Globally, some Western countries, such as France and Sweden, stand out with lower carbon footprints than other countries with similar incomes due to their use of hydro and nuclear power. In these countries, the shares of embodied emissions were significant, at 51% and 65%, respectively. (Ivanova et al. 2015.) Similarly, Clarke et al. (2017) found that 61% of Icelandic households' CBCFs were embodied emissions from overseas. Iceland's stationary energy supply is already 99.5% renewable, and thus it can be considered a forerunner in the transition to renewable energy system and carbon neutrality. Due to its high share of renewables, Iceland's share of direct emissions was 10% compared to the global average of 20%. Despite the cold environment, shelter and services only accounted for approximately half of the EU average. Despite Iceland's high share of renewables, its annual CBCF was 22.5 tCO_2e/household (Clarke et al. 2017.) This highlights the fact that improvements in energy efficiency and transitioning to renewable energy systems alone are not enough to achieve the required GHG emission reductions, and eventual carbon neutrality, globally.

Within the EU, the highest carbon intensity per consumed euro category was mobility (3.4 $kgCO_2e$/€). The shelter category had lower carbon intensity (0.9 $kgCO_2e$/€) but, due to its rather big share in the household expenditure, its total impact on household GHG emissions was 25%. Out of the six categories discussed, services had the lowest carbon intensity, but, as 45% of household expenditure was directed towards this, the total share of GHG emissions was 17%. (Ivanova et al., 2015.)

Production-based and consumption-based GHG emissions have been compared by Harris et al. (2020) and Clarke et al. (2017), among others. Harris et al. (2020) found the production-based GHG emissions of ten European cities to be approximately 52% of their consumption-based GHG emissions. In the context of Iceland, Clarke et al. (2017) found a slightly smaller difference; the production-based household CFs were 64% of the consumption-based ones. Harris et al. (2020) also presented predictions for two scenarios in 2050, business as usual (BAS) and post-carbon (PC). According to the modelling, production-based emissions will decrease significantly in both scenarios; emissions lower than 1.5 tCO_2/e per capita are mostly achieved in the PC scenario. As compared to current situation, production-based emissions would be 31% lower for BAS and 68% lower for PC. However, consumption-based emissions will grow in both scenarios, even with the expected improvements in energy efficiency, 33% and 35%. (Harris et al., 2020.) The decreasing production-based emissions and simultaneously growing consumption-based emissions highlight the importance of the latter. In contrast to most developed countries, the GHG emissions per capita in New Zealand using production-based accounting were found to be 22% higher than when using consumption-based accounting. Thus, unlike most developed countries, New Zealand is a net exporter of emissions. This is primarily due to the fact that agriculture accounted for 52% of their production-based emissions. (Chandrakumar et al., 2020.)

The socio-economic characteristics that influence households' carbon footprints have been investigated. Christis et al. (2019) studied the Flanders region in Belgium and concluded that the CBCF of the richest decile was 2.5 times higher than that of the lowest income decile. Similarly, Feng et al. (2021) estimated consumption-based GHG emissions for nine US income groups and concluded that the CBCF of the richest decile was 2.6 times higher than that the lowest income decile. In Norway, the CBCF of the highest income decile was 5.1 times higher than that of the lowest income decile, while the expenditure was 4.1 times higher (Steen-Olsen et al., 2016). Ivanova et al. (2017) found that 29% of the CBCFs could be explained by income level. A strong correlation between purchasing power parity and per capita carbon footprints was found by Ivanova et al. (2015).

In the US context, the average carbon intensity for households earning less than 70k USD/year was 0.55 kg/USD; this declined as income increased, ending at 0.44 kg/USD for the highest income group. This is explained by the fact that higher income groups spend more money on services with a lower GHG intensity (Feng et al., 2021). Similarly, in the EU it was found that a 1000€ rise in income resulted in a roughly 450, 300, and 150 $kgCO_2e$/capita increase in CFs for the 25th, 50th, and 75th income percentiles, respectively (Ivanova et al., 2017). For income groups making less than 40k USD/year, the highest share of GHG emissions came from the utility sector (Feng et al., 2021). Christis et al. (2019) found similar results in Belgium; housing, water, electricity, and gas made up over half of the CBCFs of the lowest income decile. In top income households, however, these constituted only a third of the CBCF. The same pattern can be observed in the US study; the share of imported carbon increased with income, as higher income groups spent more money on imported products, such as clothes. The total share of imported carbon was 21% for the lowest income group and 25% for the highest (Feng et al., 2021.)

Increasing the average household size by one person decreased the average electricity and housing fuels associated GHG emissions by 750 $kgCO_2$/capita and waste treatment related emissions by 80 $kgCO_2$/capita annually. Urban-rural typology explained differences in the mobility sector; urban regions had, on average, 650 $kgCO_2$/capita lower emissions from land transport. Assuming a one percent increase of tertiary education in a regional population, this increase led to higher emissions by a rate of 60 $kgCO_2$/capita. This increase was mainly driven by food consumption, particularly animal-based food. (Ivanova et al., 2017). Froemelt et al.'s (2021) findings indicate that, in Switzerland, more rural cantons have higher production-based GHG emissions per GDP, while some "city-cantons" have higher consumption-based GHG emissions per capita.

Wilting et al. (2021) studied 162 European regions. The results indicated that rich regions with high income equality have relatively high CBCFs per capita. No relationship between population density and per capita GHG emissions was found. Conversely, Ivanova et al. (2018) found that GHG emissions related to mobility and housing decreased as population density increased. Gill and Moeller (2018) saw similar results in German households; rural households created more direct GHG emissions but their carbon footprints were on the same level as households in cities. The density of cities saved some GHG emissions, but bigger salaries, smaller household, sizes and increased consumption options created extra GHG emissions.

While many studies have studied consumption-based carbon footprints of different deciles, Kalaniemi et al. (2020) analysed the carbon footprints of households participating in universal basic income (UBI) experiment. UBI is a level of income that provides enough for basic needs, such as food, shelter, and medication. Thus, UBI households offer a good example of CBCF for a household in which unessential consumption is reduced significantly. In the Finnish context, UBI is essentially the same as the lowest income decile. On average, the carbon footprint at the UBI consumption level was 4.8t CO_2e/capita. In comparison, the CBCF of an average Finn was 11.5 tCO_2e/capita (Salo & Nissinen, 2017). This implies that even people whose basic needs are fulfilled have twice the carbon footprint than is sustainable.

2.2 Consumption changes

The next section offers some background information for consumption patterns, rather than individual actions that can reduce households' carbon footprints.

Ivanova et al. (2018) studied the carbon footprints of mobility and housing, and the behavioural and structural factors behind them by conducting a survey across four different EU regions. Their findings indicated that settlement density reduced an individual's mobility carbon footprint while car ownership, higher income, and longer travel distances were associated with a higher mobility carbon footprint. On average, a one kilometer increase in the distance of a daily trip decreased the probability of active travel, such as walking or biking, by 1.2%. This was not linear; an increase from 5 km to 10 km decreased the probability by 6.8%, but from 10 km to 15 km the probability decreased by only 5.9%. Regular commuting was found to result in a 6% higher probability of using public transportation as compared to irregular trips. Explanatory factors (rush hour and traffic) were not studied. For car owners, the likelihood of taking daily drives was 46.9%. Attitudes were found to be quite irrelevant for the distance travelled by land and air. Population density increased the likelihood of active travel by 30.6% in urban environments and by 23.2% in rural environments. Household size was found to have no effect. Individuals of higher education were less likely to use public transportation, and more likely to drive and fly. An income level increase of one resulted in an average increase in daily travel by seven km.

Related to housing energy use, no significant relationship between producing one's own electricity (and energy cooperative initiatives) and increase in energy use was found. Rural houses were more likely to be heated with renewables, such as wood. Adding one person to the household decreased personal electricity use by 170 kWh/year, space heating by 800 kWh/year, and water heating by 60 kWh/year. Education level was not found to increase energy need. Age, however, was; an additional year resulted in an increase in annual energy need by some kilowatt-hours. Women were found to have a

360 kWh/capita higher annual space heating need than men. Energy use was found to be income inelastic, and the share of fossil fuels used in urban housing was found to be higher, leading to higher carbon intensity. Rural homes, however, were usually bigger, leading to increased GHG emissions. (Ivanova et al., 2018).

Urban living was associated with a decreased tendency to travel by land and an increased tendency to walk, cycle, and use public transportation more; dwelling sizes were also smaller. While urbanisation reduces dwelling sizes, it is important to shift from using fossil fuels to low-carbon heating in urban areas as well. Higher income levels and higher education created higher GHG emissions that are particularly associated with air travel and other consumption, though travel was found to be income elastic. The primary reason for not heating a house was found to be financial. Owning a car was found to be a significant lock-in with high probability of driving even short distances. A behavioural alternative, such as a manageable distance for active moving or public transport, would be needed for changes in car travel to happen. Public funds should be directed toward infrastructural development; increasing ridesharing services, for example, could increase carpooling and overall mobility choices (Ivanova et al., 2018).

Salo et al. (2021) found that people aged 25 to 44 spent considerably more money on air travel tickets than those in other age groups. A higher income increased consumption opportunities and CBCFs. Larger houses were found to result in higher expenditures on housing, services, and tangibles. Higher education resulted in higher expenditure. Consumption in service categories (accommodation, education, hairdressing, and personal grooming) was statistically higher for the more educated. No clear pattern based on type of dwelling was found. Additional income was found to increase the amount of money spent on travel the most, while the increase was lowest in the food category. The household footprint was affected more by number of adults than number of children. Younger households had both lower expenditures and food-related carbon footprints as compared to the reference group (aged 45–54). The carbon footprints of services and tangibles, however, were higher for the youngest group. Older households had smaller carbon footprints in the areas of services and travel.

In these studies, product quality could not be distinguished from the money spent; carbon intensities did not distinguish whether the money was spent on a luxury car or a basic family car, for example (Feng et al., 2021; Steen-Olsen et al., 2016; Salo et al., 2021).

2.3 Anti-consumption

Anti-consumption is in direct contradiction to materialism, which is often thought to be related to happiness and life satisfaction and is strongly tied to consumption. (Lee & Ahn, 2016). Materialistic people often lose control over their carefully planned consumption decisions (Lee & Ahn, 2016) and tend to cognitively dissociate themselves from the negative environmental effects of consumption (Kilbourne & Pickett, 2008). Conversely, anti-consumers make conscious consumption decisions, and consider their values as part of their decision-making (Garcia-de-Frutos et al., 2018; Lee & Ahn, 2016), meaning that unintentionally not consuming something or not consuming due to lack of money cannot be called anti-consumption (Garcia-de-Frutos et al., 2018). Anti-consumption also serves as self-expression (Garcia-de-Frutos et al., 2018), though it is not the same thing as anti-materialism. Anti-materialistic people seek to reject material possessions overall, while anti-consumption focuses specifically on being against consumption. (Lee & Ahn, 2016).

This thesis focuses on anti-consumption in the environmental context, and so only the relevant literature has been reviewed. Several reviewed studies discuss voluntary simplicity, which is one anti-consumption lifestyle (Touchette & Nepomuceno, 2020) that embraces reduced consumption (Alexander, 2011).

Environmentally-oriented anti-consumption (EOA) has received significant academic interest, especially in studies on marketing and management. It includes a wide range of actions that individuals can take to avoid, reduce, and reject consumption. These behaviours have been fragmented into several concepts, such as green consumption and social consumption, in different studies, and so the knowledge is rather scattered. Anti-consumption is not only being against consumption; it can also be about actions directed at more specific targets, such as companies, products, or even nations. For behaviour to be considered EOA, it has to reduce, avoid, or reject consumption due to environmental concerns or motivations. EOA can be further divided into two possible approaches, broad EOA and strict EOA. Broad EOA acknowledges that all individuals consume, and allows for alternative purchases, such as buying a bike in order to stop or reduce car use. In the strict approach, no alternative purchases are considered. (Garcia-de-Frutos et al., 2018.)

Sudbury-Riley and Kohlbacher (2018) sent a postal survey to 5000 randomly selected UK consumers aged 50 or over, as a previous study (Jayawardhena et al. 2016) had shown that older adults consume more ethical and environmentally friendly products; their response rate was 9.6%. Their analysis revealed that more people anti-consume consistently for social reasons (13%) than for ecological reasons (5%), though the majority of the latter group also anti-consume for social reasons. People who have written to an organization, used an internet forum, or publicly demonstrated were found to be significantly more likely to anti-consume for social and ecological reasons. It was also found that environmental and social concerns lead to feelings of marketplace alienation. These people feel cynical and distrustful toward firms and believe that their conservation efforts can make a difference. The results also indicated that perceived consumer effectiveness had a more significant impact on ecological anti-consumption than on social anti-consumption, which supports the idea of keeping ecological and social anti-consumption separate. The study indicated that socioeconomic status does not matter in anti-consumption behaviour. The focus is on not buying anything at all, and therefore the premium prices of green products do not act as barriers in green consumption; women were also found to be significantly more likely to participate in anti-consumerism. (Sudbury-Riley & Kohlbacher, 2018.) Black and Cherrier (2010) interviewed 16 women to examine their anti-consumption practises, motivations, and values in the context of a sustainable lifestyle. They found that anti-consumption for sustainability is primarily practised by rejection, reduction, and reuse. Anti-consumption was seen as more important than environmentally friendly consumption; the informants generally did not purchase green products, and did not adopt them in the long term when they did.

Peyer at al. (2017) studied voluntary simplicity and found that almost sixth of the German population are voluntary simplifiers; they buy more green products and have greater consciousness in terms of environmental and economic sustainability than the other four segments found. They identified the voluntary simplifiers based on their households' consumption levels, which were measured by the number of 11 consumer goods, such as cars, smart phones, and skis, in their homes, and their monthly net household income adjusted according to the number of adults and children in the household. Groups that were neither voluntary simplifiers nor over-consumers showed a strong positive correlation between owned consumer goods and income. Voluntary simplifiers had a relatively low number of consumer goods related to their income, and over-consumers had a high number. The segments of less well-off consumers couldn't afford different consumption choices as they focused primarily on bare necessities.

Most EOA studies have been published in business or psychology journals, and studies published in environmental journals have mostly focused on motivations, attitudes, reasons, and anti-consumption behaviour. (Garcia-de-Frutos et al., 2018). Touchette and Nepomuceno (2020) examined the environmental impact of anti-consumption lifestyles (voluntary simplicity, frugality, and tightwadism), environmental concern, and ethically minded consumption. They calculated respondents' carbon footprints based on information collected from them and presented a questionnaire to assess anti-consumption lifestyles and environmental and ecological concerns. The results were similar to those of Kropfeld et al. (2018), indicating that tightwadism can be associated with lower GHG emissions. Tightwads with higher knowledge of emission effects have lower GHG emissions; their desire to avoid spending causes them to consume significantly less. The results indicated that there was no correlation between environmental concerns/voluntary simplicity/frugality and positive impact on environment. Rich et al. (2020) did not study GHG emissions, but their findings are similar to those of Touchette and Nepomuceno (2020) in that they found no difference between voluntary simplifiers and non-simplifiers in terms of finding environmental important.

2.4 **Rebound effects**

The rebound effect is a phenomenon that occurs when achieved gains are partly or completely offset by increased use, such as when improvements in energy efficiency lead to an increased use of electricity. Rebound effects can be separated into direct and indirect effects in the context of microeconomies like households. Direct effects, in terms of energy efficiency, are created when cheaper energy increases the overall demand for energy. Indirect effects occur when cheaper energy increases the demand for other goods and services, which leads to increased GHG emissions in other sectors. (Chitnis, 2013; Druckman et al., 2011). Direct and indirect rebound effects can both be further divided into income and substitution effects. Income effects occur when improved energy efficiency increases the real income of households through cheaper energy bills, which leads to increased consumption overall. Substitution effects, on the other hand, occur when households' real income remains constant, and they shift their consumption of a particular service or good to a similar but differently priced service or good (Chitnis et al., 2013; Investopedia, 2020). The breakdown is theoretical in the context of GHG emissions, and the result is the sum of these two effects. In addition to these micro effects, there are macro effects that result from the interaction between consumers and producers. Secondary effects occur when, for example, an energy efficiency measure reduces costs for an industry, leading to a decrease in the prices of goods or services. This, in turn, leads to an increased demand for these goods and services, and thus also in energy. Economy-wide effects occur when the demand for fuel decreases due to increased energy efficiency; the price reduction then leads to increasing amounts of purchased fuel. Transformational effects happen when technology changes have the potential to, "change consumer preferences, alter social institutions, and rearrange the organization of production," (Hertwich, 2005). It is relevant to acknowledge the macroeffects, though this dissertation focuses on households, i.e. microeffects.

Chitnis et al. (2013) modelled how cost savings from seven energy efficiency measures in UK dwellings would be spent across different consumption categories; they included both direct and indirect effects. The range of rebound effect was 5–15%, and the main source of rebound effects was spending cost savings on non-energy related goods and services. The rebound effect stayed moderate, as these services were less GHG intensive than energy production. Similarly, Druckman et al. (2011) estimated the rebound effect to be 7% when lowering the room temperature by 1 °C in the UK context. The results of both studies were highly depended on the GHG emissions of UK energy production. In countries with lower energy-related GHG emissions, the rebound effect would be greater. Additionally, substitution effects might present a greater rebound effect depending on what the cost savings would be spent on (Chitnis et al., 2013).

Druckman et al. (2011) found the rebound effects to be significantly larger when eliminating food waste, thus reducing food expenditure by a third (51%) and for walking or cycling instead of driving a car for a trips of two miles or less (25%). In the study, savings deposited into a bank account were treated as investments and an average GHG intensity for UK investments was used. In a behaviour-as-usual scenario, 4% of the savings were invested and the rest were re-spent. If the 7% rebound effect from lowering room temperature is included, the total rebound effect for these three actions becomes 34%. They also estimated the "least-worst" rebound effect, i.e. savings used in the category of housing (household rent, maintenance, repair, and water supply), which had the lowest GHG intensity of all the consumption categories. In this case, the rebound effect was 12%. Accordingly, they also estimated the worst-case rebound effect, in which the savings were used for gas. This resulted in an extreme backfire; rebound rate of 515%. They also investigated how the savings ratio would influence the rebound effect. The lowest savings rate in the UK between 1964 and 2009 was –4%, meaning that households were withdrawing from savings; the rebound effect in this case was 35%. With a high savings ratio of 40%, the rebound effect was 31%. Assuming that all savings were invested, the rebound effect would be 26%. The difference comes from investments having a slightly lower GHG intensity than consumption expenditures.

Similarly, Chitnis et al. (2014) assumed that households saved and invested 15% of their annual income and used an UK average for the GHG intensity. According to their calculations, indirect rebound effects account for majority of GHG emissions. Embodied emissions of non-energy goods and services had the greatest impact, though a larger share of rebound effects could be attributed to direct emissions in cases of low-income households. They found that rebound effects were generally larger for low-income households due to these households spending cost savings on GHG-intensive goods like food. Murray (2013) found similar results regarding lower income households, though he still suggested targeting changes in consumer behaviour, especially conservation measures, toward higher income households.

Ottelin et al. (2017) focused on the Finnish working middle class and studied the rebound effects of reduced driving and car ownership and compared car owners to car-free households, keeping the characteristics otherwise similar. They found the rebound effect for giving up car ownership to be 68%, whereas the average rebound effect for reduced driving was 23%. Persons who own a car but drive very little were found to have the lowest carbon footprint in terms of transportation; it was estimated to be 11% lower than similar persons who do not own a car. This implies that money saved by not owning a car is directed into other consumption categories.

Font Vivanco et al. (2014) developed a general microeconomic model to study the environmental rebound effect of plug-in hybrid cars, full-battery electric cars, and hydrogen fuel cell cars. They combined LCA-based methods with a marginal consumption model based on technology choices. In terms of GHG emissions, they found a rebound effect of less than 5% for a plug-in hybrid, and a notable negative rebound effect for a full-battery electric and hydrogen fuel cell cars. The moderate rebound effect of a hybrid was due to a slight decrease in transport costs as compared to its alternative. The negative rebound effect for a full-battery car was caused by high capital costs, leaving less income for other consumption categories. The GHG emissions of using a full battery electric car were found to be 79% smaller as compared to spending the same amount of money on general consumption. In both cases, green production technologies were also named as a factor in the reduced GWP impacts. The results were also analyzed across different income quintiles; lower income groups were found to have a higher rebound effect, as freed income is generally spent on categories with higher environmental impacts.

Similar results were achieved by Mizobuchi (2008); they showed a significantly lower rebound effect when the capital costs were considered. Without considering capital costs, the rebound effect was 115%. When capital costs were considered, it was 27%. The study took electric appliances, such as air conditioners, TVs, burners, heaters, and cars, into consideration. The study indicated that most energy-efficient appliances were more expensive than less efficient ones. Chitnis et al. (2013) presented similar results; solar thermal heating and LED lightning were found to have a negative rebound effect when capital costs were considered. Similarly, Ottelin et al. (2015) suggested that the smaller carbon footprints of households living in new housing (as compared to older housing in similar area) are due to higher housing loans, leaving not as much money for other consumption. However, their results show that the carbon footprints of households living in new housing are higher as compared to older housing in inner urban areas. In these cases, high levels of other consumption counteracted the energy efficiency gains.

3 Materials and methods

This chapter presents the materials and methods used in this thesis. First, the research approach is discussed, and overview of the methods, data collection techniques, and analysis used follow. More detailed descriptions are provided in individual articles. Finally, the double impact framework created in Publication II is discussed.

3.1 Research approach

Quantitative research conventionally produces numbers and percentages which can be presented as “facts” at least within the given sample, whereas qualitative research is used in answering questions with deeper insight (Barnham, 2015). Due to the research questions of the thesis which mainly require numerical answers, a quantitative approach was selected. A multimethod approach was seen to be the most suitable method for this dissertation as various quantitative analysis were needed. Mixed methods are sometimes seen as synonymous with multimethods, and sometimes a clear distinction is created, generating confusion (Anguera et al., 2018). The prevailing consensus, however, is that, in multimethod approach, complementary methodologies are used to answer the research goal; there is not necessarily a difference in terms of whether the methodologies are quantitative, qualitative, or both. Conversely, both quantitative and qualitative methods are applied in mixed methods studies (Hunter & Brewer, 2015; Anguera et al., 2018). In this dissertation, quantitative methods were used in forms of calculations based on statistical data, questionnaires, and life cycle assessments.

The context for all publications was Finland, while the focus varied across publications (Table 1). The main research goal of the dissertation is divided into sub-questions. Publications I–III contribute to more than one sub-question, while Publication IV contributes to only one. Publications I and II focus on overall household consumption, and Publication II is partially built on the results from Publication I. Publication III focuses more specifically on low-carbon housing and Publication IV focuses on knowledge of and willingness to take climate change mitigation actions.

Table 1. Publication context and focus.

	Publication I	Publication II	Publication III	Publication IV
Publication title	The Economic Potential to Support Sustainability through Household Consumption Changes	Increasing positive climate impact by combining anti-consumption and consumption changes with impact investing	The Role of Consumers in the Transition toward Low-Carbon Living	Pre-service Teachers' Knowledge and Perceptions of the Impact of Mitigative Climate Actions and Their Willingness to Act
Context	Finnish households	Finnish households	Three Finnish residential areas	Finnish pre-service teachers
Goal	To assess how much money average Finnish households could save and invest in sustainability annually without compromising basic needs.	To present an approach to account for combined GHG emission reductions from anti-consumption and impact investing.	To study the willingness of homeowners to adopt renewable energy production systems and assess the potential GHG emission reductions.	To study knowledge and perceptions of climate change mitigation actions.

3.2 Methods

Quantitative research allows for the systematic investigation of a phenomenon; it is conducted by using mathematically-based methods to analyse numerical or statistical data (Muijs 2011, 1; Watson, 2015). Quantitative research methods were used in all four papers. In Publications I and II, publicly available statistics and GHG calculations are studied quantitatively, while quantitative analysis is performed on data acquired from questionnaires in Publications III and IV.

Life cycle assessment (LCA) is often used to assess the environmental impacts of product systems, and also allows for comparing between different systems that fulfill the same purpose (Klöpffer, 2014, 2), like a certain amount of electricity produced or appliance manufactured. One commonly used analysis is "cradle-to-grave", in which all life cycle steps are taken into consideration, starting from raw material extraction and ending in product disposal (Klöpffer, 2014, 2). The LCA approach has been standardised and has an established terminology (ISO 14040; ISO 14044). The standards are to be used together in order to ensure that the assessment has been done according to ISO (Klöpffer, 2014, 10). LCA methodology can be used to assess various environmental aspects, such as acidification, not only GHG emissions.

When only GHG emissions and GWP impacts are considered, the result of an LCA calculation is called a carbon footprint (CF). More people are familiar with the term carbon footprint than they are with LCA, and public awareness of and interest in CFs has increased in recent years. A carbon footprint can be calculated for both products and services (ISO 14067, 2018). Similar to LCA standards, carbon footprint standard ISO 14067 (2018) presents guidelines, requirements, and principles for the quantification of a product's carbon footprint. The LCA requirements are adopted from ISO 14044. In carbon footprint calculations, other greenhouse gases are considered in addition to carbon dioxide (CO_2). In order to compare the radiative forces of different greenhouse gases to the radiative force of CO_2, different GHGs are transferred into carbon dioxide equivalents (CO_2e). This is done by using global warming potential (GWP) indexes, or the characterisation factors, as defined in ISO14040, of different GHGs, which are based on their radiative properties. GWP measures, "the radiative forcing following a pulse emission … in the present-day atmosphere integrated over a chosen time horizon," (ISO 14067, 2018.) According to IPPC (2013), it would be appropriate to describe GWPs as a, "relative cumulative forcing index." GWP is usually integrated over 20, 100, or 500 years, with GWP_{100} being the most commonly used; it has also been adopted by the United Nations Framework Convention on Climate Change (UNFCCC). The GWP_{100}s for two of most common GHGs in addition to CO_2, methane (CH_4) and nitrous oxide (N_2O), are 28 and 265, respectively (IPCC, 2013). It is worth noting that in the aviation sector, it is not fully understood, how greenhouse gases and other pollutants affect in the higher atmosphere, the stratosphere. For example, nitrogen oxides add the amount of ozone (O_3) which warms up the atmosphere. Also, water vapor usually evaporates in the troposphere in 1–2 weeks but in the stratosphere it can take years. For these reasons, the radiative forcing of greenhouse gases produced in the aviation sector are not as straightforward. There are various estimations which suggest the radiative forcing is 1 to 5 times higher in the sector. (Niemistö et al. 2019)

As previously discussed, the most prevalent way to assess consumption-based carbon footprints is to use various databases (e.g. Eora, EXIOBASE) based on environmentally extended multi-regional input-output (MRIO) analysis. Before MRIO databases existed, researchers used databases that only consisted of national input-output tables. The construction of MRIO databases came from the need to measure emission responsibility and the role of international trade of goods and services; the Kyoto Protocol specified GHG reduction targets for each ratifier. However, these targets were set on a territorial basis and therefore the embodied emissions of imports and exports were not considered.

This led to an environmental discussion on producer versus consumer responsibility as similar issues arose in the trade literature (Tukker & Dietzenbacher, 2013).

As an example of a MRIO database, Eora documents inter-sectoral transfers of 190 countries and 15 909 sectors. The data is available in individual country IO tables, which contain primary input and final demand blocks, imports and exports, and environmental satellite accounts. The global MRIO table is available in a harmonized 26-sector classification as well as a full version with five margins. In addition to GHG emissions, Eora covers labour inputs, energy use, nitrogen and phosphorus emissions, and air pollution (Eora, 2019). Development of a MRIO database is described in detail e.g. by Wood et al. (2015), and its methodology and various databases are discussed e.g. by Tukker and Dietzenbacher (2013).

3.3 Data collection and analysis

Data for Publication I is publicly available in the webpage of Statistics Finland (2018). Household consumption expenditure data is based on a household budget survey (HBS), a sample survey conducted approximately every 4–6 years. Data was collected through telephone interviews and forms filled out by households, and from administrative registers and purchase receipts. In addition to consumption expenditure, the survey studies education, housing conditions, vehicles, and income (Statistics Finland, 2020). The data used here is from the year 2016; the sample size is 3673 households out of the 2 677 100 households in the country; average household size was 2.02 (Statistics Finland, 2018).

Consumption expenditure was classified using the national classification of individual consumption by purpose (COICOP-HBS), which has around 900 headings (Statistics Finland, 2020). Expenditure includes all goods and services acquired for the household's private consumption, whether from Finland or abroad; it includes gardening, collectible food such as mushrooms, and received presents, and excludes presents bought for others. It also excludes investments, direct taxes, and housing payments. However, the so-called gross rent principle is applied such that an imputed rent based on the market rent of similar rented dwellings is applied to homeowners (Statistics Finland, n.d.).

In Publication I, the possible household monetary savings were quantitatively calculated using retrieved statistical data. The deduction percentages were based on background information from relevant entities and other reliable sources. Publication II is partially built on the findings of Publication I and therefore uses the same data. Data for carbon footprint calculations was found in publicly available sources and scientific literature. Data for Publications I and II was collected in 2018 and 2019.

Data for Publications III and IV was acquired through quantitative questionnaires. The questionnaire related to Publication III was distributed to 700 household mailboxes during the spring of 2016. The questionnaire was aimed at Finnish detached house owners, and thus the three residential areas selected primarily contained detached houses.

161 replies were received, out of which 154 were acceptable. The questionnaire included 32 questions, some of which were in a multiple-statement format. Data for Publication IV was collected in late 2018 from Finnish pre-service teachers who were participating in a course on education and sustainability. The data was collected at the beginning of the course; the participants did not have any formal knowledge of the topic at the time of the data collection. Out of 255 participants, 224 allowed their data to be used for research. The questionnaire included 44 questions. SPSS software was used to analyse the data of Publications III and IV. Data for the LCA modelling in Publication III and for the carbon footprint calculations in Publication IV was abstracted from publicly available sources, scientific literature, and LCA software GaBi 6.0. Data collection and analysis methods are summarised in Table 2.

Table 2. Data collection and analysis.

	Publication I	Publication II	Publication III	Publication IV
Period	Expenditure data from 2016, retrieved 2018	Based on results of Publ. I, other data collected 2019	2016	2018
Data	Finnish household consumption expenditure (publicly available)	CF data from scientific and other reliable publ.	Postal questionnaire (N=154), CF data from scientific and other reliable publ.	Online questionnaire (N=224), CF data from scientific and other reliable publ.
Analysis	Quantitative	Quantitative	Quantitative and LCA	Quantitative and CF calculations

3.4 Developing the double impact assessment framework

The methodological contribution of this dissertation is the double impact approach, which is developed and presented in Publication II. The term "double impact" was used to describe the effects of combining anti-consumption or consumption changes and impact investing in terms of GHG emissions. The impacts were defined as follow:

1. First impact (anti-consumption or consumption change impact) is created when an individual decides to reduce consumption (quantitative change), e.g., not buy a new sofa, or when an individual decides to alter one's consumption (qualitative change), e.g., cycle instead of driving a car. In the first option, the GHG reductions

do not happen immediately but rather over time as the overall demand lowers and levels of production are affected. In the latter case, the GHG reductions are immediate due to reduced fuel consumption.

2. Second impact (investment impact) is created when the money saved from the first impact is donated or impact invested into sustainability-supporting actions, leading to further reductions in GHG emissions over different time periods. These investments can be related to the production of renewable energy or the creation of carbon sinks, among other things.

3. Tertiary impact (reverse or additional impact) is additional to the two main impacts and is based on potential interest from the investments. If this interest is then invested further, it creates an additional reduction of GHG emissions. If the interest is withdrawn, it will likely be spent on consumption, thus causing GHG emissions.

The double impact assessment could be used to analyse many other sustainability impacts in addition to GWP, but the focus here is on GHG emissions. Equation 1 was developed to calculate the double impact potential from the GWP perspective:

$$D = \sum_{1}^{n} a_a \cdot g_a + \sum_{1}^{n} I \cdot g_I - \sum_{1}^{n} c_i \cdot g_i \quad (1)$$

where D is the potential double impact (as GWP), a_a is the anti-consumption or consumption change choice [€], g_a is the life cycle GWP impact of anti-consumption goods or services [gCO_2e/€], I is the investment or donation to GWP reduction actions, g_I is the lifecycle GWP impact reduction by investment [gCO_2e/€], c_i is the money from interest or from investments that is returned to consumption [€], and g_i is the life cycle GWP impact of consumed goods or services [gCO_2e/€]. Naming the framework as triple impact framework was considered. However, as the tertiary impact was seen rather insignificant in the current setting compared to the first and second impacts, it was decided to name the framework as the double impact framework.

4 Summary of the publications and main contributions

This section outlines the publications included in the dissertation and summarises the results presented therein.

4.1 Publication I

The Economic Potential to Support Sustainability through Household Consumption Changes

4.1.1 Objectives and methods

Publication I aimed to address two assumptions; that a consumer's role in solving the sustainability crisis is small, and that environmental protection is costly and sustainable choices are too expensive as compared to conventional products. Thus, the objective of Publication I was to estimate the amount of money that could be directed toward sustainable investments without compromising basic needs.

The amount of money that could be saved by reducing unessential consumption was estimated by using statistical data obtained from an online database maintained by Statistics Finland (2018). The analysis was done for an average household, and for the 1st and 5th quintiles. The consumption of Finnish households was studied in terms of the classification of individual consumption by purpose (COICOP). Reductions were made by evaluating every categorized product and service and their necessity in terms of human well-being separately. The reduction percentages were based on information from relevant entities like the Finnish Food Authority, scientific publications, and other reliable sources. Two scenarios were formed:

- S1: An incremental situation that could be achieved in the next few years. Deduction percentages were made so that the necessary actions would be relatively small and simple, and no radical change of lifestyle would be required. The actions included, for example, reducing the consumption of meat, tobacco, and alcohol, and reducing household energy consumption.
- S2: A long term scenario that would only be realistic given fundamental changes both in Finnish society and globally. Almost all unessential consumption was cut out, without risking the ceiling of social foundation (Raworth 2017), in S2. For example, consumption of overseas travel tickets was reduced by 90%, money spent on housing by 35%, and money spent on meat and dairy products by 80%.

The reduction percentages were the same for the average household and for the 5th quintile. For the 1st quintile, the reduction percentages were accustomed so that eventually they spent the same amount of money on consumption categories as an average household, with the exception of health- based reductions (tobacco and alcohol, unhealthy food), household energy savings, and personal transport.

4.1.2 Main findings and contributions

On average, a Finnish household spent €37,551 in 2016. The biggest consumption categories and their percentages of the expenditure were: housing (30.6%), transport (15.5%), miscellaneous goods and services (13.3%), and food and non-alcoholic beverages (11.7%). For the 5th, i.e., the richest, quintile, the order was almost identical, though recreation and culture had a slightly larger share (10%) of the expenditure than food and non-alcoholic beverages (9.4%). They also spent a slightly smaller percentage on housing (28.4%) and a slightly bigger percentage on transport (17.6%) as compared to an average household. The 1st quintile spent a higher percentage on housing (37.3%), and food and non-alcoholic beverages was the second largest consumption category (13.2%). The other largest categories were transport (10.6%), and miscellaneous goods and services (9.5%).

In scenario 1 (Figure 2), the annual savings of an average household added up to €3445; savings for the 5th quintile added up to €5383 and were €1135 for the 1st quintile. The largest monetary savings for both an average household and the 5th quintile were in transport and food and non-alcoholic beverages. The total savings from these two categories added up to €1898 for an average household and €2866 for the fifth quintile; these numbers represent 53–55% of the total potential savings. For the first quintile, the largest savings were in alcoholic beverages and tobacco and food and non-alcoholic beverages, adding up to €736 and 65% of the total savings.

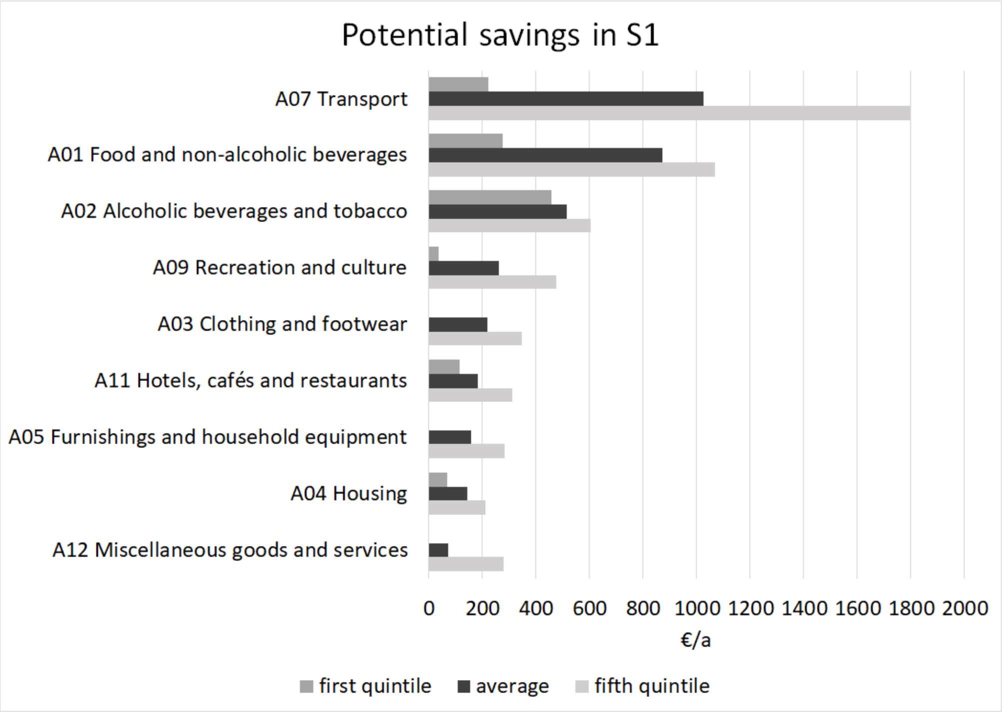

Figure 2. Potential household savings in scenario 1.

In scenario 2 (Figure 3), the annual savings for an average household would be €15224; savings for the 5th quintile would be €24367 and €3299 for the 1st quintile. In this scenario, the largest savings for an average household and fifth quintile were achieved in transport and housing, totalling to €7628 and €12303, representing 50% of the savings. For the first quintile, the largest savings came from transport and food and non-alcoholic beverages, adding up to 1633€, representing 49% of the savings.

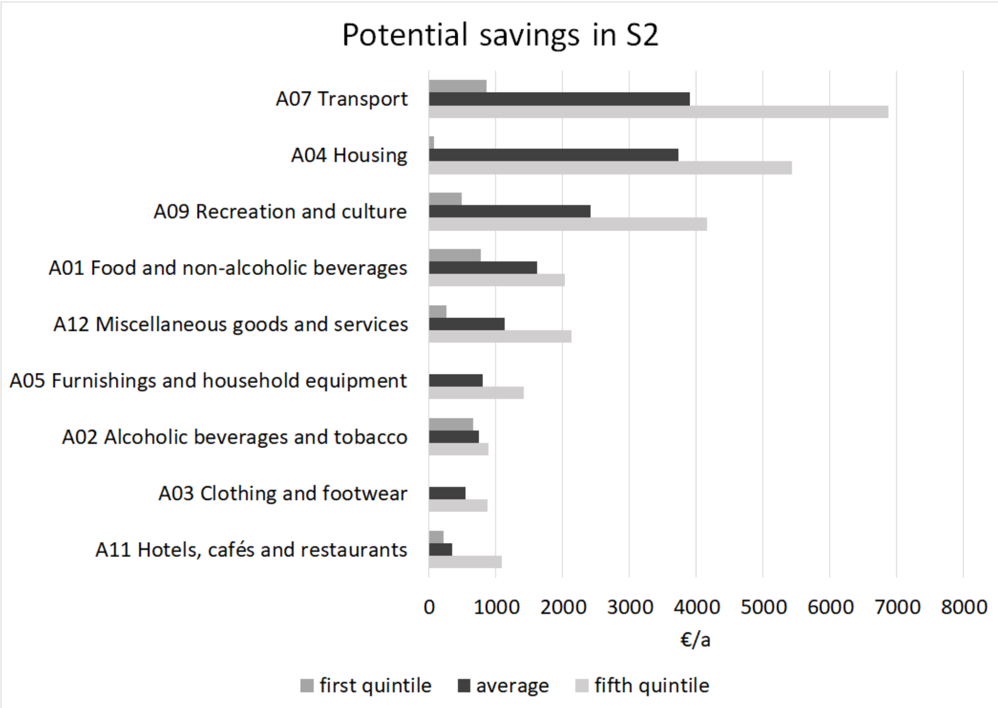

Figure 3. Potential household savings in scenario 2.

In the Finnish context, the annual savings in S1 would total up to €9.2 billion, which could provide funding for powering 60% of Finnish residential buildings with solar energy, thus providing 16% of the annual electricity consumption of Finnish households. The savings from S2, however, would total up to €40.8 billion, or 19% of the Finnish GDP, providing opportunities for significant sustainability enchantment. The findings suggest that Finnish households could indeed impact to sustainability without compromising the fulfilment of their basic needs. In a broader context, if similar reduction percentages and average consumption per capita were applied, the annual savings in the EU would range from scenario 1's 0.92 to scenario 2's 3.9 trillion.

4.2 Publication II

Increasing positive climate impact by combining anti-consumption and consumption changes with impact investing

4.2.1 Objectives and methods

Publication II assumes that households would have more money available as a result of reduced consumption (e.g., Publication I). This available money could lead to rebound effects if it is used in other consumption categories. If this money is deposited as savings into a bank account, the money would most likely be given out as a loan and thus be directed toward investments that could lead to rebound effects. The objectives of Publication II were to mitigate the lack of knowledge on the impacts of household consumption changes and household anti-consumption, and to develop a method to assess GHG emission reduction potential from combined anti-consumption or consumption changes and impact investing. The double impact method is discussed in more detail in 3.4.

4.2.2 Main findings and contributions

The anti-consumption impacts in four consumption areas were estimated based on the household expenditure survey (Statistics Finland, 2018) and Finnish carbon footprints (Salo & Nissinen, 2017). On average, one anti-consumed € equated 0.62 kgCO_2e. More specifically, the coefficients were 0.91 kgCO_2e/€ for housing, 0.73 kgCO_2e/€ for mobility, 0.68 kgCO_2e/€ for food, and 0.42 kgCO_2e/€ for goods and services. If a Finnish household were to decide to save money by reducing unessential consumption by €3445 a year, as calculated in S1 in Publication I, the GHG reductions would be 2085 kgCO_2e annually from the first impact. Further reductions would follow from impact investing. For example, if €3445 were invested in Finnish solar photovoltaics, the secondary impact would be 9990 kgCO_2e. The role of tertiary impact would be rather small; if the interest rate was 2%, further investing the interest would create additional GHG reductions of 180 kgCO_2e. In terms of other impact investing examples presented in the publication, the range of secondary impact for the invested €3445 would vary from 1378 kgCO_2e to 33072 kgCO_2e (variation of 400–9600 kg CO_2e/1000 € invested).

Publication II presented examples of anti-consumption decisions and consumption changes and their potentials for both GHG reductions and monetary savings; those with the greatest impact are presented in Figure 4. The potential of single GHG emission reductions varied considerably; decisions related to housing and mobility led to the greatest GHG emission reductions and the greatest monetary savings. However, these actions would require initial investments and/or additional tasks, such as acquiring a new car or moving to a smaller apartment. Most examples led both to reduced GHG emissions and increased monetary savings; the exceptions were changing a petrol car to a hybrid electric and replacing dairy milk with oat milk, both of which created additional costs. However, these calculations were based on certain brands and included factors like car depreciation, which is higher for an electric hybrid. Therefore, the actual money flow could vary. Similarly, it is possible that calculated monetary savings in some cases would appear as negative in some real-life cases. Some of the examples would be relatively easily done (e.g. switching to renewable energy) whereas some would require daily behavioural changes (e.g. using public transportation or cycling short distances). Some, such as switching to an electric car, would require familiarisation and investments, but not daily behavioural changes. The calculations were based on a microeconomic tool, LCA, and macroeconomic changes were not considered in the calculations.

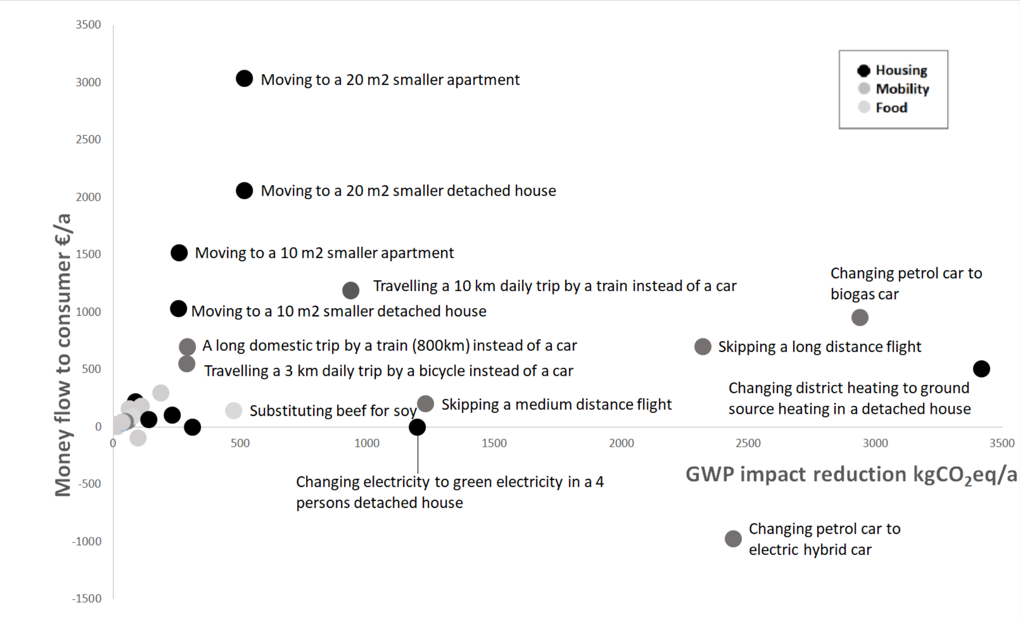

Figure 4. Examples of anti-consumption decisions and consumption changes and their potentials for GHG reductions and monetary savings.

4.3 Publication III

The Role of Consumers in the Transition toward Low-Carbon Living

4.3.1 Objectives and methods

Detached houses account for 27% of the energy consumption of Finland's total building stock. The objective of Publication III was to assess the potential GHG emission reductions in the detached housing sector if consumers were able to overcome barriers related to adopting low-carbon housing solutions. This was done by multimethod research; dwelling owners' willingness to adopt these low-carbon solutions was studied using a questionnaire in three residential areas where the dwellings were primarily detached houses. Relevant data from the questionnaire was combined with a LCA model, which was created to assess the potential GHG emission reductions. In addition, perceived barriers to adopting low-carbon solutions were studied based on the questionnaire.

4.3.2 Main findings and contributions

The main barriers were identified as lack of knowledge related to possible annual savings, costs of implementing low carbon solutions, and relevant technologies. One third of the respondents said that receiving financing would help them transition. The findings indicate that people are willing to switch to low-carbon solutions when they have both a sufficient level of knowledge and available money. If consumers were able to overcome these barriers and implement the most considered solutions, the annual GHG reductions in the studied residential areas would equal 15%. One third of these reductions would be achieved by implementing air-source heat pumps, 26% by ground-source heat pumps, 20% by solar electricity, and another 20% by solar heat. It is notable that half of the respondents had already implemented air source heat pumps; in an area with less previous implementation, the reductions would have likely been larger. The dwellings in the areas were newer than the Finnish average, and the number of houses heated by electricity was approximately double Finland's average. However, the results indicate that cost-effective technologies, such as air source heat pumps, have a role in transitioning to low-carbon housing solutions.

4.4 Publication IV

Pre-service Teachers' Knowledge and Perceptions of the Impact of Mitigative Climate Actions and Their Willingness to Act

4.4.1 Objectives and methods

Publication IV presented the impact of various climate change mitigative actions and examined pre-service teachers' knowledge and confidence in their knowledge of these actions. The correlation of this knowledge with the willingness to take mitigative actions was also studied. Data related to knowledge and willingness was collected using a questionnaire given to pre-service teachers without former formal education on climate change-related issues. As the questionnaire was outlined, GHG emission reduction potentials for 19 mitigative actions were calculated using existing research data. In the questionnaire, the respondents were asked to evaluate the impact of each action using an 11-point scale (0–100, 101–200, ---, 1000+ kg CO_2eq.). When examining the correctness of the answers, a margin of error of ±100 kg CO_2eq was allowed, and thus the range for an answer deemed correct was actually 300 kg CO_2eq. After each question, respondents used a four-point Likert scale to indicate their confidence in their answer. In the second section of the questionnaire, the respondents were asked to rank the extent to which they would be willing to take actions listed in the first section on a five-point Likert scale.

4.4.2 Main findings and contributions

The highest level of knowledge of mitigative issues was in the questions related to housing, 39–50% of the respondents assessed these mitigative actions correctly. Knowledge on diet related questions was relatively high, especially in terms of the impact of becoming vegan or vegetarian (40–42 % correct). The largest variation in correctness was found in questions related to mobility at between 23–39%. The level of knowledge was lowest on questions related to consumption and recycling and lifestyle (11–22%). The respondents over-estimated the impact of low-impact actions (below 500 kgCO_2e), but also underestimated the impact of high-impact actions (over 500 kgCO_2e). The respondents were willing to take low-impact actions, such as recycling, avoiding food waste, and smaller diet-related actions, such as having a vegetarian day once a week. They were least willing to change to a vegan diet (16% willing) and change their travel plans, by, for example, travelling to Lapland by train instead of flying to Barcelona (27% willing).

In general, confidence in knowledge was low; less than 12% of the respondents were confident or somewhat confident in their answers. Confidence in knowledge was found to positively correlate with knowledge of three high-impact actions, although the effect sizes were small. A positive correlation was also found between confidence in knowledge and willingness to act in the case of two actions. This indicates that better knowledge of mitigative actions increases confidence in knowledge. This, in turn, would lead to positive engagement, and an increased willingness to act. Therefore, achieving knowledge with confidence can be thought as an important factor in participating in mitigative actions, even though no correlation was found between knowledge and willingness to act. In light of this, it might be more productive to discuss a knowledge deficit rather than a knowledge–behaviour gap.

5 Discussion and conclusions

5.1 Main findings and discussion

The main objective, supported by four sub-questions, of this thesis was the following:

How and how much can households mitigate climate change by consumption decisions?

Publications I and II studied GHG impacts achieved via anti-consumption and consumption changes. The findings indicate that in scenario I, which could be implemented immediately with rather small changes, an average household could save €3445 annually. In terms of GHG emissions, this would mean reductions of 2085 kgCO_2e every year. In scenario II which would require fundamental changes, the saving potential would be €15224 annually, representing GHG reductions of 9439 kgCO_2e/year. Naturally, household income has a significant effect on how much a household can reduce consumption. As presented in Publication I, households belonging to the poorest Finnish quintile could save €1135 annually and households belonging to the richest could save €5383 in scenario 1. In terms of GHG reductions, this would mean reductions of 704 kgCO_2e/year and 3337 kgCO_2e/year, respectively. It is possible that the anti-consumption potential could be somewhat greater than the calculations show; it is well documented that households tend to under-report some purchases, such as sweets, tobacco, alcohol, and clothing (Steen-Olsen et al., 2016; Bee et al. 2015). Most of these purchases could be categorized as unessential consumption, and therefore reduced. Lower income households have fewer opportunities for anti-consumption, as a larger share of their consumption expenditure is spent on basic needs.

However, as stated by Lettenmeier (2019), carbon footprints per capita should be reduced to 2.5 tCO_2e by 2030 and eventually to 0.7 tCO_2e by 2050 from the current Finnish average of 10.4 tCO_2e. It seems inevitable, then, that reductions from scenario 1 would not be enough to meet these targets. In the sample, based on which the calculations of saving potentials were made, the average household size was 2.02. In theory, this would mean that the annual GHG reductions per capita would be approximately 1042 tCO_2e. In scenario 2, the GHG reductions per capita would approximate 4673 tCO_2e, which would be a significant improvement, but would still not be quite enough. However, anti-consuming and consumption changes can still be regarded as making a significant contribution toward a more sustainable lifestyle. In addition, changes in energy systems were not considered in the calculations. Future improvements in the energy sector will lower household GHG emissions to some extent. Kalaniemi et al. (2020) estimated that the carbon footprint of a Finnish person whose basic needs are covered was 4.8 tCO_2e. For these persons, the target carbon footprint levels are significantly closer with improvements in the energy systems compared to e.g. average households.

Reducing consumption alone might lead to rebound effects in the same consumption category or others. The effects could vary from reducing the mitigation effect by some percentages to backfiring, in which case the GHG emissions of consumption elsewhere would be greater than those originally avoided. Depositing the savings into a bank account would not avoid this, as rebound effects would most likely occur in the form of loans given out by the banks. Findings from Publications I–III suggest either donating or impact investing the saved money in causes supporting sustainability or using the money for things like energy efficiency improvements in the home. In this way, the largest rebound effects could be avoided. Some examples presented in Publication II, such as acquiring an electric car or switching to a ground source heat pump, included high capital costs. As concluded by Ottelin et al. (2015) and Font Vivanco et al. (2014), among others, high capital costs may lead to significantly lower rebound effects or even to negative rebound effects in some cases; the same was true in Publication II. Switching to an electric car reduced annual GHG emissions but created extra costs for the consumer due to the high price of electric cars. These extra costs would be inherently removed from additional consumption or, in the case of double impact, from money available for investments.

The examples provided in the Publication II presented some estimates for impact investing and donations. If an average household invested or donated the money saved in scenario 1 (3445€), the secondary effect would create additional GHG reductions of 1378–33 072 kgCO_2e. Together with the avoided GHG emissions from anti-consumption, this would mean annual GHG emission reductions of 3463–35157 kgCO_2e. While the annual GHG reductions from anti-consumption (first impact) were not enough to achieve the 2030 and 2050 targets, the total GHG reductions might be, depending on the investment. If, on average, every Finnish household (N = 2,677,100) achieved similar monetary savings via anti-consumption and impact invested them, the GHG reductions from anti-consumption would be 5.6 million tCO_2e and the secondary impact would be 3.2–88.5 million tCO_2e.

However, as findings from Publication IV and from Kosak et al. (2020) indicate, people lack knowledge on GWP mitigation actions. They especially tend to over-estimate the impact of low-impact actions and underestimate the impact of high-impact ones. According to the questionnaire, people were more willing to take low-impact actions that generally do not have such a big influence in daily life. The results indicated that people do not have high knowledge confidence; at the most, 12% of respondents were confident or somewhat confident in their answers. However, knowledge confidence was found to positively correlate with knowledge in some questions. A positive correlation was also found between confidence of knowledge and willingness to act for some questions. These results might indicate that people are more willing to take GWP mitigation actions when they are confident in the impact.

5.2 Limitations

This thesis aims to provide information on households' potential to mitigate climate change by their consumption decisions. As with any research, there are limitations in the study. Firstly, the research was carried out in the context of Finland. The survey of Publication III was distributed to people living in detached houses in specific residential areas. While the sample represented the population of these areas quite adequately, the representation of Finns who live in detached houses would be weaker. For the purposes of this thesis mostly the potential of energy efficiency improvements was utilized. Thus, as the houses of the sample were on average newer than Finland's average, it can be estimated that the potential for improvements in the Finnish population would not at least be significantly lower. The survey questions related to perceived barriers were close-ended questions which might have led to different results than open-ended questions would have. Similarly to Publication III, the survey of Publication IV was distributed to a limited sample of people. The sample consisted of pre-service teacher students who participated in a course of Education for Sustainability. The respondents were not asked for their socio-economic background, but they were receiving tertiary education and it can be assumed that on average they were young adults. Thus, in terms of socio-economic background the sample did not represent Finnish population well. However, as the respondents had not yet received education on the topic, it can be assumed that they somewhat represent Finns' knowledge on the topic. Both of the surveys offered primary data for this thesis.

The calculations to estimate how much households could reduce their consumption in monetary terms were made on publicly available statistical data on household consumption, thus being secondary data. The calculations were based on average consumption expenditure of average households, and households of first and fifth quintiles. No other socio-economic factors than income were considered. Thus, it needs to be acknowledged that the presented potentials across categories vary a lot even within households belonging to the same income group. For example, households in rural regions are capable to reduce their driven kilometres only to some extent but they might be able to reduce their consumption in some other categories more than households in urban areas.

As the aim of this thesis was to show that households do have possibilities to mitigate climate change, and to estimate households' potential in doing so, the calculations were made on microeconomic level. The macroeconomic changes that would follow are acknowledged but not further discussed in this thesis.

5.3 Implications and future research

In Publication II, the double impact method was created and tested. This method does not take systemic changes into consideration, although they could alter both potential monetary savings and potential GHG reductions. Instead, the method presents the potential for GHG reductions calculated based on current knowledge. Therefore, further research to evaluate how these changes and factors like time would affect the double impact potential is needed. The context of this thesis was Finland, and the results can cautiously be broadened to other similar countries. However, it would be a point of interest to perform similar calculations in the context of other countries.

It is inevitable that if anti-consuming and impact investing suggested in the method would become mainstream, changes would occur on macroeconomic level over time in addition to the microeconomic levels discussed in this thesis. The relations between these levels would need further consideration. For example, a recent study shows the potential of renewable energy projects in creating millions of new jobs globally (EY-Parthenon, 2021). It would be a point of interest to study, to what extent is sustainable economic growth possible. Another direction of further studies could be the possible role of degrowth related to double impact framework. If people radically reduced their consumption, they would at some point end up in a situation where they could reduce their working hours instead of impact investing the money saved. In the current economic system this would lead to a recession and weaken the welfare state.

However, solving the sustainability crisis should be prioritized over debating whether economic growth can be infinite. Also, it is nearly impossible that anti-consuming and impact investing would suddenly become so popular that an economic downturn would occur because of them. Thus, in comparison to the current situation, the double impact effect should start to be taken into consideration at policy levels. Firstly, it would benefit individuals whose amounts of loans have been steadily growing (European Banking Authority, 2020). Secondly, it has benefits on national and global levels via reduced global warming potential impacts. Therefore, people should be encouraged to reduce their unessential consumption and to impact invest the money saved. This would be one way for fast reduction of GHG emissions which is highly needed. This could be done, for example, by presenting fiscal incentives, similarly to purchase subsidy for electric vehicles.

In the double impact method, the second impact only considered sustainability supporting investments, whereas also reverse impacts were considered for the tertiary impact. Similarly, the method could be used for assessing possible rebound effects created as the second impact. The method was created and tested to assess global warming potential impacts, but it could similarly be applied and further developed to the assessment of other environmental impacts. Also, evaluating co-benefits and trade-offs related to sustainable development goals, for example, or environmental impacts other than GWP would be required to fully understand the method's potential. In the development of the method, ways in which households could be inspired to actually impact invest their savings rather than consuming them were not considered. Thus, future research could focus on how to ensure, whether technically or otherwise, that saved money from consumption is directed toward impact investing. As the double impact method is limited to the current situation, it does not consider other future benefits than GHG emission reductions. Therefore, future research could also focus on how the benefits created for future generations could be considered in the method. Despite the limitations of the double impact method, it is a good tool for assessing the combined impact of anti-consumption or consumption changes and their subsequent impacts.

Publications II, III, and IV mostly concentrated on categories of mobility, housing, and food, although it has been documented that goods and services cause 36 % of an average European consumption-based carbon footprint (Ivanova et al., 2017). In publication I these categories were considered while calculating the monetary potential of anti-consumption. However, in other publications these categories were discussed only briefly, e.g. the double impact framework examples included only two cases from the category of goods and none from the category of services. Therefore, further testing the double impact framework in these sectors would be needed. Related to the category of goods, the possibilities of acquiring recycled goods over new ones was not covered in the thesis. As recycling and upcycling are receiving growing interest, future research could consider these in addition to absolute reduction of consumption.

The results of Publication IV indicated that higher knowledge regarding GHG mitigative actions might be an important factor in engaging people therein. However, this was not actually tested, as no post-class questionnaires were made. Therefore, future studies should also include questionnaires that would be presented to the sample group after they had received education on climate change and climate change mitigation. This might help determine the best ways to educate people in order to enhance their willingness to act on this important issue.

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Publication I

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The Economic Potential to Support Sustainability through Household Consumption Choices

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Abstract: The amount of money that could potentially be saved by households by reducing unnecessary consumption and directed to sustainable investments without compromising the social needs in Finnish households was studied. The study was conducted by using statistical data and by creating short- and long-term scenarios to assess potential savings resulting from changes in household behaviour. According to the results, a Finnish household could save and subsequently allocate an average of €3400–€15,000 annually to invest in sustainability. The greatest potential for preventing unnecessary consumption is related to (1) food and drinks, and (2) transportation. In the long-term scenario, reducing expenditures in the category of housing also provides opportunities for high savings. A significant share of the saving created by sustainable patterns of consumption can be directed for example to investments in renewable energy.

Keywords: sustainability transition; consumer; household consumption expenditure; scenario

1. Introduction

The world is currently facing challenges calling for immediate action. The climate is changing rapidly, and even though globally emitted carbon dioxide emissions were levelling for three years, the emissions are growing again [1,2]. According to Figueres et al. [3], humankind has three years to safeguard the climate by decreasing the amount of greenhouse gas emissions. Otherwise, the temperature goal of the 2015 Paris climate agreement will be nearly unobtainable, and achieving the UN Sustainable Development Goals will be extremely difficult [3].

A solution to the sustainability crisis does exist. In fact, scientists have offered a variety of possible pathways [3], but large-scale concrete results are lacking. The Paris Agreement, an accord to curb greenhouse gas emissions [4], is a step forward and offers the world a roadmap in the right direction. Action must be taken by entities and individuals at all levels: nations, companies and corporations, cities and municipalities; and above all, individual citizens. It is often thought that actions promoting sustainability are costly, especially when it comes to individual customers and the micro level in general [5–10]. However, societies and consumers are already spending a great deal of money on operations with minor importance for human well-being. Today, the environmental discourse seems to embrace two built-in assumptions used to downplay consumer environmental responsibility.

The first assumption is that the possible role of consumers in resolving the sustainability crisis is often incorrectly considered to be small [10–13]. However, for instance, in Finland, the greenhouse gas emissions from private household final consumption (later on referred to as household consumption) amounted to 47.9 million tonnes of CO_2-eq in 2012 [14]. The amount includes greenhouse gas emissions from production and distribution chains, and from the consumption use of products [14]. According to Seppälä et al. [15], individual consumption accounted for 68% of GHG emissions caused by the domestic final use of products on the Finnish level. Housing causes roughly one-third of the total household-related emissions [14], mainly because of the considerable amount of energy needed for the heating of homes in northern latitudes. In 2012, the household sector accounted for 21% of the total end-use of energy in Finland, space heating comprising 71% of the total residential use [16]. Furthermore, sustainability in other consumption sectors, such as transportation or food, is compromised because of the excessive consumption patterns. Material-intensive consumption has been identified as a major threat to sustainability in many studies and contexts [17–19]. Consumer choices may potentially have a high impact on production and on society in general, as the world economy is based on consumption. The final consumption expenditure of households in Finland accounted for 52% of the total gross domestic product (GDP, expenditure approach) [20].

The second assumption is that environmental preservation is costly, and sustainable products are too expensive compared to conventional choices [5–10]. However, it could be argued that resolving the sustainability crisis should be highly prioritised, and as this requires immediate action, cost should not be the determining factor. Furthermore, from the standpoint of sustainability, an average Finnish citizen's consumption is clearly on "overshoot". Basic needs are met relatively easily, and more money can be allotted towards unnecessary consumption than ever before. The term "unnecessary consumption" is used in this paper to refer to, in the context of the Western welfare society, consumption that does not support the fulfilment of basic needs. In this paper, basic needs refer to Raworth's Donught's [21] inner ceiling of the social foundation, which consists of health, education, networks, income and work, political voice and social equity. An example of unnecessary consumption could be the excessive usage of unhealthy foods (e.g., sweets) or drinks (e.g., soft drinks), superfluous electric kitchen appliances (e.g., popcorn machines), or any material-intensive luxury product.

Environmental impacts of the household expenditure structure in the EU were studied by Liobikienė & Mandravickaitė [22]. Of the consumption categories studied, food and beverages, transport, and housing were found to be the most polluting ones in terms of greenhouse gas emission and acidifying compound emission intensities. The three consumption categories of clothing and footwear, furnishings and household equipment, and restaurants and hotels were found to be moderately polluting. The lowest intensities of greenhouse gas emissions were attributed to the remaining five categories of health, communications, education, recreation and culture, and miscellaneous good and services. Similar results were obtained by the European Environmental Agency (EEA) [23]. Liobikienė & Mandravickaitė [22] point out that it is not possible to achieve more sustainable consumption patterns by only changing the household consumption structure. Governmental policies affecting technological development and inducing more sustainable production and consumption are required as well.

Ivanova et al. [24] analyzed the environmental impact of household consumption using data from 43 countries. Similar to Liobikienė & Mandravickaitė [22], they also found that mobility, shelter and food are the most influencing categories for environmental footprints in terms of greenhouse gas emissions, land use, water use and material use. Similarly, Poom & Ahas [25] found shelter, transport, and food and non-alcoholic beverages to be the three main causes of the carbon load of household consumption in Estonia. Kalbar et al. [26] assessed lifestyle aspects such as the choice of diet, the use of a private car and the household size, and found these aspects to have a significant influence on consumption related environmental impacts of Danish. Girod et al. [27] reviewed the carbon footprints of products in five main categories including food, shelter, transportation, goods and service. According to their findings, in all of the categories, there are consumption options, which enables the limiting the global temperature rise to 2 °C.

This paper focuses on Finnish households' economic potential to contribute to a solution to the sustainability crisis. The main goal is to estimate the amount of money that could be directed toward sustainable investments while staying above the ceiling of a social foundation. First, in this paper, the expenditure structure of an average Finnish household is presented and analysed to find out what portion of disposable income is used to cover the basic needs [28] in the context of the Finnish welfare society, and how much is available for purchasing other products and services referred to as unnecessary consumption. This latter proportion of spending is examined more closely, as its necessity may be questioned from the sustainability perspective. A calculation model is then created to indicate how customers could change their spending habits and to approximate the amount of economic potential that could be directed towards sustainable investments. In addition to an average household, the calculation model is applied to the first and fifth income class quintiles to assess the different potentials the income classes hold. This paper focuses on the calculation of the potential amount of money instead of focusing on ways of how to encourage consumers to adopt the change. These ways, in reality, are manifold and studied for example by Sheth et al. [29], Thøgersen [30], de Boer et al. [31], and Byerly et al. [32]. Presumably, households are not likely to reduce their consumption but rather shift towards more sustainable choices. At the end of this paper, a rough calculation is presented where households purchase solar panels or EV's with the total savings. More generally, investing in sustainable businesses could be profitable for both customers and the environment.

This paper answers the following research questions:

- How much an average Finnish household could reduce its consumption of disposable income by reducing unnecessary consumption while simultaneously reducing the environmental impact?
- What is the economic potential for making sustainable consumption choices in Finland?

2. Materials and Methods

2.1. Background Information

In 2016, the average Finnish household spent €37,551, and the number of households was 2.68 million [33]. Hence, the total expenditure of households accounted for €101 billion. The consumption of Finnish households has been studied in terms of the classification of individual consumption by purpose (COICOP) and divided into 12 categories, A01–A12 (Table 1). The categories of housing, transport, and food, and non-alcoholic beverages have the largest shares of the total expenditure as well as the highest environmental impacts, as stated earlier. By this account, it is clear that the consumption pattern of Finnish households causes a major environmental burden.

Table 1. The consumption structure of an average, 1st and 5th quintile of Finnish households in 2016 [33].

	Average		1st Quintile		5th Quintile	
	€/a	%	€/a	%	€/a	%
Aver. household consumption expenditure	37,551	100.0	18,545	100.0	59,453	100.0
A04 Housing	11,480	30.6	6909	37.3	16,869	28.4
A07 Transport	5808	15.5	1964	10.6	10,462	17.6
A12 Miscellaneous goods and services	4998	13.3	1766	9.5	8599	14.5
A01 Food and non-alcoholic beverages	4381	11.7	2457	13.2	5606	9.4
A09 Recreation and culture	3445	9.2	1516	8.2	5943	10.0
A11 Hotels, cafes and restaurants	1769	4.7	728	3.9	3483	5.9
A05 Furnishings and household equipment	1595	4.2	603	3.3	2826	4.8
A06 Health	1257	3.3	725	3.9	1758	3.0
A03 Clothing and footwear	1091	2.9	545	2.9	1742	2.9
A08 Communication	881	2.3	586	3.2	1110	1.9
A02 Alcoholic beverages and tobacco	792	2.1	698	3.8	960	1.6
A10 Education	55	0.1	48	0.3	97	0.2

2.2. Data Collection

The consumption expenditure of Finnish households was explored at a more detailed level of COICOP classification than that expressed in Table 1. The data were obtained from an online database maintained by Statistics Finland [33]. The data were used in their original format, in which the 12 main consumption categories are divided into several subgroups. Depending on the main category, these subgroups are further divided as many times as required to describe an exact product or service. The amount of annual expenditure is available separately for each product and service; therefore, it was possible to make specific calculations.

2.3. Calculation Model

In order to estimate the amount of the economic potential in question, a calculation model was created to calculate both the short-term and long-term potential values. Similar scenario methodology has been used e.g., by Bonilla et al. [34]. Every product and service included in the consumption data was evaluated separately to determine whether the product or service was essential to human well-being. If the necessity of any product or service was debatable, a percentage of deduction was defined and applied to the original amount of expenditure. The total economic potential value was approximated by adding up the possible savings of all consumption components. Additionally, background information from relevant entities and other reliable sources was used as a reference to support the choices of the deduction percentages.

No reductions were made in the consumption categories of health, communication and education. Firstly, these categories can be seen as an essential core of any welfare state; and secondly, they represent multiple sectors of Raworth's [21] and Donught's inner ceiling of social foundation (health, education, networks, income and work, political voice and social equity). They are also part of Gough's [35] three basic needs (participation, health, and autonomy). In addition, these categories compose only 5.9% of Finnish household consumption expenditure. In the consumption category of miscellaneous goods and services, no reductions were made for insurance or items falling outside of consumption expenditure, which includes, for example, tax-like charges, membership fees, fines and interest payments, as their necessity and role in the future economy are difficult to predict.

The following two scenarios were formed to calculate the short-term and long-term economic potential values:

- Scenario 1 (S1) describes an incremental situation which may be achieved quickly and easily over the next couple of years. In S1, the savings can be reached with rather simple and small actions, and a radical change of lifestyle is not required. These small actions include for example reducing the consumption of meat and reducing household energy consumption by performing small energy-saving actions.
- Scenario 2 (S2) is a long-term-goal scenario, which is also realistic provided that Finnish society is ready to implement fundamental changes. To be able to achieve the S2 situation, considerable willingness and action to shift towards more sustainable lifestyles would also be required globally. In S2, the ceiling of the social foundation is not risked, but almost all unnecessary consumption has been cut out. S2 may be viewed as describing the target for the next 15–20 years, as it requires significant changes at many societal levels.

Figure 1 presents how the total consumption expenditure is reduced in Scenario 1 and in Scenario 2. The ceiling of the social foundation is not risked in either of the scenarios.

Next, both of the two Scenarios are presented by category and quintiles with descriptions of the done reductions, reasoning, and reduction percentages. The changes in consumption can be either qualitative or quantitative. In our scenarios, the changes are quantitative with the exception of category A01 Food and non-alcoholic beverages in which the changes are partly qualitative. The deduction percentages can be found from Table 2. For category A01, Food and non-alcoholic beverages reductions are made in the consumption of meat, dairy and egg products, and unhealthy foods such as foodstuff containing lots of sugars, salt, and/or saturated fats. Reductions are based both into health and environmental sustainability claims. In Scenario 2, consumption of coffee, tea, and cocoa is also reduced. In category A02 (Alcoholic beverages and tobacco), the reductions are health based in both scenarios. In category A03 (Clothing and footwear), the reductions are based on the current amount of textile waste and reductions on the synthetic material used. In category A04 (Housing), the reductions are based on reductions on residential energy consumption, and room density per person. For category A05 (Furnishing and household equipment), the reductions are based on material footprint and the decreased need for furnishing following from the decreased floor area. In category A07 (Transport), the reductions are achieved with decreased purchase and usage of private vehicles and decreased purchase of overseas travel tickets. For category A09 (Recreation and culture), for example, the decrease in package tours and cruises abroad was estimated. For category A11 (Hotels, cafés and restaurants), the reductions are based on the reductions in unhealthy foods and alcoholic beverages, and accommodation services. For category A12 (Miscellaneous goods and services), a reduction in personal care and in consumption abroad were assumed.

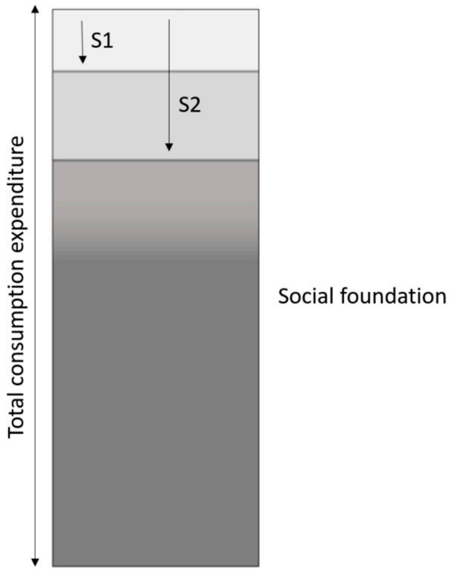

Figure 1. The reductions of S1 and S2 from the total consumption expenditure.

As meat consumption was decreased in both scenarios, a rough calculation was made to estimate the necessary addition in plant-based protein intake. The average price per gram of protein was studied in eight common meat products and plant-based products. The nutritional information and prices were obtained from a Finnish retailer's online service, Foodie.com [36]. According to the calculation, the average price of a plant-based protein gram is 32% lower than that of meat protein. In the final expenditure calculation, a conservative estimate of 25% was used, in which case 75% of the hypothetical savings from meat was used to purchase plant-based products. Possible other feedback loops were not identified and considered in this study.

In addition to calculating the Scenarios with a consumption structure in an average Finnish household, the Scenarios were also calculated for the first and fifth quintiles of income classes. The reductions for the first quintile were done so that the money available for consumption in each category equals the money available of an average household. This does not apply to unhealthy foods, alcohol and tobacco as the reduction are health based. Additionally, the reduction percentages are equal to an average households in categories A072 Operation of personal transport equipment and A045 Electricity, gas and other fuels because of there are alternative ways for private car use, and small changes in electricity use are generally doable in lower income households as well. For the fifth quintile, the same reduction percentages are applied as to average households. The reduction percentages for the scenarios are presented in Table 2.

More detailed description of the deduction percentages used in the calculation model and background information can be found in the Supplementary Materials, a link to which is provided at the end of this paper.

Table 2. The reduction percentages for S1 and S2 for an average household and first and fifth quintiles.

Consumption Category	S1			S2		
	Average	1st Quintile	5th Quintile	Average	1st Quintile	5th Quintile
A01 Food and non-alcoholic beverages						
A0112 Meat (ND)	50%	3%	50%	80%	61%	80%
A0114 Milk, cheese and eggs	20%	0%	20%	80%	63%	80%
A0121 Coffee, tea and cocoa				50%	22%	50%
Unhealthy foods *	75%	36–65%	75%	90%	75–86%	90%
A02 Alcoholic beverages and tobacco						
A021 Alcoholic beverages	60%	60%	60%	90%	90%	90%
A022 Tobacco	75%	75%	75%	100%	100%	100%
A03 Clothing and footwear	20%	0%	20%	50%	0%	50%
A04 Housing, water, electricity, gas, and other fuels						
A041 Rental housing				35%	0%	35%
A0421 Housing of owner-occupiers				35%	0%	35%
A045 Electricity, gas and other fuels	10%	10%	10%	30%	10%	30%
A05 Furnishings, household equipment and routine maintenance of the house	10%	0%	10%	50%	0%	50%
A07 Transport						
A071 Purchase of vehicles	20%	0%	20%	75%	0	75%
A072 Operation of personal transport equipment	20%	20%	20%	75%	75%	75%
A0730 Overseas travel tickets	20%	20%	20%	90%	90%	90%
A09 Recreation and culture				70%	32%	70%
A09611S1 Package tours and cruises abroad	20%	20%	20%			
Toys, hobby equipment, major durables for sport and leisure	30–50%	0–15%	30–50%			
A11 Hotels, cafés and restaurants						
Unhealthy foods *, alcohol	50%	50%	50%	90%	90%	90%
A112 Accommodation services				50%	0%	50%
A12 Miscellaneous goods and services						
A121 Personal care	10%	0%	10%	50%	0%	50%
A122 Personal effects				50%	0%	50%
A1271002 Consumption n.e.c. abroad	10%	0%	10%	80%	80%	80%

Note: * incl. soft drinks and processed food containing lots of sugar, salt and/or saturated fat.

3. Results and Discussion

After applying the reduction percentages, the Finnish household's economic potential to support sustainability can be calculated. The results for average households and the first and fifth quintiles by scenarios are presented in Figures 2 and 3.

In Scenario 1, for an average household and fifth quintile, the largest savings in monetary terms are made in the consumption categories of transport and food, which also result in significant environmental impacts. For the fifth quintile, the savings in transport are noticeably higher than in other categories compared to an average household. This is because the quintile spends approximately twice as much on transport than an average household. The consumption categories of food and transport are among the top three in terms of the present household expenditure as well. While housing makes up almost one-third of the total expenditure, the savings in S1 are minor because the only reductions in this category are made in the household energy consumption. A large amount of money could be saved in alcoholic beverages and tobacco as well, according to S1. In other categories, the savings are more marginal. The largest monetary savings for the first quintile are made in the consumption categories of alcoholic beverages and tobacco, and food and non-alcoholic beverages. In some categories, there are no reductions at all.

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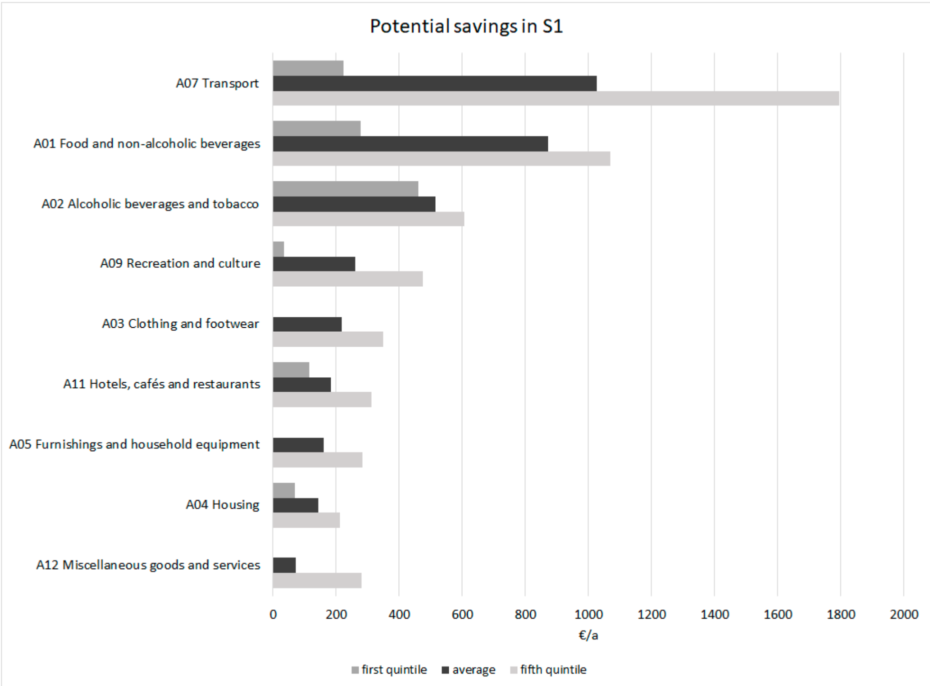

Figure 2. The potential savings in S1 for an average household and the first and fifth quintiles.

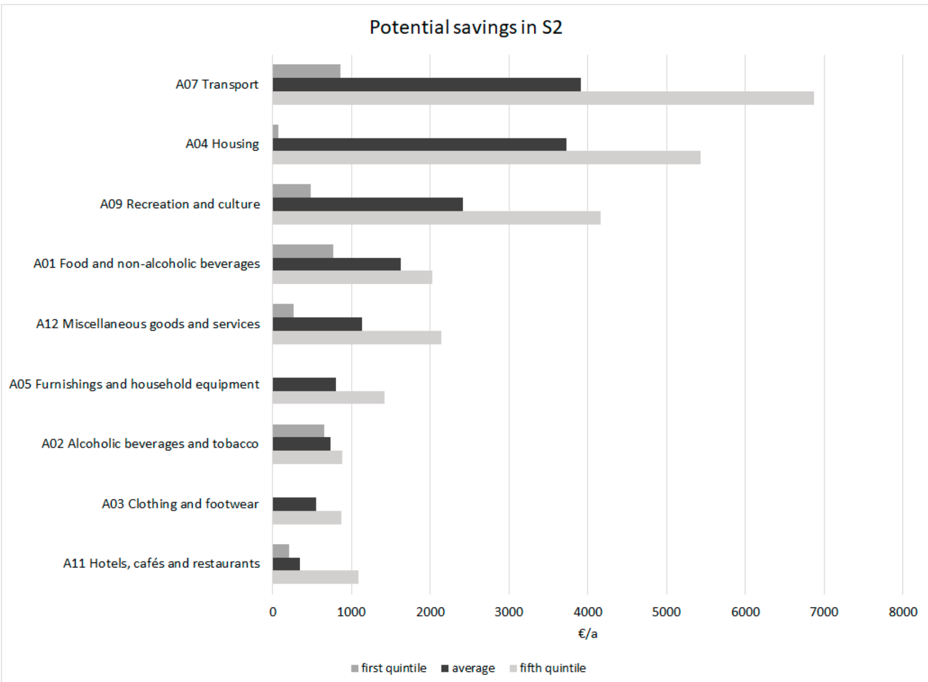

Figure 3. The potential savings in S2 for an average household and the first and fifth quintiles.

Savings in Scenario 2 present a potential future scenario in which the most polluting consumption categories are reduced considerably. For an average household and the fifth quintile, the largest savings are made in the areas of transport, housing, recreation and culture, and food and non-alcoholic beverages. While the recreation and culture category is of a low environmental intensity, it is substantial in monetary terms and broadly consists of unnecessary consumption. Significant savings may also be achieved in miscellaneous goods and services, furnishings and household equipment, and alcoholic beverages and tobacco. The smallest savings are found in the consumption groups of clothing and footwear and hotels, cafés and restaurants, but these groups also represent some of the smallest in terms of the present expenditure.

Whereas for an average household and fifth quintile household there are large savings in the category of housing, there are almost no savings in that category for the first quintile. The biggest savings are made in the categories of transport, food, and alcoholic beverages and tobacco.

In Table 3, the total economic potential values in Scenario 1 and Scenario 2 for an average household are presented. Even though the implementation of expenditure reductions in S1 is not very demanding for individual households, the total amount of economic potential is remarkable. In the case of S2, households are expected to save 40.5% of their expenditure. This is a challenging amount, but it is clear that sustainability cannot be achieved without a drastic shift towards much more frugal lifestyles. With approximately 41 billion €—19% of Finland's GDP [20]—per annum, Finnish households would have the opportunity to enhance sustainability significantly. The potential savings are calculated using the consumption expenditure and euro value of 2016, and the future value of the savings is not considered. In Table 4, the total economic potential values are calculated for the first and fifth quintiles. In S2, the economic potential of a fifth quintile household is 62% higher compared to an average household. The savings of the first quintile household in S2 approximately equals the savings of an average household in S1.

Table 3. The economic potential values for an average Finnish household in Scenario 1 and in Scenario 2.

	2016	S1	S2
Total consumption expenditure, €/a	37,551	34,107	20,327
Economic potential per household, €/a		3445	15,224
Economic potential per household, % of present expenditure		9.2	40.5
Total economic potential in Finland [1] in bn €/a		9.2	40.8

[1] 2.68 million households.

Table 4. The economic potential values for the first and fifth quintile of Finnish households in Scenario 1 and Scenario 2.

	1st Quintile			5th Quintile		
	2016	S1	S2	2016	S1	S2
Total consumption expenditure, €/a	18,545	17,410	15,246	59,453	54,070	34,816
Economic potential per household, €/a		1135	3299		5383	24,637
Economic potential per household % of present expenditure		6.1	17.7		9.1	41.4

According to the results, it could be argued that private households have the opportunity to take a leading role or at least play a significant part in sustainability crisis management. Investment possibilities for the money saved are numerous. Figueres et al. [3] have set six milestones which identify the ideal situation for 2020 concerning energy, infrastructure, transport, land use, industry, and finance. Households could impact all of these categories, either directly or indirectly. The most concrete actions could likely be taken in the energy and transport sectors, as individual households become able to purchase, for example, solar panels or electric vehicles for themselves.

Two rough calculations were made to estimate the potential to support solar energy production or electric private transportation with S1 savings (Table 5).

Table 5. The potential to invest in solar energy production or electric private transportation with Scenario 1 savings.

Solar Energy		
Solar power system [37]	10,00	€
Residential buildings in Finland [38]	1,290,300	pcs
Estimated that 60% of the buildings could be installed with solar power	774,180	pcs
Total price	7.74	bn €
Electric Transportation		
Average price of a new electric car in Finland [39]	38,617	€
Average amount of new car registrations in Finland in 2010–2016 [40]	122,500	pcs/a
Possible new electric car registrations with S1 savings	238,238	pcs/a

The results indicate that, with only small changes in behaviour and consumption expenditure, households have the opportunity to choose to support sustainability with a high financial input. According to the calculations, 60% of Finnish residential buildings could be solar powered in one year with the potential savings from Scenario 1. This represents 16% of the total Finnish electricity consumption in households, as the average annual electricity production of solar panel system is 4450 kWh [37], and the total annual Finnish electricity consumption on housing is 21 TWh [41]. Concerning electric transportation, Figueres et al. [3] suggest that globally, 15% of annual new car sales should consist of electric cars. With the savings from Scenario 1, virtually double the amount of newly registered cars could be purchased as electric vehicles. Investments into solar power, and to some extent into electric vehicles, will be paid back because of reduced operating costs. The earned savings can be used, for example, for further investments in renewable energy. It is also a possibility that some of the savings may be invested into additional free time by, for example, reducing working hours. However, our aim was to focus more on calculating the potential of initial savings instead of discussing further investment opportunities.

While Scenario 1 is achievable without major systemic changes within Finnish society, the situation with Scenario 2 is different. Radical reduction in consumption as we know it will have far-reaching effects on many levels. Transitions must occur everywhere: the global economy and politics must be based on more ecological and humane values than what they are today; the dominance of fossil-fuel based industries must vanish; businesses that destroy nature beyond repair or do not contribute to sustainability in any way, shape, or form must be radically decreased; the concepts of private ownership and materialism must be praised no longer; and more generally, the global mindset and focus should be directed squarely at solutions to the sustainability crisis. As entire industries disappear, jobs must be created elsewhere. This shift will require more than a couple of years, but change must begin immediately.

Liobikienė & Mandravickaitė [22] point out that it is not possible to achieve more sustainable consumption patterns by only changing the household consumption structure. Government policies affecting technological development and inducing more sustainable production and consumption are required as well. Political decision-making can indeed be a major contributor to the change towards a more sustainable society. However, as our calculations indicate, it is indeed possible to support sustainability by changing consumption patterns. Political action should be taken to support sustainable consumption choices and to induce general household-level participation. Examples of possible policies include taxation systems favouring sustainable choices, science-based decision-making or leading by example. The results of the study could also be linked to the managerial use of sustainable factors [42] or collaborative economy analyses [43]. In the EU level, the potential savings are even higher. According to a rough calculation based on an average consumption per capita in EU [44], the total household consumption is approximately 9.2 trillion €. If similar redirection of consumption potential than in Finnish S1 and S2 is assumed, the economic potential in EU level would be from 0.92 to 3.9 trillion €. The study of household expenditure in other countries is necessary in order to understand the economic situation globally.

This research was carried out using the average consumption pattern of Finnish households. The first and fifth quintiles of income classes were studied as well. There are major differences in the relative and absolute potentials between these quintiles. It is possible that with the fundamental changes needed in Scenario 2, the savings achievable by the fifth quintile could be even higher.

Much of the existing research [22,24–26] conclude that housing, transportation and food are the three most polluting consumption categories in terms of greenhouse gas emissions. Categories of transportation and housing are also the ones which provide the biggest possibilities for monetary savings in S2. Category of food and non-alcoholic beverages is also among the four biggest potentials, whilst the category of recreation and culture has the third biggest potential. For future research, it would be a point of interest to assess the greenhouse gas reductions achieved by reducing unnecessary consumption. Additionally, what should be done with the saved money in order to avoid consumption shifting from unsustainable consumption category to another unsustainable use should be studied. Another point of interest would be performing an analysis for a scenario in which the households shift their spending towards more sustainable categories instead of mostly reducing their consumption. Additionally, a topic for future research could be studying the possible consumers' decisions which would not only benefit the environment but also enhance individuals' well-being such as reducing housing area and spending the amount saved for recreational and cultural activities that do not require a lot of resources.

4. Conclusions

In this study, two scenarios were formulated to estimate the amount of money that Finnish households could use to support sustainability after changing their consumptive behaviour. Scenario 1 only requires relatively easy and small changes in household consumption, whereas Scenario 2 requires households to change their lifestyles more radically. In S1, an average household could save €3400 annually, which translates into €9.2 billion in total in Finland. In S2, the economic potential of an average household is €15,000 per year, adding up to €40.8 billion in total. The largest savings would be realised in the four consumption categories of transport, housing, recreation and culture, and food and non-alcoholic beverages. Out of these categories, transport, housing and food are the three most polluting consumption categories in terms of greenhouse gas emissions as well. Therefore, a relevant topic for future research is to assess the greenhouse gas reduction impact, which is created together by reduced consumption and money directed to sustainable investments.

The results of the study suggest that Finnish households could significantly impact sustainability without compromising the fulfilment of basic needs in the context of the Finnish welfare society. In Scenario 1, savings can be reached with rather simple and small actions, and a radical change of lifestyle is not required. With the amount saved in Scenario 1, solar power could be installed in 60% of Finnish residential buildings, which is more than all the detached houses of Finland. Alternatively, all new car registrations could be for electric cars. In Scenario 2, a considerable willingness and action to shift towards more sustainable lifestyles would be required, and fundamental changes would be needed as almost all unnecessary consumption would have to be cut out. Some businesses would have to vanish, but there would be a need for new ones. This change will take time, but the transition should start immediately. Based on an average consumption per capita in the EU, the savings of Scenario 2 would add up to 3.9 trillion €. The results show that although governmental policies are needed to support sustainability, the consumption choices of households indeed have a significant role in safeguarding the planet.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/11/3961/s1, Table S1: Deduction percentages used in the calculation model for Scenario 1, Table S2: Deduction percentages used in the calculation model for Scenario 2.

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Publication II

Claudelin, A., Uusitalo, V., Hintukainen, I., Kuokkanen, A., Tertsunen, P., Leino, M., and Linnanen, L.

Increasing positive climate impact by combining anti-consumption and consumption changes with impact investing

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RESEARCH ARTICLE

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Increasing positive climate impact by combining anti-consumption and consumption changes with impact investing

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Abstract

Household consumption leads to global warming potential impacts, for example, via energy consumption, production processes, and transportation. About 72% of global greenhouse gas (GHG) emissions are related to household consumption. Some of this consumption is nonessential and could therefore be reduced, leading to decreased GHG emissions. There is, however, a risk of a rebound effect if money saved by reducing consumption is used or invested in a way that leads to GHG emissions elsewhere. Therefore, in efforts to further mitigate climate change via anti-consumption behavior or changes in consumption, it should be ensured that money saved is impact invested in climate change mitigating actions, thus creating a secondary impact. Previous studies have not considered the need to account for this double impact dynamic in climate change mitigation. An approach to calculate potential for double impacts is developed in this work. The article also presents quantitative GHG emissions reduction potentials, for example, some anti-consumption actions and consumption changes as well as for possible impact investments.

KEYWORDS
anti-consumption, climate change mitigation, global warming potential, household consumption, impact investing

1 | INTRODUCTION

To stay within the planetary boundaries of the safe operational space for humanity presented by Rockström et al. (2009) and Steffen et al. (2015), global resource use has to be decreased to a more sustainable level. The Intergovernmental Panel on Climate Change (IPCC) report on limiting global warming to 1.5°C above pre-industrial levels demands action in all areas of human activity (IPCC, 2018). One of the actions needed is more responsible and sustainable consumption (Southerton & Welch, 2018). The majority of global greenhouse gas (GHG) emissions are related, directly or indirectly, to household consumption; the share of GHG emissions related to household consumption is estimated to be 72% of global emissions (Hertwich & Peters, 2009). Household consumption choices impact climate change, for example, via goods and services production, energy usage, logistics, and waste handling. According to World Bank (2018) figures, global consumption has increased constantly over the last decades. In the European Union (EU), production-based CO_2 emissions have decreased the targeted 20% to below 1990 levels (European Environment Agency, 2018), but if the simultaneous growth in imported carbon is considered, total emissions have remained almost at the same level as in 1990 (Buy Clean, 2018). Based on the McKinsey Global Institute's (2016) report, global consumption will continue to grow also in the near future. A dramatic change is that the main driver behind the growth is no longer population increase but greater spending by the individuals (McKinsey & Company, 2016). According to Druckman and Jackson (2016), household GHG emissions are highly dependent on household consumption. In developed countries, a significant share of consumption can be regarded as nonessential and could be reduced without compromising basic human needs. Claudelin et al. (2018) show that the Finnish households could, with rather simple changes, save total of €9 billion annually by reducing unessential consumption.

Anti-consumption can be seen as one option for households to reduce their sustainability impacts. Sustainability oriented anti-consumption is mainly driven by acts of reduction, rejection, and reuse (Black & Cherrier, 2010). Lee and Ahn (2016) review literature on anti-consumption and find that most anti-consumption research has been related to motivation. They further conclude that the consequences of anti-consumption have received less consideration. Sudbury-Riley and Kohlbacher (2018) surveyed 457 adults, and their work presents that social reasons are a greater driver for anti-consumption than ecological reasons, although both aspects are seen as important. According to Peyer et al. (2017), voluntary simplifiers, that is, consumers who voluntarily reduce nonessential consumption, buy more green products and exhibit greater environmental and sustainability awareness than other consumer groups. The research reports that one-sixth of the German population can be considered simplifiers to a lesser and greater extent. In this article, anti-consumption may also refer to changes in consumption behavior, for example, substituting meat for plant based proteins. Our argument is that households can reduce their sustainability impact by reducing nonessential consumption through anti-consumption. This anti-consumption behavior can be an active and conscious lifestyle change or an unconscious change. This article focuses on the potential impact of anti-consumption rather than motivations for anti-consumption and consumption changes, which have been studied, for example, by Rezvani et al. (2018), Gul Gilal et al. (2020), Hurth (2010), and Nguyen et al. (2018). As the article focuses on GHG emissions, it does not cover all aspects of sustainability, but focuses on achieving the Sustainable Development Goal (SDG) number 13 (Climate action). Causal interactions among SDGs have been studied elsewhere, and the result of systematic compilation is illustrated in Global Sustainable Development Report (2019). Most of the articles have studied co-benefits to be harnessed, whereas trade-offs to be addressed have not been studied as much. The focus of the article is on developed countries as the citizens of those have more opportunities to make consumption changes than citizens of developing countries.

Reducing consumption alone does not ensure a more sustainable future. In this work, we assume that as a result of reduction in consumption, households would have more money available. Money saved could be used either for investments or deposited in a bank account. In this case, money would typically be given as a loan by banks and directed to investments. Consequently, reduction in household consumption could lead to rebound effects via investments as banks might loan money for projects and companies contributing to climate change. The household savings rate in the EU currently varies from −1% (Cyprus) to 21% (Luxembourg) with the EU average being 11%. Households use their savings mainly for the purchase and renovation of dwellings (Eurostat, 2018). Thus, money is channeled back to the consumption side and there is a risk that its use leads to additional sustainability impacts. However, sustainability impacts may also be positive, for example, through investment in energy efficient home improvement (Claudelin et al., 2017; Dobler et al., 2018). According to Statistics Finland (2018a), Finnish household savings are allocated to the following categories: bank deposits 30%, other stocks and shares 27%, insurance 20%, quoted shares 12%, investment funds 7%, and others 5%.

In addition to consumption, another major challenge from the climate change perspective is transition from fossil energy to renewable energy sources. The transition requires huge investment in new energy infrastructure (Alfredsson et al., 2018). According to International Energy Agency (2014), investment totaling €35 trillion is needed by 2050 to enable the transition to a clean energy future. IPCC (2018) estimated that global annual investment need in the energy system are approximately 2.38 trillion USD_{2010} between 2016 and 2035, which equals approximately €42 trillion over a 20 year period. The European Commission (2018) estimated that in the EU the annual gap in current emissions mitigation investments is €180 billion. To put this figure into context, EU households spend approximately €9.2 trillion on consumption annually (Eurostat, 2017).

Impact investing is a type of investing which generates social and environmental impact in addition to providing financial returns (Global Impact Investing Network, 2018). Mudaliar, Bass, and Ditrich (2018) conducted a survey of actors in the impact investment sector and, based on information from respondents, found that impact investing had grown to $228 billion. They also reported that most of the investors plan to increase their investments. Directing even a small share of household consumption to sustainability supporting investments could make a considerable contribution to sustainability transition. Additionally, increased impact investment would also ensure that reduction in consumption does not lead to GHG emissions through rebound effects generated in the investment sector.

The aim of this article is to mitigate a lack of knowledge on household anti-consumption and consumption change impacts, and to develop a method to assess GHG emission reduction potential from combined anti-consumption or consumption change and impact investing. The method is tested using Finnish households as a case example, and the method is applicable for developed countries.

2 | DEVELOPING THE DOUBLE IMPACT ASSESSMENT FRAMEWORK

In this work, the term "double impact" is used to describe the effects of the combination of anti-consumption or consumption behavior change and impact investing. Double impact thus includes both impacts from anti-consumption or consumption behavior change and impacts from impact investing. In theory, the methodology developed in this article could be applied for analysis of many different sustainability impact categories but in this work only global warming potential (GWP) impacts through changes in GHG emissions are calculated. This work does not take into consideration how possible co-benefits and trade-offs related to other systems might alter the results, and therefore the method presents rather a potential for GHG reductions calculated with current knowledge.

2.1 | First impact (anti-consumption or consumption change impact)

The primary possibility for consumers to decrease GHG emissions is to reduce consumption (quantitative change) or alter consumption patterns (qualitative change). Reduced levels of overall consumption influence overall demand, which affects levels of production. However, this impact is rather mid- or long-term, and GHG emission reductions will happen over time. Some qualitative changes, on the other hand, for example, cycling instead of driving, have immediate effects in the short term through reduced fuel combustion. During the life cycle of goods, GHG emissions are generated in logistics, retail, use, and dispose phases in addition to during production. Consequently, GHG emissions have to be taken into account from the whole life cycle perspective, that is, life cycle assessment (LCA). Although GHG emissions vary considerably between different products and services, there is quite a lot of data already available on life cycle GHG emissions of different goods and services.

2.2 | Second impact (investment impact)

Banks create money by loaning and investing the money that consumers have deposited, that is, their savings. To ensure that savings from consumption lead to GHG emission reductions, it has to be ensured that money will not return to unsustainable consumption. A solution is that saved money is donated or impact invested to sustainability supporting actions. Such investments can, for example, be related to creation of carbon sinks or the production of renewable energy. GHG emission reductions through impact investing are challenging to evaluate as impacts typically happen over different time scales.

2.3 | Tertiary impact (reverse or additional impact)

Investments usually gain interest over time. It is up to the consumer to decide what they wish to do with interests gained. If consumers use the interest for further investment, they may achieve additional GHG emission reductions. On the other hand, if the interest returns to the consumption side, it will likely cause GHG emissions. Also, if consumers withdraw their investments in the future, the withdrawn money will again have impacts on the consumption side. There are many consumer behavior aspects which affect the magnitude of impacts, and therefore there is considerable uncertainty regarding tertiary impacts.

Figure 1 presents typical consumer's money flows between consumption and investment sectors. To ensure that anti-consumption or consumption change actions do not lead to money flow to unsustainable investments in the investment side the money has to be directed to sustainability supporting impact investing.

The following equation was developed to calculate the potential for the double impact from the GWP perspective:

$$D = \sum_{1}^{n} a_a \cdot g_a + \sum_{1}^{n} I \cdot g_I - \sum_{1}^{n} c_i \cdot g_i,$$

where D is the potential double impact (as GWP), a_a is the anti-consumption or consumption change choice [€], g_a is the life cycle GWP impact of anti-consumption goods or services [gCO_2eq/€], I is the investment or donation to GWP impact reduction actions [€], g_I is the life cycle GWP impact reduction by investment [gCO_2eq/€], c_i is the money from interest or from investments that is returned to consumption [€], and g_i is the life cycle GWP impact of consumed goods or services [gCO_2eq/€].

3 | DATA COLLECTION TO TEST DOUBLE IMPACT ASSESSMENT FOR A CASE STUDY OF FINNISH HOUSEHOLDS

There is a considerable body of research on household consumption in different consumption categories and comprehensive statistical data is available. Similar data is also available for consumer or household carbon footprints. The potential GWP impacts of overall consumption and different consumption categories and regions can be calculated using such data. Table 1 presents data on Finnish household consumption for different sectors and related average GHG emission reductions.

Using data presented in Table 1, GHG emission reduction potential from anti-consumption choices in general can be calculated. The same data can be used if a consumer decides to use interest or withdraw money from the investment side and use it in the consumption side. However, these impacts are dependent on time and possible system changes. Claudelin et al. (2018) calculated the potential for Finnish households to reduce consumption with moderate changes in lifestyles. According to their calculations, households could annually, on average, save €150 from housing costs, €1000 from mobility, €1500 from food purchases, and €450 from goods and services. These results are utilized to calculate average annual GHG emission reduction potential and revenue of anti-consumption choices of different categories (Table 2). In addition to general categories related to anti-consumption impacts, also detailed examples of anti-consumption or consumption change impacts are calculated. Background data and assumptions for these calculations are presented in Appendix.

As mentioned above, the secondary impact is created through sustainable impact investments. There are several options related to these investments, and examples of investment options and related assumptions for the cases studied are presented in Table 3.

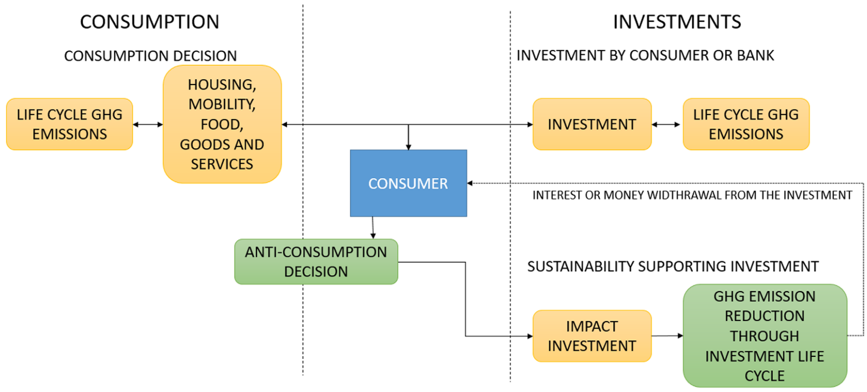

FIGURE 1 Money flows between consumption and investments and opportunity for double impact [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Consumption and carbon footprints of Finnish households (Statistics Finland, 2018b; Salo & Nissinen, 2017)

Consumption Category	Consumption [€/a]	Carbon Footprint [$kgCO_2eq$]
Housing	4973	4500
Mobility	3025	2200
Food	2641	1800
Goods and services	7068	3000

TABLE 2 Global warming potential impacts from Finnish consumer consumption choices (Statistics Finland, 2018b; Salo & Nissinen, 2017)

Consumption Category	Anti-consumption Impacts [$kgCO_2eq$/€]	Anti-consumption Potential for Finnish Households [$kgCO_2eq/a$]
Housing	0.91	137
Mobility	0.73	730
Food	0.68	1020
Goods and services	0.42	198
Average	**0.62**	**Total 2085**

4 | RESULTS AND DISCUSSION

Table 2 presents potential for primary impacts for Finnish households for one anti-consumed € in different sectors and total anti-consumption potential based on the moderate scenario presented by Claudelin et al. (2018).

As can be seen in Table 2, if Finnish consumers decided to save their money instead of consuming they would be able to reduce 0.62 $kgCO_2eq$/€ on average, and the annual potential that could be relatively easily achieved would be 2085 $kgCO_2eq$. Higher reductions can be achieved if savings are focused on housing, mobility, or food sectors. However, reductions in housing consumption may not be as easily obtained because they are limited by current housing and might require, for example, relocation. Reductions in goods and service consumption lead on average to lower global warming impact reductions than other categories. On the other hand, this category is the area that most likely includes some nonessential consumption and consumption which is more easily controlled by the consumer.

Figures 2 and 3 present examples of consumption behavior changes and anti-consumption decisions and their potential economic and GHG emission changes. As can be seen in the figures, single GHG emission reduction actions vary considerably. However, it seems that mobility and housing related decisions bring the greatest economic savings and GHG emission reductions of the chosen examples. However, actions with the highest impacts may require investments and additional tasks, for example, purchase of a new car or moving to a smaller apartment. In general, most of the examples that led to GHG emission reductions also saved consumers money. Data from Figures 2 and 3 can be directly used for primary impact (anti-consumption and consumption change impact) assessment. Background data and assumptions for these calculations are presented in Appendix.

Changing a petrol car to a hybrid electric car and substituting dairy milk for an oat-based alternative seems lead to reductions in GHG emissions but they also increase costs for the consumer. However, the calculations are made for only certain car models, and the calculations include also car depreciation, which is higher for electric hybrid cars. Therefore, depending on the models, the money flow to the customer could be either more negative, closer to zero or positive. On the other hand, as the fixed costs of a car are included in the calculations, living without a car would be needed to achieve the full calculated money flows. The gasoline costs of driving a kilometer would be approximately €0.11 whereas the costs per kilometer would be €0.33 if also the fixed costs were considered. If only gasoline costs

TABLE 3 Data and assumptions for secondary impact assessment of sustainable investments. (Hamrick & Gallant, 2017; Suomen tuulivoimayhdistys, 2017)

Sustainability Supporting Investment	Expected Life Time	Investment Size of a Unit	Other Data Needed	Life Cycle GHG Emissions from the Investment	Life Cycle GHG Emissions from Substituted Investment
Solar photovoltaics (PVs)	25	1000 €/kWp	Operational period 800 h/a	55 $gCO_2eq\ kWh^{-1}$	Electricity production mix in Finland 200 $gCO_2eq\ kWh^{-1}$
Wind power	25	1500 €/kWp	Operational period 3000 h/a	8 $gCO_2eq\ kWh^{-1}$	Electricity production mix in Finland 200 $gCO_2eq\ kWh^{-1}$
Biogas power	5	€740 plastic tank digester	Two cows' manure 3.6 GJ/a energy for cooking	No life cycle emissions included	Charcoal use 67 gCO_2eq/MJ
Carbon offsetting	n.a.	0.4–44 €/tCO_2 (average 3 €/tCO_2)			

FIGURE 2 Global warming potential impacts and costs of anti-consumption or consumption change choices of Finnish households

were considered, it would actually be cheaper to drive the 10 km daily trip instead of taking a train. Also, changing to ground source heating might, depending on details of the house and location, cause negative money flow to the customer. However, most of the anti-consumption and consumption change choices studied for this work clearly have positive effects on both GHG emission reductions and money flow to the consumer.

Some of the choices, for example, changing to green electricity, are relatively easily done and do not require familiarization or changes in everyday behavior. Choices related to changing a heating system and changing a car to a biogas or electric hybrid car require both familiarization and possibly large investments, but they do not require daily behavioral changes. Some choices, for example, skipping a flight or using public transportation or a bicycle instead of a car, require

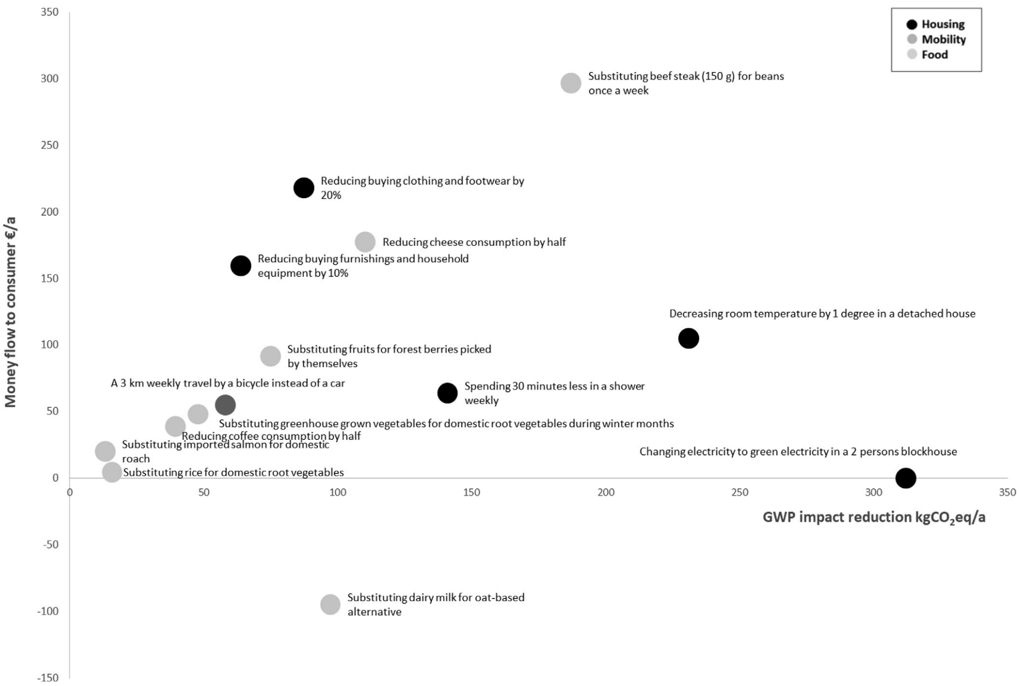

FIGURE 3 Global warming potential impacts and costs of anti-consumption or consumption change choices of Finnish households for examples with lower potential

TABLE 4 Global warming potential impact mitigation through life cycle of investment from example impact investments when €1000 is invested

Impact Investment	GWP Reduction [kgCO_2eq 1000/€]
Solar photovoltaics in Finland	2900
Wind power in Finland	9600
Biogas in Africa	1600
Carbon sequestration	400–44 000

changes in behavior. Over half of the example changes are relatively small and result annually in less than €350 of savings and 350 kgCO_2eq of GHG emission reductions. Most of these changes require changes in behavior to some extent. The achievable reductions and savings are not significant by themselves but combined they will have significant impact.

The results of secondary impacts through impact investing are presented in Table 4. Relatively high variation in potential GHG reductions from chosen energy infrastructure investments as well as from carbon sequestration options can be seen.

Table 5 presents example cases of potential double impacts by combining anti-consumption or consumption change and impact investing. It also presents tertiary impact through use of interest. The total potential double impact is calculated based on these three impacts.

Other environmental impact categories could be assessed similarly but there may be more limitations in data availability and accuracy related to impacts from different consumption categories. Tables 4 and 5 indicate that the total impact varies mainly depending on the primary and secondary impacts. The tertiary impact is relatively insignificant compared to the other two impacts. If a household anti-consumed the €3100 Claudelin et al. (2018) calculated, the interest rate was 2%, and savings and interests were invested in solar photovoltaics in Finland, the impact achieved via interest would be 180 kgCO_2eq while the primary impact would be 2085 kgCO_2eq and the secondary impact 8990 kgCO_2eq.

There is a lot of discussion about consumers' possibilities to mitigate global warming. Anti-consumption or consumption changes have been seen as a potential method to reduce consumption related GWP impacts. However, consumption change alone does not ensure that anti-consumed money is not directed back to consumption as investments via bank loans. Therefore, to ensure that there really are positive impacts from the GWP perspective, money has to be invested in sustainability supporting actions. There are, however, many uncertainties related to exact numbers because this approach combines consumer level actions and wider perspective system changes, for example, through changed consumption patterns.

TABLE 5 Example cases for double impact calculations

Case	Primary Impact (Anti-consumption) [kgCO_2eq]	Secondary Impact (Impact Investment) [kgCO_2eq]	Tertiary Impact (Reverse or Additional Impact) [kgCO_2eq]	Double Impact (Total Impact) [kgCO_2eq]
Person saves €200 by skipping a medium distance flight and donates money for carbon sequestration project	1230	800 (price 4 € /kgCO_2eq)	—	2030
Person substitutes his weekly steak with beans and invests savings (€300) for solar energy projects. Also 2% interest is invested to the same target	187	861	17	1065
Person decreases room temperature by 1°C in a detached house and invests savings (€105) for a biogas project in Africa. Also 1% interest returns to consumption	231	171	−0.7 (average consumption 0.6 kgCO_2eq/€)	401

It is likely that some consumers will, at some point, withdraw their invested money to use it for consumption. Consequently, whether the total impact of anti-consumption is negative or positive can vary considerably. For example, if the investments and interests are withdrawn and used for energy efficiency improvements of current dwellings, further reductions in GHG emissions may be achieved. From the point of GHG emissions reduction, the worst option would be to anti-consume on something that has high economic saving potential but low GHG emission reduction potential, and then later use the saved money, for example, on a long distance flight.

The calculations are based on LCA which is a microeconomic tool, and therefore macroeconomic changes are not considered in the calculations. The results might not be as straightforward as displayed in the double impact method and the method merely presents potential with the current knowledge. Especially time affects both the amount of money saved and GHG emissions reduced, and also, for example, global situations have effects on all levels creating uncertainty for quantified assessment. For example, a positive side of the current Covid-19 virus has been that is has temporarily decreased GHG emissions (Le Quéré et al., 2020). As a negative side effect, it has affected the economies making it harder to invest money in climate change mitigation and adaptation. Lack of mitigative actions increases GHG emissions possibly leading to increased occurrences of natural hazards, such as, cyclones and droughts that are further burdens for economies. Already in 2007 it was pointed out by the Stern Review (2007) that without investing approximately 1% of yearly GDP into climate change mitigation the costs and risks caused by climate change will cause a loss of at least 5% of global GDP each year.

5 | CONCLUSIONS

Anti-consumption or consumption changes of households have potential to reduce GHG emissions. The scale of GHG reductions varies considerably depending on the actions undertaken, and the behavior may provide savings or additional costs for households. To ensure that saved money from anti-consumption or consumption changes does not lead to additional GHG emissions via rebound effects, the money should be impact invested to provide additional GHG reductions. For this purpose of assessing additional impacts, a double impact calculation method was created. Double impact calculation combines potential sustainability impacts that are achieved through anti-consumption or consumption behavior change, impact investment, and the use of interest from investments. Households in developed countries have huge potential to reduce consumption related GHG emissions and, through impact investing, to, for example, promote sustainable energy transition. The double impact method is created based on the current standards of LCA (International Organization for Standardization, 2006, 2018) which do not necessarily take systemic changes into consideration. The changes might alter the results for both GHG reductions and monetary savings. Therefore, further research to evaluate co-benefits and trade-offs related, for example, to SDGs are needed. Future research should also focus on how to technically ensure that saved money from consumption is directed to impact investing. Despite the limitations of the double impact method, it is a good tool for assessing the combined impact of anti-consumption or consumption changes and the additional impacts.

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APPENDIX A.

Mobility Category	GWP Impact Data	Economic Data	Other Assumptions	References
Skipping a long distance flight	Direct emissions: 114 gCO_2eq/pkm Plane manufacturing emissions: 7 gCO_2eq/pkm Jet fuel production: 15 gCO_2eq/MJ	€700 back and forth trip	Fuel consumption: 3.5 MJ/pkm	Technical Research Center Finland (2018), Chester & Horvath (2009), and Travel agencies
Skipping a medium distance flight	Direct emissions: 165 gCO_2eq/pkm Plane manufacturing emissions: 7 gCO_2eq/pkm Jet fuel production: 15 gCO_2eq/MJ	€200 back and forth trip	Fuel consumption: 2.2 MJ/pkm	Technical Research Center Finland (2018), Chester & Horvath (2009), and Travel agencies
Travelling a 3 km daily trip by a bicycle instead of a car	Direct emissions: 135 gCO_2eq/pkm Car manufacturing emissions: 20 gCO_2eq/pkm Petrol production; 15 gCO_2eq/MJ	Car use costs 0.33 €/km	Fuel consumption of a car: 2.3 MJ/pkm Bicycle driving is assumed to have no GWP impacts or costs 5 days a week	Technical Research Center Finland (2018), Chester & Horvath (2009), and YLE (2018)
Travelling a 10 km daily trip by a train instead of a car	Direct emissions from a car: 135 gCO_2eq/pkm Car manufacturing emissions: 20 gCO_2eq/pkm Petrol production: 15 gCO_2eq/MJ Train manufacturing emissions: 20 gCO_2eq/pkm Electricity production: 17.4 gCO_2eq/MJ	Car use costs 0.33 €/km A monthly train ticket is €54	Fuel consumption of a car: 2.3 MJ/pkm Electricity consumption of a train: 0.30 MJ/pkm Trains are using 70% hydro and 30% grid mix electricity 5 days a week	Technical Research Center Finland (2018), Chester & Horvath (2009), YLE (2018), and HSL ticket prices
Changing petrol car to electric hybrid car	Direct emissions from a petrol car: 135 gCO_2eq/pkm Petrol car manufacturing emissions: 20 gCO_2eq/pkm Petrol production: 15 gCO_2eq/MJ Electric car manufacturing emissions: 35 gCO_2eq/pkm Electricity production: 48.6 gCO_2eq/MJ	Petrol car use costs 0.33 €/km Electric car use costs 0.41 €/km	About 18 000 km annual driving Fuel consumption of a petrol car 2.3 MJ/pkm Electricity consumption of an electric car 0.7 MJ/pkm	Technical Research Center Finland (2018), Chester & Horvath (2009), and YLE (2018)
Changing petrol car to biogas car	Direct emissions from a petrol car: 135 gCO_2eq/pkm Petrol and gas car manufacturing emissions: 20 gCO_2eq/pkm Petrol production: 15 gCO_2eq/MJ Gas production: 12 gCO_2eq/MJ		About 18 000 km annual driving Fuel consumption of a petrol car: 2.3 MJ/pkm Fuel consumption of a gas car: 1.9 MJ/pkm	Technical Research Center Finland (2018), Chester & Horvath (2009), and YLE (2018)
A long domestic trip by a train (800 km) instead of a car	Direct emissions from a car: 135 gCO_2eq/pkm Car manufacturing emissions: 20 gCO_2eq/pkm Petrol production: 15 gCO_2eq/MJ Train manufacturing emissions: 20 gCO_2eq/pkm Electricity production production: 17.4 gCO_2eq/MJ	Car use costs 0.33 €/km One way train ticket is €80	Fuel consumption of a car: 2.3 MJ/pkm Electricity consumption of a train: 0.30 MJ/pkm Trains are using 70% hydro and 30% grid mix electricity 5 days a week	Technical Research Center Finland (2018), Chester & Horvath (2009), andYLE (2018)

Mobility Category	GWP Impact Data	Economic Data	Other Assumptions	References
A 3 km weekly travel by a bicycle instead of a car	Direct emissions: 135 gCO_2eq/pkm Car manufacturing emissions: 20 gCO_2eq/pkm Petrol production: 15 gCO_2eq/MJ	Car use costs 0.33 €/km	Bicycle driving is assumed to have no GWP impacts or costs	Technical Research Center Finland, (2018), Chester & Horvath (2009), andYLE (2018)

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Abbreviation: GWP, global warming potential.

Food Category	GWP Impact Data	Consumer Price Data	Other Data	References
Substituting beef for soy	Beef: 25 $kgCO_2eq$/kg[a] Soy: 0.49 $kgCO_2eq$/kg[b]	Beef: 12.97 €/kg Soy: 5.66 €/kg	Beef consumption per person: 19.4 kg/a	Clune et al. (2017), Finnish grocery stores, and Natural Resources Institute Finland (2018)
Reducing cheese consumption by half	Cheese: 8.65 $kgCO_2eq$/kg[b]	Cheese: 13.75 €/kg	Cheese consumption per person: 25.8 kg/a	Clune et al. (2017), Finnish grocery stores, and Natural Resources Institute Finland (2018)
Substituting imported salmon for domestic roach	Salmon: 4.5 $kgCO_2eq$/kg Roach: 0.72 $kgCO_2eq$/kg	Salmon: 12.22 €/kg Roach: 22.5 €/a[c]	Salmon consumption per person: 3.5 kg/a	Silvenius (2014), Metsähallitus (2015), and Natural Resources Institute Finland (2018)
Substituting rice for domestic root vegetables	Rice: 2.8 $kgCO_2eq$/kg Root vegetables: 0.13 $kgCO_2eq$/kg	Rice: 2.09 €/kg Root vegetables: 1.33 €/kg	Rice consumption per person: 6 kg/a	Saarinen et al. (2011), Finnish grocery stores, and Natural Resources Institute Finland (2018)
Substituting beef steak (150 g) for beans once a week	Beef: 25 $kgCO_2eq$/kg[a] Beans: 0.51 $kgCO_2eq$/kg[b]	Beef tenderloin: 50.4 €/kg Beans: 6.49 €/kg	Protein content of beef: 57% Protein content of beans: 30%	Clune et al. (2017), Finnish grocery stores, and National Institute for Health and Welfare (2018)
Reducing coffee consumption by half	Coffee: 8.0 $kgCO_2eq$/kg	Coffee: 7.84 €/kg	Coffee consumption per person: 9.9 kg/a	Wallén et al. (2004), Finnish grocery stores, and Natural Resources Institute Finland (2018)
Substituting fruits for forest berries picked by themselves	Fruits: 1.3 $kgCO_2eq$/kg[d] Forest berries: 0 $kgCO_2eq$/kg	Fruits: 1.56 €/kg Berries: 0 €/kg	Fruit consumption per person: 58.8 kg/a	Clune et al. (2017), Finnish grocery stores, and Natural Resources Institute Finland (2018)
Substituting greenhouse grown vegetables for domestic root vegetables during winter months (December, January, and February)	Greenhouse vegetables: 3.1 $kgCO_2eq$/kg[e] Root vegetables 0.13 $kgCO_2eq$/kg[e]	Salad, cucumber and tomato: 2.17 €/kg Root vegetables: 1.33 €/kg	Greenhouse vegetable consumption per person: 15.95 kg/winter months (consumption does not vary between different months)	Saarinen et al. (2011), Finnish grocery stores, and Natural Resources Institute Finland (2018)

(Continues)

Food Category	GWP Impact Data	Consumer Price Data	Other Data	References
Substituting dairy milk for oat-based alternative	Dairy milk: 1.3 $kgCO_2eq$/kg[a] Oat drink: 0.45 $kgCO_2eq$/kg	Dairy milk: 0.99 €/L Oat drink: 1.82 €/L	Milk consumption per person: 114.4 L/a	Clune et al. (2017), Florén et al. (2013), Finnish grocery stores, and Natural Resources Institute Finland (2018)

[a]EU median value.
[b]Median value.
[c]Average: Fisheries management fee 45 €/a and angling 0 €/a.
[d]Median value for field grown fruits 0.42 kgCO2eq/kg, median value for greenhouse grown fruits 2.13 kgCO2eq/kg.
[e]Average value (greenhouse vegetables 3.1 kgCO2eq/kg and root vegetables 0.13 kgCO2eq/kg).

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Abbreviation: GHG, global greenhouse gas.

Other Consumption Category	GWP Impact Data	Consumer Price Data	Other Data	References
Reducing buying clothing and footwear	0.4 $kgCO_2eq$/€	Average annual consumption: 720 €/a	20% reduction	Claudelin et al. (2018) and Seppälä et al. (2009)
Reducing buying furnishing and household equipment	0.4 $kgCO_2eq$/€	Average annual consumption: 1062 €/a	10% reduction	Claudelin et al. (2018) and Seppälä et al. (2009)

Reference:
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Abbreviation: GHG, global greenhouse gas.

Housing Category	GWP Impact Data	Consumer Price Data	Other Data	References
Moving from 80 m^2 apartment to 60 m^2 apartment	District heating 188 gCO_2eq/kWh	District heating costs 85 €/MWh Price for a square meter €2500	Need for heating 55 kWh/ m^3, house built in the 1980's Loan for 20 years, interest 2%	Motiva (2018), Finnish Energy (2018), and Motiva (2016)
Moving from 150 m^2 house to 130 m^2 house	District heating 188 gCO_2eq/kWh	District heating costs 85 €/MWh Price for a square meter €1500	Heating energy consumption 24 625 kWh/a for 150 m^2 and 21 875 for 130 m^2 Loan for 20 years, interest 2%	Motiva (2018), Finnish Energy (2018), and Motiva (2017)
Changing to green electricity in an apartment	Electricity production 164 gCO_2eq/kWh	Approximately same prices	One person living in an apartment, electricity consumption 1400 kWh/a	Motiva (2018) and Adato Energia (2013)
Changing to green electricity in an detached house	Electricity production 164 gCO_2eq/kWh	Approximately same prices	Four persons living in a detached house, electricity consumption 7300 kWh/a	Motiva (2018) and Adato Energia (2013)
Changing district heating to a ground source heat pump	District heating; 188 gCO_2eq kWh Electricity production 164: gCO_2eq kWh Ground-source heat pump manufacturing, transport and borehole 7.7 $kgCO_2eq/GJ$	District heating costs 85 €/MWh Electricity costs 13.4 c/kWh Investment €15 000, no interest	Detached house €150 m^2, heating energy consumption 24 625 kWh/ a Life expectancy 20 a	Finnish Energy (2018), Motiva (2017), and Saner et al. (2010)
Lowering room temperature by 1°C (detached house)	District heating: 188 gCO_2eq kWh	District heating costs 85 €/MWh	Detached house 150 m^2, heating energy consumption 24 625 kWh/ a Lowering room temperature by 1°C lowers energy consumption by 5%	Motiva (2018) and Finnish Energy (2018)
Spending 30 mins less in a shower/week	District heating: 188 gCO_2eq/ kWh	District heating costs 85 €/MWh	Shower uses water 12 L/min Energy needed for heating 0.4 kWh/L	Verto (2019), Finnish Energy (2018), and D-mat Oy (2018)

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Abbreviation: GHG, global greenhouse gas.

Publication III

Claudelin, A., Uusitalo, V., Pekkola, S., Leino, M., and Konsti-Laakso, S.
The Role of Consumers in the Transition toward Low-Carbon Living

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Article

The Role of Consumers in the Transition toward Low-Carbon Living

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Abstract: Improvements in energy efficiency and production of renewable energy hold significant potential for reducing greenhouse gas emissions of housing, which accounts for 14% of global greenhouse gas emissions. In our research, we focused on the willingness of owners of detached houses to adopt renewable energy production systems of their own, and we examined perceived barriers to adopting these systems. The research was conducted using a survey and a life cycle assessment model. The survey covered three residential areas in Lahti, Finland, and the potential reductions in greenhouse gas emissions were estimated using a life cycle assessment model based on the survey results. The barriers to transformation were identified as a lack of knowledge in the following three areas: (1) the possible annual savings attained; (2) the costs of implementing energy efficiency and renewable energy production solutions; and (3) the technologies used in renewable energy production. The greenhouse gas emission reductions in the residential areas surveyed would amount to approximately 15% if the consumers implemented the solutions they considered.

Keywords: consumer; housing; low carbon; survey; life cycle assessment; sustainability

1. Introduction

To maintain the global temperature rise at or below the targeted 2 °C (from the pre-industrialized temperature level), urgent and fundamental actions must be taken [1]. The European Union (EU) is committed to reducing its greenhouse gas (GHG) emissions by 80–95% from the 1990 level by 2050 [2], and the buildings sector is a priority area for meeting the target [3]. Globally, residential buildings account for 24% of total final energy use, which equates to 14% of global GHG emissions [4]. Thus, reducing the use of energy in the housing sector plays an important role in mitigating climate change. The new building stock boasts better energy efficiency than the older (but current) stock; however, as the building renewal rate is slow, it is important to improve energy efficiency and to increase the use of renewable energy in current buildings. Of all buildings in the EU, 74% of the floor area comprises residential buildings, and in turn, 66% of that area comprises detached houses [5]. Also, in Finland, new detached houses are not built as actively as before [6], which increases the value of improving the state of current houses. Therefore, owners of detached houses constitute a significant group to be taken into consideration when one thinks of ways to reduce GHG emissions. This group could reduce their contribution to GHG emissions by changing their heating systems, by implementing renewable energy production technology, and by adjusting their daily habits of energy usage.

Thus far, existing research has mainly focused on technologies related to energy efficiency and renewable energy. The role of consumers—who actually make the decisions—has not been researched as much. Based on a survey of 1250 residents, Newton and Meyer [7] established three types of environmental lifestyle segments: 'committed' greens, 'material' greens, and 'enviro-sceptics'. Only a few differences were found in the actual consumption of energy, housing space, etc. among the segments. The research suggests that certain factors, related, for instance, to information, finance, and organization, override attitudes, opinions, and intentions as indicators of consumer behaviour. Ek and Soderholm [8] sent out a postal survey to 1200 Swedish households to analyse their willingness to save electricity by changing daily habits. The results indicated that important factors of energy-saving activities are cost, environmental attitude, and social interaction. They found no statistically significant impact from socio-economic background factors.

Valkila and Saari [9] used consumer panels to gather data about consumer attitudes and potential for readiness to act in a more environmentally friendly manner. The themes of the study were urban structure, household energy consumption, mobility, and lifestyle. Based on the results, all research subjects were willing to reduce their consumption, but they were not ready to invest in more expensive, environmentally-friendly equipment.

Jakob [10] identified factors affecting the building envelope renovation decisions of detached-house owners. Based on the three approaches used, it was concluded that renovation decisions are affected by technical parameters and by general housing activities more than by socio-economic factors. The most oft-cited reasons for insulation were the building lifespan and environmental and energy considerations. Economic savings and fiscal incentives were mentioned only rarely. Also, Banfi et al. [11] evaluated consumers' willingness to pay for the insulation of windows and facades and for ventilation systems. Their results demonstrated that consumers value energy savings, environmental benefits, and comfort benefits. However, in addition to legal, structural, and socio-economic hurdles, consumers felt that information is lacking concerning the benefits of energy efficiency measures, and that possibly the methods are insufficient for evaluating the benefits in economic terms.

Even though the role of consumers has been researched [12], the focus has been mainly directed at general attitudes and electricity saving [13–16]. What has not been researched as much is knowledge of and attitudes toward different technologies for using renewable energy, and the barriers encountered by consumers. Therefore, the research questions which this paper poses are as follows:

- What are the perceived barriers to adopting low-carbon housing solutions?
- What is the potential for greenhouse gas emission reductions if those barriers are overcome?

2. Materials and Methods

The approach of this study is quantitative. A survey was conducted to collect data about consumers' attitudes and willingness concerning energy saving measures and renewable energy use. In addition, a life cycle assessment (LCA) model was created to estimate the potential reduction of annual GHG emissions in the studied regions if the consumers implemented the energy production systems they had already considered. The research was carried out in three residential areas featuring detached homes in Lahti, which is a city of 120,000 residents in southern Finland [17]. The areas selected mainly contain detached houses (93–94% of the buildings in the three areas) [17].

2.1. Survey

Data for the research were collected during the spring of 2016 via a postal survey distributed to 700 household mailboxes. It was possible to respond to the survey either online or on paper. Although 161 home owners replied, seven respondents lived in a row house or had not answered that question, and those replies were not considered since the research focused on owners of detached homes. There were thus 154 relevant replies, and the response rate was 22%. Eight of the replies were returned online, and the rest by mail.

The survey included 32 questions, some of which had a multiple-statement format. The questions were divided into four main categories: respondent's background information, housing information, current household energy systems, and energy saving measures and transportation. The survey was broad, and not all the data were utilized for this paper. Most questions incorporated the Likert scale (a common rating format of surveys) [18]. The survey questions that were utilized in this research may be found in Appendix A.

Reliability

The reliability of the survey was analysed by comparing the sample (number of acceptable survey participants) and population of the studied areas (Tables 1–4). The information about population was acquired from an online statistics database maintained by the City of Lahti [17]. In Table 1, the population is the number of detached houses in the studied areas. In Table 2, persons aged 18 or above are included in the population, as the survey was aimed for adult home-owners. In Tables 3 and 4, the population number is higher because persons aged 15 or above were included in the statistics of the database, and it was not possible to acquire more detailed data.

Table 1. Comparison of home construction years in terms of sample versus population sizes.

	Sample	**Population**
Number	154	1101
Construction year	[%]	[%]
–1949	9	13
1950–1959	6	13
1960–1969	4	6
1970–1979	4	4
1980–1989	22	15
1990–1999	18	18
2000–2010	20	17
2010–	15	13

Table 2. Comparison of age groups in terms of sample versus population sizes.

	Sample	**Population**
Number	154	2306
Age Group	[%]	[%]
Under 25	0	9
25–34	8	14
35–44	29	26
45–54	23	23
55–64	21	14
65–74	16	10
75 or over	3	4

Table 3. Comparison of income classes in terms of sample versus population sizes.

	Sample	**Population**
Number	154	2399
Income Class	[%]	[%]
Under €10,000	5	13
€10,000–€20,000	15	16
€20,001–€34,999	32	28
€35,000–€44,999	25	16
€45,000–€60,000	13	13
Over €60,000	5	10

Table 4. Comparison of educational background in terms of sample versus population sizes.

	Sample	Population
Number	154	2399
Educational background	[%]	[%]
Comprehensive school education	12	25
Upper secondary education	35	41
Tertiary education	51	34

The construction years of the houses correlate well. The biggest difference between the sample number and population number occurs in the decades of 1950–1959 and 1980–1989 (7%), but within the other time periods, the difference is 4% or less. There is more variation within the age groups. The sample best correlates with the population within the age groups of 45–54 and 75 or over, while within the other age groups, the range is 6–9%.

Household combined yearly income was asked about in the survey, whilst population income was listed per person in the database. Thus, to be able to compare the reported incomes, the incomes reported by the respondents were divided by two, as there are generally two adults per household. Persons over 14 years old are listed in the population, which increases the percentage of people in the lowest income group. The same phenomenon emerges within the education comparison in the percentage of the population having completed with comprehensive education.

2.2. Life Cycle Assessment Model

An LCA model was created to evaluate the GHG emission reduction potential for the three regions studied if households could be activated towards investing in decentralized renewable energy production. Two scenarios were created: the first presenting the current state of the household; and the second presenting a future state in which the respondents will have implemented the solutions considered. The LCA model is based on ISO 14040 [19] and ISO 14044 [20] standards. The functional unit of the model is annual energy (electricity and heat) consumption in the region. The impact category of climate change, and the characterization factor of global warming potential were selected for the study. The model was created using GaBi 6.0. LCA software (thinkstep: Leinfelden-Echterdingen, Germany). Primary data generated by the survey were applied for evaluating (1) the current energy consumption and energy production methods in the region; and (2) the possibility of a transition toward low-carbon living. Key parameters included both the willingness of households to invest in new solutions and technologies, as well as the technologies and solutions themselves that people considered most interesting. Secondary data such as specific GHG emissions related to energy production methods were mainly applied from the professional database GaBi 6.0. The values were chosen for the Finnish operational environment. The GHG factors used for electricity and district heating came from the local energy company, Lahti Energia. The model is described in Figure 1.

Based on the construction year categories and the main heating systems of the detached houses, the homes were classified into energy efficiency classes C–G (in Finland, classification is A–G) using information from the literature [21,22]. The energy efficiency numbers (kWh/m^2a) used are the averages of the limits of each energy class (which are determined by the Ministry of the Environment of Finland [23]). The average area of the houses in each energy class was also incorporated into the calculation.

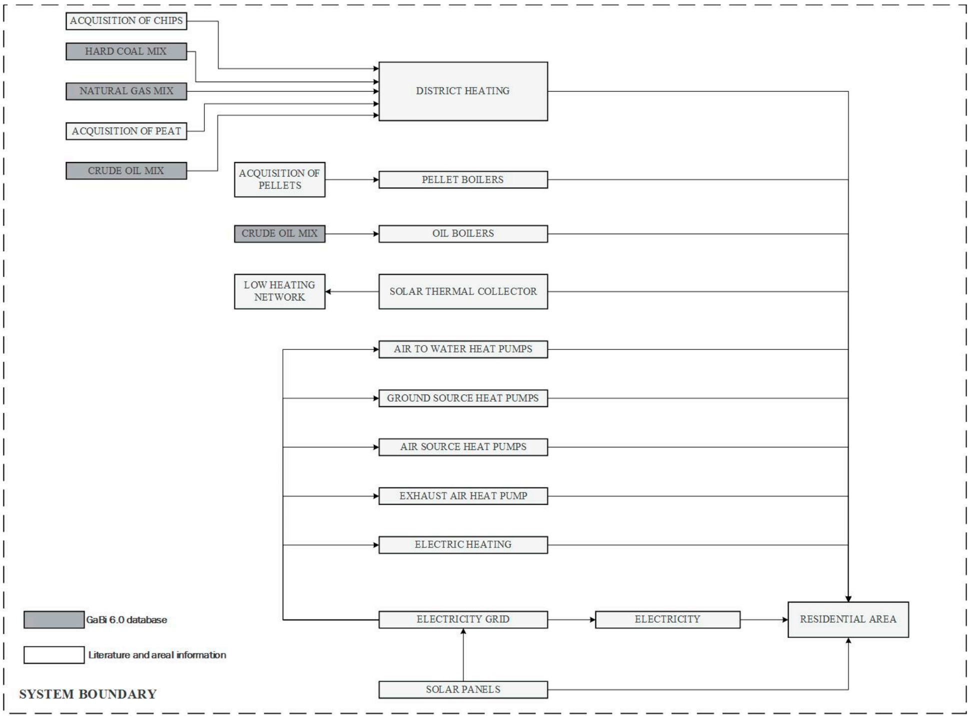

Figure 1. The life cycle assessment (LCA) model created, and the system boundary.

3. Results

3.1. Survey

Based on the survey results, most respondents (about 80%) were willing to save energy for environmental reasons, and they aim to act in an environmentally friendly manner as often as possible. The majority of respondents (88%) were interested in saving energy to achieve economic savings. However, virtually half of the respondents (47%) believed that they are not able to save enough energy to achieve real economic savings. In addition, nearly three-quarters of those surveyed (73%) were not willing to lower their standard of living to save energy.

We had listed different renewable energy production solutions, and in relation to those, the respondents were requested to choose from five options: implemented, considered, familiarized with, not familiar, or not interested. The solutions and percentages of the answers are presented in Figure 2.

As can be seen from Figure 2, most respondents had already implemented fireplaces, especially conductive ones. Air source heat pumps had also been implemented by over half of the respondents. The remaining energy production solutions had not been widely implemented. The solutions which respondents had most considered include air source and ground source heat pumps, solar electricity, and solar heat. Some solutions, such as air to water heat pumps and solar heat, were still unfamiliar to approximately 40% of respondents. Even solar electricity, which has been widely discussed in Finland, was still unfamiliar to 20% of the respondents. We also presented multiple statements about new technologies to the respondents. The statements and responses are presented next in Figure 3.

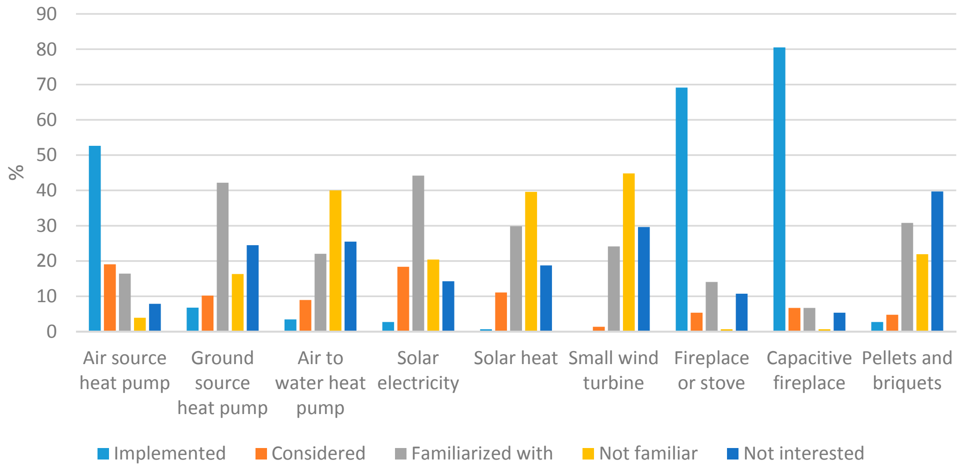

Figure 2. Renewable energy production solutions listed on the survey and corresponding percentages of the responses.

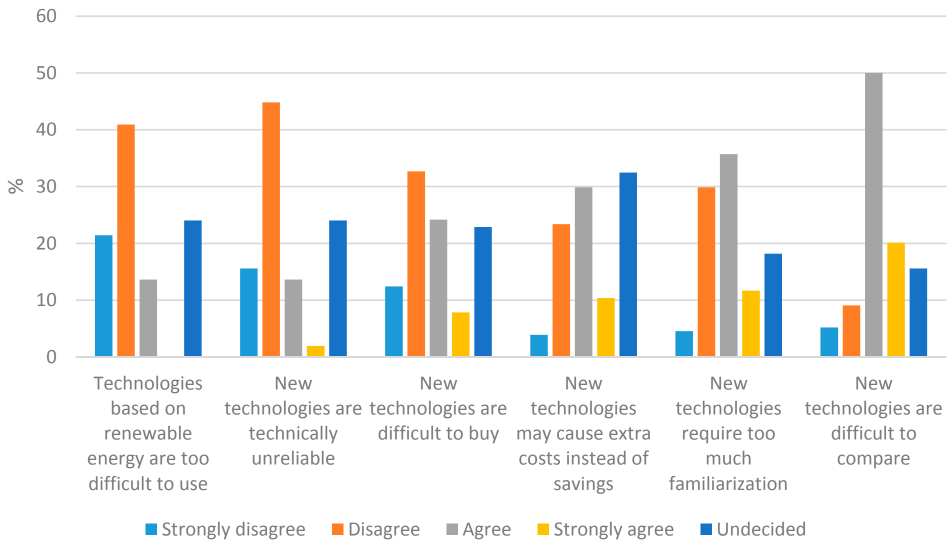

Figure 3. Statements about new technologies and respondents' reactions to those.

The majority of respondents strongly disagreed or disagreed that technologies based on renewable energy are difficult to use (62%) and that they are technically unreliable (60%). However, 40% of those surveyed agreed or strongly agreed that new technologies may incur extra costs, and 47% feel that new technologies require too much familiarization. Additionally, 70% also thought that it was difficult to compare new technologies, and 33% found it difficult to buy new technologies.

On the survey, we had also listed seven factors, of which the respondents were asked to choose three that would most assist them in making changes related to the energy technologies (Figure 4). The factors were all weighted equally, and respondents were not requested to rank them in any order.

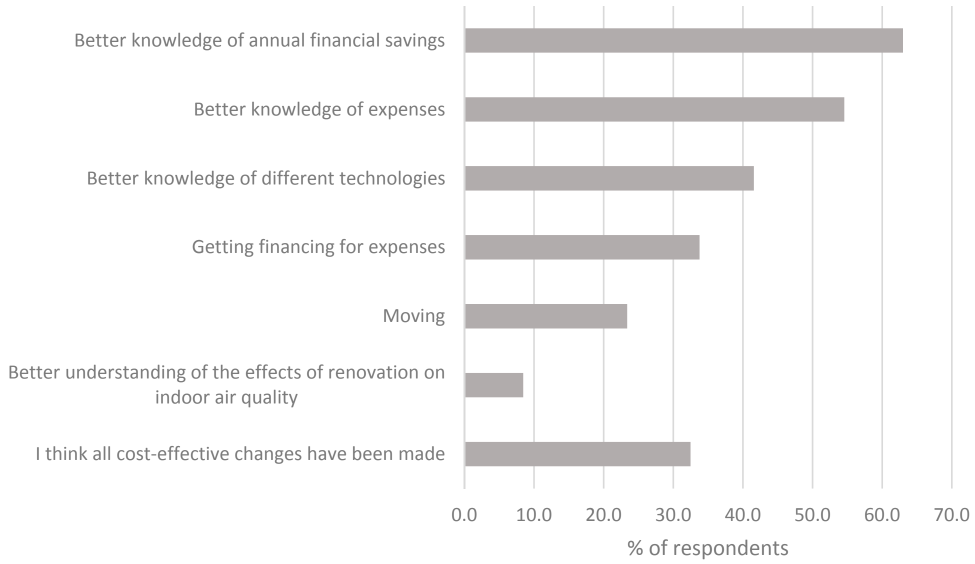

Figure 4. Factors that would assist consumers in making energy-system changes.

What turned out to be the most important factor was *better knowledge of annual financial savings*, as 63% of the respondents chose this. Additionally, 55% of respondents chose *better knowledge of resulting expenses*, and 42% selected *better knowledge of different technologies*. A third named *getting financing* as an important factor. Notably, 10% (N = 16) of the respondents had chosen all three factors related to economics, and 62% (N = 95) of the respondents had chosen at least two of the factors related to economics.

3.2. LCA Model

The results of the survey showed that the respondents' houses were mainly heated by electricity, while a few used ground source heat pumps, oil, wood, or district heating (Table 5). The percentages of supplemental heating systems are presented above in Figure 2.

Table 5. Current main heating systems of the respondents' houses.

	Electric Heating	Ground Source Heat Pumps	Oil Heating	Wood/Pellets/ Chips	District Heating	Other	Total
N	117	10	12	8	3	3	153 [1]
%	76	7	8	5	2	2	100

[1] One of the respondents had not marked the heating system.

Two scenarios were created for the assessment of the annual GHG emissions. The first one presented the current situation, and the second one presented a future situation in which the respondents would have implemented the solutions they had considered. Table 6 presents the percentages of respondents who had considered updating their energy production systems (based on answers presented in Figure 2). To simplify the calculation, we assumed that for the different energy efficiency classes, the percentage of the owners implementing changes would be the same. Also, we assumed that the energy efficiency classes of the houses would not change even if the yearly energy consumptions were reduced.

Table 6. Percentages of respondents who had considered updating their energy production systems.

	Energy Production Systems Respondents Had Considered Switching to				
	Air Source Heat Pumps	Ground Source Heat Pumps	Solar Electricity	Solar Heat	
Current Main Heating System	**Percentage of Respondents Switching Energy Sources [%] (N in Brackets)**				**N Total**
Electric heating	17 (20)	9 (10)	16 (18)	10 (11)	(117)
Oil	33 (4)	9 (1)	10 (1)	11 (1)	(12)
Wood	20 (1)	75 (3)	100 (4)	50 (2)	(4)
Ground source heat pumps	0	0	20 (2)	0	(10)
District heating	67 (2)	0	0	0	(3)
N total	(27)	(14)	(25)	(14)	

If the consumers implemented the solutions they had most considered, the studied households' annual GHG emissions would be reduced from 1026 t CO_2-eq to 873 t CO_2-eq (Figure 5). This reduction equates to 15% of the annual GHG emissions. Air source heat pumps have the most effect on this reduction, as they account for 5% of it. Ground source heat pumps account for 4% of the reduction, and both solar electricity and solar heat account for 3%.

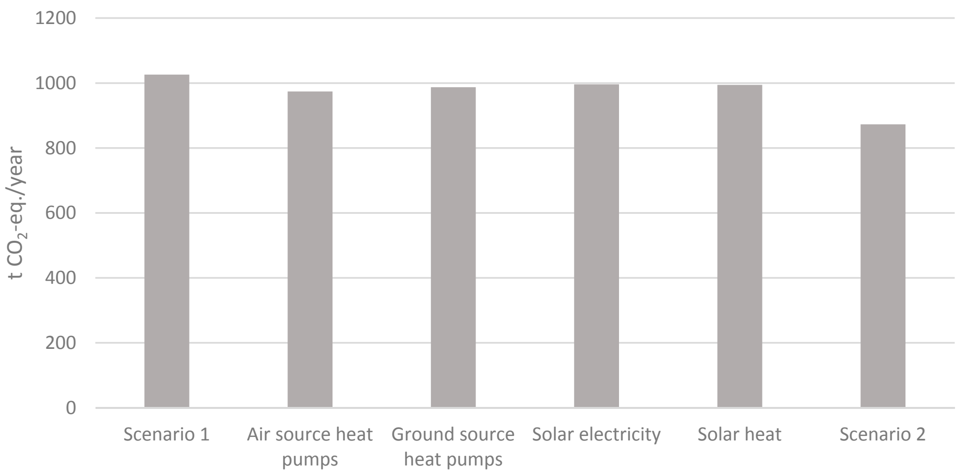

Figure 5. Annual greenhouse gas (GHG) emissions of the households studied for the two different scenarios. In addition to Scenario 2, where all the energy production systems are considered, the influence of each heating system is presented one by one.

4. Discussion

The findings from our research are similar to those of Newton and Meyer [7], as they suggest that factors related to information and finance override other factors, such as attitudes, as indicators of consumer behaviour. Our results are also similar to those of Ek and Soderholm [8], as their findings indicate that important factors of energy saving include those of cost and environmental attitude. Valkila and Saari's [9] research subjects were willing to reduce their consumption, but were not ready to invest in more expensive equipment. However, based on our findings, people are willing to invest in technologies when they have a sufficient level of information and amount of money. In Jakob's [10] research, the reasons listed for adding insulation rarely pertained to savings and fiscal incentives, which is the opposite of our research findings.

As Figure 4 shows, most respondents perceived that economic factors have the most impact on implementing new technologies. Interest in cheaper technologies, such as air source heat pumps, may indicate the same. Also, the majority (88%) of respondents were interested in saving energy to achieve economic savings, although almost half (47%) thought they would not be able to save enough energy to obtain considerable economic savings. We did not ask in the survey what the respondents considered to be considerable savings; thus, there might be variation in the replies. This aspect could be a topic of further studies. A third of respondents replied that receiving financing would assist them in making improvements with energy production technologies. In Finland, until 2017, it was possible to get discretionary grants for materials for energy renovations of detached houses, but these grants are no longer available, as Law (22.12.2005/1184), which the grants were based on, was repealed [24]. Even though the expenses of the work performed may still partially be deducted from taxes as household expenses [25], there might be a need for new kinds of funding instruments, such as energy loans with low interest rates offered by the government.

Based on our findings, we conclude that the respondents desire more information on the resulting costs and possible savings of renewable energy technologies. As we did not specifically ask what kind of information the respondents would like and in what form, the matter could be researched further. There are already multiple free calculators available providing detailed information about annual savings and costs, using different repayment periods.

Based on our survey results, 42% of respondents named *a better understanding of technologies* as an important factor in the decision to implement new technologies. The same need for information is also manifested in Figure 2, which indicates some technologies were unfamiliar to over a third of respondents. The survey did not specify what sort of information the respondents were lacking; therefore, that too could be researched further. However, it should be noted that merely knowing more about the technologies does not necessarily increase the implementation rate, as respondents with educational background in technology had not implemented the solutions more than the other respondents had.

Based on the LCA model, implementing air source heat pumps has the biggest influence on reducing the residential areas' GHG emissions. This is because the respondents had most considered implementing air source heat pumps (although half of the respondents had already implemented them). Ground source heat pumps and air to water heat pumps would have a greater effect on the GHG emission reductions, but since the investment costs are higher and they are more difficult to install, they appear to be not as popular. Also, if a house has direct electric heating, it most likely does have the necessary water-circulating heating system, and ground source heat pumps cannot be installed on every lot. Energy efficiency of housing could also be improved by installing new monitoring technologies which would lead to the reduction of GHG emissions.

We cannot be sure that respondents answered the survey questions truthfully, but we have no reason to believe they would have sent false replies. Also, the same problem is faced with all survey-based studies. Houses in the area researched are on average newer than in Finland in general [26], and the number of houses heated by electricity is approximately double that of Finland's average [27]. These issues may somewhat influence the generalizability of the research. Also, in the calculation of GHG emissions, we assumed that the energy classes of the houses would not change despite the improvements made; thus, the yearly energy consumption would remain the same. The energy production systems that respondents had considered the least were not included in the LCA model. If these factors had been considered, the possible GHG emission reductions could have been greater than those calculated. However, some respondents had considered more than one energy production system, and in reality, they would most likely implement only one, which was not taken into account when we made the calculation. The calculation was based on the respondents' interests and current knowledge, which are not necessarily the most rational. Therefore, it is possible that with the same energy-efficiency investments, the GHG reductions and economic savings achieved could be greater.

The research was carried out in a small area, so the impact pertaining to reducing GHGs from that area would be insignificant even on a regional level. However, the results can be generalized to a wider area, as detached houses account for 27% of the energy consumption of Finland's total building stock [21]. A quarter of the housing building stock was built in the 1960s and 1970s, and buildings from those decades are currently mostly renovated [28]. Thus, consumers play an important role in reducing GHG emissions, and in turn, in mitigating climate change. The results can also be generalized to other countries and areas with somewhat similar climate and buildings. In a warmer climate, the achieved reductions would be smaller, as the percentage of energy used for space heating is not as great.

Based on the survey and the LCA model created, the reduction in GHG emissions would be 15% in the areas studied. This is still far from the EU's reduction targets and carbon neutrality, and it indicates that consumers cannot be overburdened with too much responsibility. In the areas under study, the greatest GHG emissions originate from the production of electricity. Thus, the biggest reductions could be achieved by increasing the share of renewable energy in the production of electricity.

It worked well to combine the survey with LCA modelling. The survey yielded data from consumers for use in the LCA model, and the model provided numeric data supporting the survey.

5. Conclusions

A survey was distributed to owners of detached houses in order to obtain information about their attitudes towards renewable energy solutions and their willingness to implement them. Also, barriers to the implementation of these solutions were examined. A lack of knowledge of annual economic savings, of resulting expenses, and of different technologies were the three most cited barriers. Based on the results, the solutions that respondents were most interested in were air source and ground source heat pumps, solar electricity, and solar heat.

An LCA model was created to be able to estimate how much reduction in the households' GHG emissions could be achieved if the respondents were to implement the solutions they had considered. The results indicated that the reduction could be 15% of the annual emissions. The reduction is not the most optimized, and a greater reduction could possibly be achieved in the areas if the respondents had had better knowledge of economic and technological issues. The use of a survey to acquire data for an LCA model worked well. Future research could focus on the kind and form of information consumers need to implement more technical solutions based on renewable energy, and on what people consider to be real economic savings achieved from saving energy. Finally, it would be a point of interest to observe how the results would differ if the survey was conducted in another country.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Questions from the survey used to gather the data for this paper.

Background questions

2. Educational background

- ○ No basic education
- ○ Lower level of comprehensive school
- ○ Upper level of comprehensive school
- ○ High school, matriculation, or vocational qualification
- ○ Academic degree (e.g., bachelor's or master's degree)
- ○ Licentiate or Doctor
- ○ None of these

4. Age

- ○ Under 25 years
- ○ 25–34 years
- ○ 35–44 years
- ○ 45–54 years
- ○ 55–64 years
- ○ 65–74 years
- ○ 75 years or over

5. Combined yearly income of household

- ○ I cannot say
- ○ Under 15,000 €/year
- ○ 15,000–19,999 €/year
- ○ 20,000–39,999 €/year
- ○ 40,000–69,999 €/year
- ○ 70,000–89,999 €/year
- ○ 90,000–119,999 €/year
- ○ 120,000–139,999 €/year
- ○ 140,000 €/year or more

Questions related to living

8. Type of housing

- ○ Block of flats
- ○ Row house
- ○ Semi-detached house
- ○ Detached house

9. Construction year of the house

- ○ –1949
- ○ 1950–1959
- ○ 1960–1969
- ○ 1970–1979
- ○ 1980–1989
- ○ 1990–1999
- ○ 2000–2009
- ○ 2010–

12. Main heating system of the house

- ○ Electric heating
- ○ Oil
- ○ Wood
- ○ District heating
- ○ Ground source heat
- ○ Wood/pellets/chips
- ○ Other, what? ____________________

17. How strongly do you agree or disagree with the following statements?

	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Agree	I Cannot Say
I aim to act in an environmentally friendly way whenever possible (i.e., saving energy, sorting waste, recycling, avoiding unnecessary use of car)	○	○	○	○	○
I aim to save energy actively, but I am not willing to lower my standard of living to do so	○	○	○	○	○
I am interested in saving energy for environmental reasons	○	○	○	○	○
I do not believe my household can save energy to the extent that it would have any real economic effect	○	○	○	○	○
I am interested in saving energy because of economic savings	○	○	○	○	○

Current energy solutions of your household

21. Assess the following solutions related to your household energy

	I Have Implemented	I Have Considered	I Am Familiarized with	Not Familiar	Not Interested
Air source heat pump	○	○	○	○	○
Ground source heat pump	○	○	○	○	○
Air to water heat pump	○	○	○	○	○
Solar electricity	○	○	○	○	○
Solar heat	○	○	○	○	○
Small wind turbines	○	○	○	○	○
Fireplace or stove	○	○	○	○	○
Capacitive fireplace	○	○	○	○	○
Water-circulating fireplace	○	○	○	○	○
Pellets and briquettes	○	○	○	○	○
Central heating boilers	○	○	○	○	○

23. How strongly do you agree or disagree with the following statements?

	Strongly Disagree	Disagree	Agree	Strongly Agree	Undecided
Technologies based on renewable energy are difficult to use	○	○	○	○	○
New technologies are technically unreliable	○	○	○	○	○
New technologies are difficult to buy	○	○	○	○	○
New technologies may result in extra costs instead of savings	○	○	○	○	○
New technologies require too much familiarization	○	○	○	○	○
New technologies are difficult to compare	○	○	○	○	○

24. Choose the three most significant factors that would assist your household in making changes related to energy

○ I think all cost-efficient changes have been made
○ Moving
○ Better understanding of the effects of renovation on indoor air quality
○ Getting financing for expenses
○ Better knowledge of annual financial savings
○ Better knowledge of expenses
○ Better knowledge of different technologies
○ Other, what? ____________________

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Publication IV

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Pre-service Teachers' Knowledge and Perceptions of the Impact of Mitigative Climate Actions and Their Willingness to Act

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Pre-service Teachers' Knowledge and Perceptions of the Impact of Mitigative Climate Actions and Their Willingness to Act

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Abstract

A 44-item questionnaire was created to examine pre-service teachers' knowledge and perceptions of the impact of mitigative climate change actions and how willing they are to undertake these actions. Responses ($N = 224$) were collected from pre-service teachers at the University of Eastern Finland. The findings show that pre-service teachers have a very low level of knowledge of the impact of different mitigative climate change actions. Furthermore, the students tend to overestimate the carbon footprint of low-impact actions and underestimate the carbon footprint of high-impact actions and they are unable to make a clear distinction between low- and high-impact actions, though the impact of the high-impact actions may be many times greater than those of low-impact actions. In general, pre-service teachers were willing to take low-impact actions, somewhat willing to take mid-impact actions, but reluctant to take the highest-impact actions. Knowledge of the impact of actions did not correlate with willingness to act, possibly due to low levels of knowledge. Some correlation between confidence in knowledge and willingness to act was found. This article discusses the importance of considering confidence in knowledge in future research examining the relationship between knowledge and action. The implications of the findings on teacher education and environmental education are also discussed.

Keywords Climate change education · Climate change mitigation · Climate change knowledge · Pro-environmental behavior · Willingness to act · Confidence in knowledge · Carbon footprint

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Introduction

Scientific consensus indicates that the climate is changing and that current changes are mostly driven by humans through increased greenhouse gas (GHG) emissions (IPCC, 2014a). As the consequences of climate change have been shown to pose serious risks to the environment and society, an immediate response to climate change is called for (IPCC, 2014b). Therefore, climate change mitigation is needed at both an individual and societal levels. While some may argue that the only way to achieve this is through international agreements that force the industry and citizens to change their consumption patterns, many have also argued for the importance of educating and empowering citizens to take action (e.g., Anderson, 2012, Schreiner et al., 2005).

In order to stay under 1.5 °C degrees of global warming, a goal set by the EU, the carbon footprint of individuals needs to be reduced significantly. For instance, it should be reduced to 2100 kg of CO_2eq by 2050 even to stay below a maximum temperature increase of 2 °C (Girod et al., 2014). In western countries, this means a three to ten-fold decrease, depending on the country (c.f. Ivanova et al. 2015). To reach such emission cuts, lifestyle changes should be focused especially on those actions that have a high impact on climate change. Although extensive research has been done on pro-environmental behavior and people's willingness to undertake certain actions, studies that consider the impact of different actions are scarce. For this reason, this study first examines pre-service teachers' understanding of the impact of different types of mitigative actions, and then examines how willing they are to take these actions.

Literature Review

Impactful Climate Change Mitigation

On a global level, 65–72% of GHG emissions are related to household consumption (Hertwich and Peters 2009; Ivanova et al. 2015), the majority of which is caused by mobility, shelter, and food (Ivanova et al. 2015). Due to this high share of emissions caused by household activities, there are multiple ways individuals could reduce their GHG emissions. Different studies have calculated that the average consumer in a Western country could reduce their carbon footprint by at least 20–37% (Salo & Nissinen 2017, Jones & Kammen 2011) by making various changes to housing, transport, food, and purchased goods and services. Most importantly, these reductions are achievable with existing solutions and technologies.

While carbon footprints are globally at an average of 3.4 tCO_2eq/capita, in the EU the range is from Bulgaria's 5.4 tCO_2eq/cap to Luxembourg's 18.5 tCO_2e/cap. In the USA, the average carbon footprint is as high as 18.6 tCO_2eq/cap (Ivanova et al. 2015). Finland's carbon footprint per capita (including embodied emissions) is among the highest in Europe at 11.5–13.6 tCO_2eq/a (Nissinen et al. 2017; Ivanova et al. 2015). On average, 39% of this comes from housing, 19% from transportation, 16% from food, and 26% from goods and services (Salo & Nissinen 2017).

To determine the individual actions that could have the biggest mitigative impact on climate change, Wynes and Nicholas (2017) categorized 148 different actions from 39 sources as high-, moderate-, and low-impact actions based on the GHG emissions of a particular action. In their study, all actions were framed to produce the highest possible reduction potential, and substitution effects and rebound effects were not taken into consideration due to lack of data. According to their study, high-impact actions, which can reduce GHG emissions by more than 0.8 tCO_2eq/year, include having one fewer child, living car-free, avoiding air travel, and switching to a plant-based diet. In some regions, switching to green energy would also be classified as a high-impact action. Moderate impact actions (reduction potential of 0.2–0.8 tCO_2eq/year) include replacing a gasoline car with a hybrid car, washing clothes in cold water, recycling/reusing, and hand-drying clothes. The low-impact category includes upgrading light bulbs and conserving water.

These findings are mostly similar to calculations made in Finland. For instance, actions such as living car-free, avoiding air travel, and switching to a plant-based diet are also categorized as high-impact actions in Finland (Häkkinen and Kangas (2012). In fact, the only difference in categorizations seems to be in recycling, which Wynes and Nicholas (2017) have calculated as having a moderate impact of 210 $kgCO_2eq$/year, while in Finland it is calculated as having a low impact of only 18 $kgCO_2eq$/year (see Appendix in Table 6), possibly due to differences in the factors connected to avoided GHG emissions and different baseline scenarios, i.e., amounts of waste and recyclable materials.

Teachers' Knowledge of Climate Change and Climate Change Mitigation

Given the scientific, political, and societal nature of climate change, many educators have emphasized that it is one of the most important socio-scientific issues that teachers should address with students (e.g., Dawson, 2015, Schreiner et al., 2005). Unfortunately, numerous studies have shown that teachers' and pre-service teachers' knowledge of the causes and consequences of climate change is unacceptably low. For example, a study conducted in Finland shows that the factual knowledge and conceptual understanding of the greenhouse effect by pre-service teachers is incomplete and even incorrect (Ratinen, 2013). Similar findings are reported in other countries such as Australia (Boon, 2010), Canada (Puk & Stibbards, 2012), and the USA (Lambert & Bleicher, 2013).

Due to the lack of knowledge of climate change issues, it is fair to assume that knowledge of climate change mitigation is also low. However, studies examining *knowledge* of the impact of different mitigative actions are scarce if not non-existent, as most studies typically only examine participants' *perceptions* of mitigative actions. Nonetheless, studies on *perceptions* help give a general understanding of pre-service teachers' conceptions and misconceptions of mitigative issues when compared with literature on the impact of these actions. For instance, a Greek study showed that the majority of teachers believed that climate change can be mitigated by recycling paper, while not believing that nuclear power is a good option to do so (Ikonomidis, et al., 2012). However, research shows that the mitigative impact of recycling is relatively low (Wynes and Nicholas, 2017), whereas nuclear power can be a significant way to reduce carbon emissions (Gibson et al., 2017). Similarly, a study conducted in Oman showed that pre-service teachers believe that recycling and turning off devices are more useful than reducing meat consumption and improving home insulation (Ambusaidi et al., 2012), when in fact the opposite is true (Wynes and Nicholas, 2017; Lim et al., 2016). These studies indicate that pre-service teachers' knowledge of mitigative actions is low and that education on climate change mitigation is called for. Similar findings have been noted among the general public in energy-related issues, which are closely related to climate change. For instance, a study showed that participants underestimate the saving capacity of different pro-environmental energy-related behaviors by an average factor of 2.8, and the importance of high-energy activities was particularly underestimated (Attari et al., 2010).

Educators have pointed out that climate change education should help improve the ability of students to take action, also called action competence (Jensen, 2002; Jensen & Schnack, 1997). In order to do so, teachers need to understand the impact of different mitigative actions, as students tend to ask questions related to the usefulness of different types of actions (Tolppanen & Aksela, 2018). Teachers therefore need to be able to distinguish which mitigative actions have a greater impact. For instance, reducing the number of annual long-distance flights by one can have a greater positive impact on climate change mitigation than recycling all household garbage for many years (see, e.g., Wynes and Nicholas, 2017). Furthermore, correct knowledge of mitigative actions is important, so that individuals do not think that they are living an environmentally friendly life when their calculated carbon footprint actually indicates the opposite. This current study examines pre-service teachers' perceptions and knowledge of mitigative actions and their willingness to take mitigative action.

Willingness to Take Action

Although individuals are concerned about climate change (e.g., Ilmastobarometri, 2019) and carbon footprint calculators have been available for decades, carbon footprints have not significantly decreased in recent years. One reason is that individuals, including teachers, tend only to take low-impact mitigative actions (e.g., Hermans, 2016; Ambusaidi et al., 2012).

Researchers have made many potential suggestions as to why individuals are not taking more mitigative actions. For instance, a study conducted in the UK shows that barriers to adopting climate mitigative action are caused by a lack of knowledge of consequences and potential solutions (Lorenzoni et al., 2007). However, the relationship between knowledge and action is complex. Although research has shown that knowledge and pro-environmental action are strongly interrelated (e.g., Zsóka et al., 2013), there is also abundant evidence showing that an increase in knowledge does not necessarily increase pro-environmental action (Kollmuss & Agyeman, 2002). This dissociation between knowledge and actions has been discussed for decades and is often referred to as the "knowledge-behavior gap" (see Kollmuss & Agyeman, 2002) or a "commitment gap" (Emanuel, & Adams, 2011).

A number of factors may account for the knowledge-behavior gap. Firstly, behavior is influenced by many other variables besides knowledge. These can include attitudes towards the environment, social acceptance of a behavior, values, and situational factors such as ease of taking an action (Steg and Vlek, 2009). Therefore, although knowledge of an environmental issue may be necessary in order to take pro-environmental action, alone it may not lead to taking action (e.g. Balmford, et al., 2017). Second, the knowledge-behavior gap may be caused by educational objectives that are too narrow (Boyes et al., 2009). Jensen (2002) has argued that "environmental knowledge" should not only refer to knowledge of environmental "effects" but also examine the "root causes," "strategies for change," and "alternatives and visions". For instance, in a recent model for holistic climate change education, researchers suggest that climate change education should include knowledge of issues such as adaptation, political decision-making, human behavior, and emotional aspects (Tolppanen et al. 2017; Cantell et al. 2019). The assumption is that when "knowledge" also includes an understanding on impactful behavior and possible hindrances to taking action, the gap between knowledge and behavior narrows. In other words, knowledge is only one factor among many for the development of climate change understanding and the ability to take action (Tolppanen, et al., 2017; Cantell, et al., 2019). Third, the knowledge-behavior gap is also partially due to the fact that some studies examine a relationship between general environmental knowledge and overall pro-environmental behavior, rather than specific knowledge and behaviors (Kollmuss & Agyeman, 2002). This is problematic, especially in a climate change context, where different behaviors can have significant differences in their mitigative impact, as discussed above. Finally, individuals may resort to "single-action bias" (see Weber, 2010), meaning that they try to justify their behavior by over-concentrating on single mitigative actions and over-emphasizing the impacts of these actions. This may lead individuals to underestimate the impact of high-impact actions and overestimate the impact of low-impact actions.

For climate change mitigation to be possible, education should aim to narrow the knowledge-behavior gap. Teachers in particular play an important role in this, as they may work as "socializers" or influencers for students and may affect how their students perceive and implement pro-environmental behavior (Chawla, 2009). However, as suggested by the social cognitive theory (e.g., Bandura, 2011), for teachers to be influencers of climate change mitigation, they first need to understand climate change mitigation actions and be willing to take mitigative actions themselves. We therefore first need to broaden our view of what is meant by climate change knowledge to also include knowledge of mitigative actions. Research is then needed to examine how pre-service teachers adopt and learn this knowledge and, even more importantly, how they are able and willing to take individual action and teach climate change mitigation to their students. Furthermore, for education to be able to address climate change mitigation in a meaningful way, students' pre-knowledge and pre-conceptions must be understood. Only then will education be able to be implemented in a way that supports conceptual change (Posner et al., 1982) in impactful mitigative actions.

The Current Study

As studies measuring pre-service teachers' knowledge of mitigative actions are scarce and previous studies have not considered the importance of confidence in knowledge, the current study examines pre-service teachers' knowledge and confidence in knowledge of mitigative actions and compares these to their willingness to take action. The aim of the study was to answer the following research questions:

1. How knowledgeable are pre-service teachers about the impact of mitigative climate change actions and how confident are they in their knowledge?
2. How does knowledge and confidence in knowledge correlate with pre-service teachers' willingness to take mitigative climate change action?

Method

Sample and Data Collection

Data was collected from 255 primary school pre-service teachers, who participated in a course on Education for Sustainability, held by the University of Eastern Finland. Among them, 224 participants agreed to offer their data for this research. The participants were at various stages of their pre-service teacher training. The data was collected through a closed form questionnaire, containing a total of 44 items. The questionnaire was filled out prior to lessons on climate change–related issues to measure participants' pre-knowledge. By measuring pre-knowledge, the findings give an indication of the level of knowledge of teachers who have not received formal education on climate change–related issues, as most teachers have not.

Measures

The questionnaire created for this study contained two sections. The first section contained 19 items measuring knowledge and perceptions of climate change mitigation (CCM). The questions included 3–4 items from each of the following six categories: Car use, Diet, Travel, Consumption and Recycling, Lifestyle and Housing. The items for the questionnaire were chosen so that they measured a wide range of mitigative actions. In this section, participants were asked to evaluate the size of the carbon emissions of each of the actions, using an 11-point scale, where answers were given from a range of 0–100 kgCO_2eq to 1000+ kgCO_2eq (the scales were 0–100, 101–200, 201–300, etc.). Furthermore, after the questions in each of the six categories, participants used a four-point Likert scale to indicate how confident they were about their answers. As it was mandatory to answer all the questions, the confidence scale was used as an indicator of whether the participants thought they knew the answer, or whether they may have been guessing their answers.

The impactt of each of the 19 mitigative actions was calculated using existing research data (see Appendix in Table 6) allowing scrutiny of the correctness of the participants' answers, so the aim of the CCM questionnaire was two-fold. First, it gave data on the *perception* that pre-service teachers have of the impact of different mitigative actions. Second, by comparing participants' perceptions of the actual impact of the mitigative actions, it gave insight into the level of *knowledge* that pre-service teachers have of the mitigative actions. To examine the level of knowledge of participants, the goal was not to see whether the participants could point out the exact correct value for the mitigative action. Rather, the goal was to understand if the participant had a general understanding of the impact of the mitigative actions. For this reason, when examining the correctness of the answers, a minimum margin of error of ± 100 kgCO_2eq was allowed. In other words, if the correct answer was in the range of 301–400 kgCO_2eq, answers would be considered correct if they were in the range of 201–500 kgCO_2eq. This approach also took into consideration the possible margin of errors in calculating the carbon emissions of a mitigative action. The format of the questions was adopted from Boyes et al. (2009), but as the carbon emissions of the actions needed to be calculated, some questions were modified, some were added, and some omitted.

The second section of the questionnaire measured Willingness to Take Action (W-ACT). This section of the questionnaire also contained 19 items, which were partially adopted from Boyes et al. (2009). The items were created to form pairs with the questions in the previous section (CCM). For instance, if in the first section the participant needed to estimate how much an individual's annual GHG emissions would *decrease* due to a certain action, in the second section they needed to answer to what extent they were willing to participate in that particular action for environmental reasons. Answers to this section were given on a 5-point Likert scale from very unwilling to very willing.

The questionnaire was scrutinized by a group of researchers consisting of three experts in education and two experts in climate change. After slight modification of a few of the questions, the questionnaire was then trialed with 26 university students. The wording of questions was then modified based on feedback.

As shown in Table 1, the questions in the CCM and W-ACT questionnaire were grouped into seven categories based on the topic areas and the impact of the mitigative actions.

Analysis

We first conducted descriptive analyses for four core variables—perception, willingness, content knowledge, and confidence in one's own knowledge. Regarding perception and willingness, we used their own scale ranges (11 for kgCO_2eq and 5 for willingness to act) since we mostly focused on the correlation of the four constructs for further analyses. In order to make the knowledge-related variables, we created dummy variables for each question (1 for the correct answer and 0 for the wrong answer) and calculated the average scores of each topic. Regarding confidence in the knowledge of CCM, the participants were asked to indicate how confident they were about their answers on each topic using a four-point Likert scale (very unconfident, somewhat unconfident,

Table 1 Calculated carbon footprint of actions, wording, and categories used in this study

Category	Item	CCM items	W-ACT items	Calculated impact of action ($kgCO_2eq$)
		Estimate by how much would an individual's annual GHG emissions would *decrease*, if they would…	Even if it would feel less pleasant (or cost more), would you be willing to do the following for environmental reasons?	
Car use	Car1	Change the car (petrol) to a hybrid car.		620
	Car2	Change the car (petrol) to an electric car		1450
	Car3	Change the car (petrol) to a biogas car.		1690
Travel	Travel1	Travel all short distances by bike or foot, rather than car (=100 km/week)		970
	Travel2	Change a return air flight (e.g., Bangkok, Thailand) to a mid-distance air flight (e.g., Barcelona, Spain).		1230
	Travel3	Change a mid-distance return air flight (e.g., Barcelona, Spain) to a domestic long-distance train trip (e.g., Helsinki-Rovaniemi, Lapland)		1070
Diet Low	DL1	Have a vegetarian day (=2 meals) once a week.		190
	DL2	Change beef to chicken once a week.		110
Diet High	DH1	Change half of their main meals to vegetarian.		660
	DH2	Change their diet to 100% vegan		1390
Consumption and recycling	CnR1	Recycle all household paper, cardboard, metal, and glass.		20
	CnR2	Eat all leftovers and not throw any food away.		190
	CnR3	Buy half of their clothes second hand.		120
	CnR4	Use their mobile phone for two years instead of 1 year, before buying a new one		50
Lifestyle	Life1	Turn off all home appliances when not in use.		10
	Life2	Spend 30 minutes less in the shower per week		120
Housing	Housing1	Change to green electricity		310
	Housing2	Change to nuclear electricity		310
	Housing3	Change to new windows		450

somewhat confident, and very confident). As a very small proportion of participants were somewhat confident or very confident in their answers, we concluded that a binary yes/no scale would give enough information about the participants' confidence, so we combined the first two scales into "unconfident" and the last two scales into "confident," then calculated the averages for the confidence-related variables of each topic. With the created compound variables, correlation analyses were conducted to explore the relationships between the four core constructs in the seven topics. First, we investigated the association between willingness and perception, and willingness and knowledge, to find if perception and knowledge might affect willingness on mitigative actions. Second, we investigated the relationships between confidence and knowledge, and confidence and willingness, to check how the confidence of the knowledge might correlate with willingness to take action. In our correlation analyses, we only focused on the relationships under the same topic. That is, our results reported the correlation of knowledge of Diet Low with the perception of Diet Low only, not with the perception of Energy or Lifestyle, for instance.

Results

Descriptive Statistics

Pre-service teachers' level of knowledge of mitigative issues was the highest in issues related to *Housing*. In this group, 39–50% of participants correctly stated the impact of these actions. Participants were also relatively knowledgeable about the impact of *Diet*, especially on the impact of switching to a vegetarian or vegan diet (40–42% correct). Level of knowledge was lowest on issues regarding questions in the *Consumption and Recycling* and *Lifestyle* categories. In these categories only 11–22% of participants were able to correctly answer the questions. In questions related to *Travel*, the discrepancy within the group was largest, ranging from 23 to 39% of participants answering the questions correctly (see Table 2).

As shown in Table 2, most pre-service teachers have incorrect knowledge of the impact of particular mitigative actions. Furthermore, the pre-service teachers perceived the high-impact actions as having a lower impact than they actually do, and the low-impact actions to have a higher impact than they actually do. In most of the questions measuring high-impact actions, over 30% of the participants perceived these actions as having an impact of less than 500 $kgCO_2eq$. For instance, 39.7% of students believed that traveling all short distances by bike or on foot would decrease their carbon footprint by under 500 $kgCO_2eq$, where in reality the reduction is 970 $kgCO_2eq$. In other words, a big proportion of pre-service teachers perceived the impact of the action to be at least twice as small as it actually is.

A similar but greater misconception is seen regarding low-impact actions. In all but diet-related questions, 30–40% of participants believed that low-impact actions had an impact of above 500 $kgCO_2eq$. For instance, over 42% of participants believed that buying half their clothes second-hand would have a medium-high or high impact, whereas in fact the impact of the action is only 120 $kgCO_2eq$, or 4–7 times smaller than the pre-service teachers perceived it to be. Disturbingly, more pre-service teachers perceived the action to have a high impact rather than a low impact (12.1% and 11.6% respectively).

The findings show that pre-service teachers show high willingness to undertake the lowest-impact actions (see Fig. 1). Willingness to take actions related to *Lifestyle* and *Consumption and Recycling* was especially common. In these categories, 75% of participants were quite willing or very willing to take action, with the exception of buying half of their clothes second-

Table 2 Pre-service teachers' perceptions of mitigative climate change actions. Correct answers marked in bold

		Low 0–200 $kgCO_2eq$	Low-medium 201–500 $kgCO_2eq$	Medium-high 501–800 $kgCO_2eq$	High 800 + $kgCO_2eq$
Car use	Change to a hybrid car.	8.5%	51.8%	**28.1%**	11.6%
	Change to an electric car	4.5%	30.9%	32.7%	**31.8%**
	Change to a biogas car.	4.5%	30.8%	35.7%	**29%**
Travel	Travel all short distances by bike or on foot	9.8%	29.9%	35.7%	**24.6%**
	Change a long-distance flight to a mid-distance one	7.6%	37.1%	32.6%	**22.8%**
	Change a mid-distance flight to a domestic train journey	8.1%	29.1%	24.2%	**38.6%**
Diet High	Change half of main meals to vegetarian.	7.6%	38.1%	**40.8%**	13.5%
	Change diet to 100% vegan	5%	22.5%	30.2%	**42.3%**
Diet Low	Have a vegetarian day once a week.	**25%**	59.8%	14.3%	0.9%
	Change beef to chicken once a week.	**36.5%**	46.4%	15.3%	1.8%
Consumption and recycling	Recycle all household waste	**14.8%**	46.2%	25.6%	13.5%
	Eat all leftovers and not throw any food away.	**13.8%**	42.4%	33%	10.7%
	Buy half of clothes second-hand.	**11.6%**	46%	30.4%	12.1%
	Use mobile phone for two years instead of one.	**20.5%**	42.9%	27.2%	9.4%
Lifestyle	Turn off all home appliances when not in use.	**21.9%**	43.8%	24.6%	9.8%
	Spend 30 minutes less in the shower per week	**18.8%**	48.2%	25.9%	7.1%
Housing	Change to green electricity	14.3%	**49.8%**	28.7%	7.2%
	Change to nuclear electricity	36.5%	**39.2%**	18%	6.3%
	Change to new windows	21.5%	**49.8%**	24.7%	4%

hand, in which case 48% of participants were willing to do so. Most (over 90%) of the pre-service teachers were also quite willing or very willing to take action in minor diet-related issues (*Diet1*) but showed less enthusiasm to take action in diet-related issues with a higher impact (*Diet2*). Changing to a vegan diet in particular was something that only 16% of the participants were willing to do. The majority of pre-service teachers were willing to take action in housing-related issues, especially changing to green energy (68%) and changing to better insulated windows (61%), but less than 50% of them were willing to take high-impact actions (over 800 $kgCO_2eq$), with the exceptions of walking or biking all short distances (75%) and changing a long-distance flight (e.g., Bangkok) to a mid-distance flight (e.g., Barcelona) (60%). Participants were least willing to change to a vegan diet (16%) and change their holiday plans from an international mid-distance flight (e.g., Barcelona) to a domestic train journey (e.g., to Lapland) (27%).

To simplify the grouping of the data, the impact of the mitigative actions was divided into two categories: high-impact (over 500 $kgCO_2eq$) and low-impact (below 500 $kgCO_2eq$). For instance, while both Diet Low and Diet High dealt with change of diet for environmental reasons, they were put into two different categories as questions in Diet Low consisted of the low-impact actions while questions in Diet High consisted of the high-impact actions. The grouped data in Table 3 clearly shows that pre-service teachers are more willing to take low-impact actions than to take high-impact actions, even though they did not perceive these actions

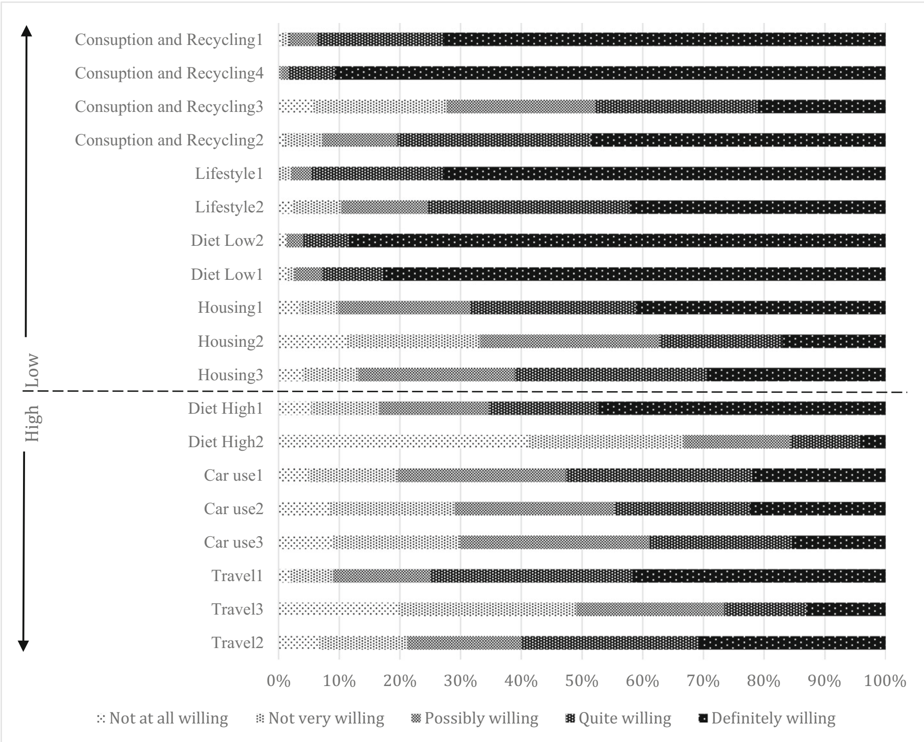

Fig. 1 Pre-service teachers' willingness to take mitigative climate change actions

to be the most effective. The results show that, in general, the participants perceived high-impact mitigative actions (Diet2, Travel, and Driving) to have a greater environmental impact than low-impact actions (Consumption and Recycling, Lifestyle, Living, and Diet1), but the data also shows that the teachers often perceived the difference between high-impact and low-impact actions as marginal, although in fact the differences may be very large. For instance, the

Table 3 Pre-service teachers' confidence in the knowledge and descriptive analysis of their perceptions of mitigative actions and their willingness to act

Topic (impact)	Core construct (range)			
	Perception (1–11) Mean (S.D)	Willingness (1–5)	Knowledge Percentage	Confidence in knowledge
Diet High (high)	6.60 (2.44)	3.00 (1.11)	42%	8%
Travel (high)	6.50 (2.33)	3.47 (0.95)	29%	9%
Car use (high)	6.30 (2.24)	3.32 (1.09)	30%	4%
Consumption and Recycling (low)	5.13 (2.18)	4.27 (0.52)	15%	8%
Lifestyle (low)	4.67 (2.32)	4.35 (0.69)	20%	12%
Housing (low)	4.37 (1.78)	3.59 (0.85)	46%	6%
Diet Low (low)	3.60 (1.71)	4.76 (0.57)	31%	8%

mean values for the impact of *Car use* (6.3) and *Consumption and Recycling* (5.13) are relatively close to each other, although in reality the impact of the actions related to *Car use* is many times greater than those related to *Consumption and Recycling* (see Table 1 for comparison). Intriguingly, less than 12% of the pre-service teachers were confident or somewhat confident about their answers.

Correlation

To determine whether there is a relationship between willingness to act and participants' perceptions of impact or knowledge of impact, we examined the correlation in the seven categories.

As shown in the upper part of Table 4, there were no significant correlations between the constructs of willingness and perception, except in *Lifestyle (.137)*, which indicated a small effect. In addition, significant correlations were not found between willingness to act and knowledge of impact (see the lower part of Table 4). That is, the students' willingness to act is not affected by their perceptions or knowledge of the impact of the actions, but by some other factors. However, since the participants' confidence in their own knowledge was very low, it is hard to conclude that knowledge may not impact willingness to act, so we further explored the relationships of knowledge and willingness to act by examining the confidence in knowledge that the teachers had.

Confidence in knowledge positively correlated with knowledge of three of the high-impact mitigative actions (Car use (.215), Diet2 (.137) and Travel (.236)), although the effect sizes were small (see the upper part of Table 5). A positive correlation was also found between confidence of knowledge and willingness to act on *Travel*-related (.134) and *Housing*-related *(.175)* issues (see the lower part of Table 5). We can therefore assume that, for instance, when students get more

Table 4 Correlation between willingness, perception, and knowledge

Willingness	Diet High	Car use	Travel	Consumption & Recycling	Lifestyle	Housing	Diet Low
Perception							
Diet High	.044	.065	-.049	-.039	.036	.041	.154*
Driving	-.035	-.035	-.116	-.147*	.093	-.052	-.002
Travel	-.012	.043	.035	-.059	.035	-.012	.084
Consumption & Recycling	-.030	.096	-.003	-.040	.113	.035	.110
Lifestyle	-.016	.097	-.019	-.061	**.137***	.035	.087
Housing	.059	.103	.066	.114	.095	.106	.058
Diet Low	.054	.116	.020	.005	.029	.104	.102
Knowledge							
Diet High	.040	.022	.053	-.038	.034	.050	.077
Driving	-.140*	-.061	-.123	-.208**	.024	-.041	-.071
Travel	-.032	.025	.039	-.081	-.001	.038	.029
Consumption & Recycling	.032	-.089	.003	.061	-.085	-.016	-.132*
Lifestyle	.064	-.006	.028	.093	.004	.028	-.134*
Housing	.013	-.084	-.064	-.096	-.038	-.036	-.004
Diet Low	.072	.015	-.002	.047	.012	-.023	-.063

knowledge of the impact of mitigative actions related to Travel, their confidence in their knowledge of Travel will increase, and their increasing confidence in their knowledge of Travel will affect their willingness to engage positively with the Travel-related mitigative actions. Therefore, although no relationships were found between mere knowledge and willingness, *achieving knowledge with confidence* may be an important factor in making students participate in mitigative actions.

Discussion

Previous studies have found that pre-service teachers' understanding of climate change issues is unacceptably low (e.g., Ratinen, 2013; Boon, 2010; Puk & Stibbards 2012; Lambert & Bleicher, 2013). The findings of this study show that this is also the case regarding knowledge of mitigative actions. More specifically, this study shows that, at best, Finnish pre-service teachers have a vague understanding of the mitigative impact of different actions but in general their level of knowledge and especially their confidence in their knowledge of mitigative actions are low. The low level of knowledge shows that the majority of pre-service teachers had false perceptions of the impact of mitigative actions. Participants especially underestimated the impact of high-impact actions and overestimated the impact of low-impact actions, a trend that was also noted in the context of energy by Attari et al. (2010). Significantly, this study gives insight into how big of a problem this issue with false perceptions really is. For instance, the data shows that pre-service teachers consider consumption- and recycling-related activities to have almost an equal impact on climate change to travel, although the items in the travel category are actually 5–10 times more effective mitigative actions than those in consumption and recycling. In essence, pre-service teachers seem to consider all mitigative actions to have a moderate impact and are unable clearly to distinguish between low- and high-impact actions.

Table 5 Correlation between certainty, knowledge, and willingness

Knowledge \ Certainty	Car use	Diet	Travel	Consumption & Recycling	Lifestyle	Housing
Knowledge						
Car use	**.215****	.131	.108	.139*	.183**	.066
Diet High	.114	**.137***	.085	.087	.050	.027
Diet Low	-.081	-.044	-.094	-.143*	-.066	-.083
Travel	.116	.097	**.236****	.129	.157*	.137*
Consumption & Recycling	.023	-.002	-.013	.000	.048	-.013
Lifestyle	.061	.044	.004	.020	.042	.034
Housing	.042	.087	-.009	.011	-.004	.066
Willingness						
Driving	.042	.073	.065	.043	.013	.086
Diet High	-.080	.115	-.008	.003	-.029	-.025
Diet Low	-.120	.057	-.052	.006	.003	-.039
Travel	.053	.111	**.134***	.179**	.104	.085
Consumption & Recycling	-.043	.042	-.036	-.063	-.095	-.099
Lifestyle	.092	.141*	.103	.101	.028	.071
Housing	.169*	.151*	.150*	.107	.137*	**.175****

Increasing Knowledge to Support Action Competence

The findings suggest that, in order for pre-service teachers to teach action competence (Jensen 2002; Jensen, & Schnack, 1997), empower their students to take action (e.g., Anderson, 2012; Schreiner, et al. 2005), and address students' questions on climate change mitigation (Tolppanen & Aksela, 2018), they need more specific knowledge of the impact of different mitigative actions. Furthermore, pre-service teachers should be made aware of their possible single-action bias (see Weber, 2010) by debunking their perceptions regarding the impact of different mitigative actions. One way to approach this would be to encourage the teachers to analyze their environmental actions critically (see Tolppanen, 2015), taking the carbon footprint of their actions into consideration. This process of critical analysis is what distinguishes environmental action from mere environmental behavior (see Jensen & Schnack, 1997) and at best can lead to a dissatisfaction of current understanding and the openness to accommodate new beliefs (Posner et al., 1982) and ultimately new behavior (Bandura, 2011). One way to do this could be first to familiarize participants with the carbon emission cuts that need to be reached in the coming decades and then ask participants to create for themselves a "carbon diet," in which they reduce their personal carbon footprint by 10%, 20%, or 30%. In doing so, participants would need to examine the impact of each action on climate change, as well as their willingness to take those actions. Such a planning process could help participants realize the great difference in the impact of different mitigative actions, as well as help them to understand which actions by individuals are most needed in order to combat climate change. Ideally, it may even affect their willingness to take high-impact actions rather than only low-impact ones.

One reason why pre-service teachers do not distinguish between high-and low-impact actions could be that they may perceive climate change mitigation and environmental protection as one entity, assuming that everything that is good for the environment is also good for climate change mitigation, and vice-versa. In the current study, the strongest indication of mixing up environmental issues is seen in how pre-service teachers perceive nuclear power; although its mitigative impact is the same (or similar) as that of green energy, participants tend to think that it has a smaller mitigative impact. This is in line with previous studies that have shown that individuals do not necessarily see nuclear power as part of the solution to climate change mitigation (Vainio et al., 2017). Therefore, to develop pre-service teachers' education, a distinction between climate actions and general environmentally friendly actions needs to be made. One way to do this could be to compare the environmental impact and climate impact of several pro-environmental actions such as locally produced organic food in a cold climate and internationally produced food that has been sprayed with pesticides. In this comparison, ethical issues such as work conditions can also be considered in order to show the array of things that may affect our consumption habits. Based on the comparison, differences between environmental impact, climate impact, and social impact could be discussed to help people understand why they should be distinguished from each other.

The Depth of the Knowledge-Behavior Gap

The findings of this study show that pre-service teachers are mostly willing to take low-impact mitigative actions, but reluctant to take high-impact ones. This is in line with a previous qualitative study which indicated that Finnish teachers mainly state that they take only low-impact actions (Hermans, 2016). The findings also show that the teachers are aware that the actions they are willing to undertake may not have the greatest mitigative impact, suggesting that some level of a knowledge-behavior gap (see Kollmuss and Agyeman, 2002) exists. However, to understand the depth of the knowledge-behavior gap in climate change mitigation, we must first be confident that the participants answering a question correctly have not merely made a lucky guess. In many of the questions of this study (9/19), the participants received lower scores than if they had merely guessed their answers. Furthermore, participants' confidence in their knowledge was very low (4–12% were confident in their answers) so, in order to understand whether a knowledge-behavior gap exists in climate change mitigation, it would be necessary first to improve the participants' level of knowledge of mitigative issues. For more in-depth analysis, it would also be useful to examine actual behavior rather than just intent, or willingness to act. However, as a knowledge-behavior gap has been shown to exist in environmental contexts other than climate change (Kollmuss & Agyeman, 2002), it is fair to assume that such a gap also exists in climate change–related issues. One way to potentially decrease such a gap is to address the potential negative impacts of climate change and help students understand that these negative impacts are not distant problems, as they will be increasingly realized in the next few decades. Combining this knowledge to behavior could be done through exercises, such as the "carbon diet" explained above, as such tasks can help change habits and make planned behavioral change, rather than living spontaneously. The rationale to do so is that studies have shown that individuals most concerned about climate change are also the most willing to take action to mitigate it (SITRA, 2019). That said, if students see climate change mitigation as impossible, this can affect their emotional well-being (Pihkala, 2018), so students must be given abundant tools to mitigate climate change as individuals and members of society. These can include personal responsible action such as lifestyle choices, participatory actions such as voting, and future-oriented actions such as deciding to address climate change issues with their own students (see Vesterinen et al., 2016).

Interestingly, confidence in knowledge was found to have a stronger correlation with willingness to act than knowledge itself. This suggests that people want to be sure that they are making a significant environmental impact before undertaking mitigative actions that will affect their lives. It is also worth noting that confidence in knowledge correlated with some of the high-impact actions, but none of the low-impact actions. This may suggest that once an individual's confidence in the impact of certain actions increases, they are more willing to take those high-impact actions as they understand their significance. As confidence in knowledge has not been examined in previous studies, the low confidence found in this study also raises the uncomfortable question of how well previous studies have managed to measure knowledge rather than the hunches or lucky guesses of participants. We can assume that, at least in some of these studies where confidence has not been measured, it would be more correct to talk about a knowledge deficit rather than a knowledge-behavior gap. As confidence in knowledge seems to be a better indication of willingness to act than knowledge itself, future studies examining the relationship between climate change knowledge and willingness to act should take confidence in knowledge into consideration. Furthermore, to address the depth of the knowledge-behavior gap, future studies should examine whether increasing one's confidence in knowledge has an effect on willingness to act. Examining this more deeply may further help explain why individuals are not doing more to combat climate change, even though they show deep concern about it (ilmastobarometri, 2019). Based on our findings it seems that pre-service teachers do not know what they should do, or at least they do not believe that the impact of high-impact actions is as impactful as it truly is. Unfortunately, this indicates that the teachers do not have the tools to teach action competence (Jensen 2002; Jensen, & Schnack, 1997) to their students, nor would they be able to answer their students' questions on climate change mitigation (see Tolppanen & Aksela, 2018). Future studies should examine how pre-service teachers' knowledge of climate change mitigation can be improved, and how an improved level of knowledge and confidence may affect willingness to act, conceptual change, and actual behavior. One interesting area of focus in pre-service teacher education (at least in Finland) should be on the impact of walking short distances and changing the destination of long-distance flights. If participants could be encouraged to take these two actions alone, their annual carbon footprint would decrease by around 5–20% a year. In both these categories, participants showed a relatively high willingness to act, although their level of knowledge was low. Furthermore, willingness to act increased as confidence in knowledge increased, so further studies should examine whether increasing knowledge of these two issues in particular could help pre-service teachers adopt a more environmentally friendly lifestyle. However, as previous studies indicate that a knowledge-behavior gap does exist in environmental issues (Kollmuss & Agyeman, 2002), climate change education should not only focus on increasing knowledge, but also on providing a platform to discuss and evaluate values, social norms, and emotions, and to develop pre-service teachers' future-oriented thinking skills, as has been presented in the model for holistic climate change education (Tolppanen, et al., 2017; Cantell, et al., 2019). Studies have also found that presenting students with interesting and convincing reading on climate change may help them change their attitudes and willingness to act towards climate change mitigation (Sinatra et al. 2012).

Limitations of the Study

One of the limitations of this study is that it was conducted in a single country, Finland. Future studies should examine whether similar findings are found in other parts of the world, but as previous studies show that teachers have a low level of knowledge of climate change (see, e.g., Boon, 2010; Puk & Stibbards, 2012; Lambert & Bleicher, 2013), it is likely that their level of knowledge of mitigative issues is also low, as was found in this study. Another limitation is that this study did not examine how teaching practices affect pre-service teachers' knowledge and willingness to act on climate change, so the findings only shed light on the existence of a problem in education on climate change mitigation, but are not able to give concrete suggestions on how this problem could be solved, other than of course by stating that pre-service teachers' knowledge of mitigative actions needs to be increased. That said, future studies should examine pre-post test results after implementing an intervention on climate change issues, which also address mitigation.

Conclusions

In order to combat climate change through education, pre-service teachers' knowledge of climate change mitigation needs to be increased. As confidence in knowledge increases, individuals may also be more willing to take more high-impact mitigative actions. Most importantly, teachers will be able to educate the future generations on the lifestyle choices needed to significantly reduce carbon emissions. Increasing knowledge is one important aspect of climate change education, as it helps increase action competence among teachers and students. However, as this study and numerous previous studies show, the relationship between knowledge and willingness to take action is not straightforward and it is naïve to say that increasing knowledge of mitigative issues is sufficient to decrease carbon footprints significantly. Many other factors are also at play, and more research is needed to understand how pre-service teacher training can take these factors into consideration, so that our teachers will be able to train a new generation of critical and action-competent citizens.

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Appendix

Table 6

Action	GHG impact data	Other assumptions	References
Traveling short distances on foot or by bike (=100 km/week)	Direct emissions from petrol car 135 g CO_2eq/km Emissions from petrol car manufacturing 20 gCO_2eq/km Petrol production 15 gCO_2eq/MJ	Fuel consumption of petrol car 2.3 MJ/km	Liikennevirasto 2018 VTT Technical Research Centre of Finland 2017 Chester & Horvath 2009
Flying a mid-distance flight (Barcelona) instead of a long distance (Bangkok)	Direct emissions of a long-haul flight 114 gCO_2eq/pkm (passenger km) Direct emissions of a long-distance flight 165 gCO_2eq/pkm Emissions from plane manufacturing 7 gCO_2eq/pkm Emissions from jet fuel manufacturing 15 gCO_2eq/MJ	Fuel consumption of a long-haul flight 1.6 MJ/pkm Fuel consumption of a long-distance flight 2.2 MJ/-pkm Length of long-haul flight 16,000 km Length of long-distance flight 5300 km	VTT Technical Research Centre of Finland 2009 Chester & Horvath 2009
Traveling by train across Finland (Helsinki-Rovaniemi) instead of a mid-distance flight (Barcelona)	Emissions from train manufacturing 20 gCO_2eq/pkm	Electricity used is 100% hydro energy Length of train travel 1800 km	VR Group 2018 Chester & Horvath 2009
Changing petrol car for a hybrid car	Direct emissions from petrol car 135 gCO_2eq/km Emissions from petrol car manufacturing 20 gCO_2eq/km Petrol production 15 gCO_2eq/MJ Emissions from electric car manufacturing 35 gCO_2eq/km Electricity production 48.6 gCO_2eq/MJ	Annual kilometers 12,000 km Fuel consumption of petrol car 2.3 MJ/km Electricity share for hybrids 0.425	Liikennevirasto 2018 VTT Technical Research Centre of Finland 2017 Plötz et al. 2017 Chester & Horvath 2009
Changing petrol car for an electric car	Direct emissions from petrol car 135 gCO_2eq/km Emissions from petrol car manufacturing 20 gCO_2eq/km Petrol production 15 g CO_2eq/MJ Emissions from electric car manufacturing 35 gCO_2eq/km	Annual kilometers 12,000 km Electricity share for hybrids 0.425 Fuel consumption of a petrol car 2.3 MJ/km Electricity consumption of an electric car 0.7 MJ/km	Liikennevirasto 2018 VTT Technical Research Centre of Finland 2017 Chester & Horvath 2009

(continued)

Action	GHG impact data	Other assumptions	References
	Electricity production 48.6 gCO_2eq/MJ		
Changing petrol car for a biogas car	Direct emissions from petrol car 135 gCO_2eq/km Emissions from petrol or biogas car manufacturing 20 gCO_2eq/km Petrol production 15 gCO_2eq/MJ Biogas production 12 gCO_2eq/MJ	Annual kilometers 12,000 km Fuel consumption of a petrol car 2.3 MJ/km Fuel consumption of a biogas car 1.0 MJ/km	Liikennevirasto 2018 VTT Technical Research Centre of Finland 2017 Chester & Horvath 2009
Having one vegetarian day a week	GHG emissions of sauce with chicken and pasta: 1.95 $kgCO_2eq/serve$ GHG emissions of ground beef casserole: 3.81 $kgCO_2eq/serve$ GHG emissions of soybean patty and mashed potatoes: 1.17 $kgCO_2eq/serve$ GHG emissions of beetroot patty with barley: 0.98 $kgCO_2eq/serve$	Two warm meals a day. Example meals includes salad, bread etc. which are not considered in this calculation. Percentages of warm ingredients listed are 68%, 45%, 44% and 35%.	Saarinen et al. 2011
Switching beef to chicken once a week	GHG emissions of beef: 35 $kgCO_2eq/kg$ GHG emissions of chicken: 5 $kgCO_2eq/kg$	One meal includes 200 g of meat	Savikko et al., 2013
Switching half of main meals to vegetarian ones	GHG emissions of sauce with chicken and pasta: 1.95 $kgCO_2eq/serve$ GHG emissions of ground beef casserole: 3.81 $kgCO_2eq/serve$ GHG emissions of soybean patty and mashed potatoes: 1.17 $kgCO_2eq/serve$ GHG emissions of beetroot patty with barley: 0.98 $kgCO_2eq/serve$	Two warm meals a day. Example meals include salad, bread etc. which are not considered in this calculation. Percentages of warm ingredients listed are 68%, 45%, 44% and 35%	Saarinen et al. 2011
100% vegan	GHG emissions of soybean patty and mashed potatoes: 1.17 $kgCO_2eq/serve$ GHG emissions of broad bean patty and mashed potatoes: 0,65 $kgCO_2eq/serve$	Two warm meals a day. Example meals include salad, bread etc. which are not considered in this calculation. Percentages of warm ingredients listed are 44% and 47%	Saarinen et al. 2011

(continued)

Action	GHG impact data	Other assumptions	References
Recycling of all paper, cardboard, metal and glass	GHG emissions of recycling -cardboard 0.003 $kgCO_2eq/kg$ -paper − 0.253 $kgCO_2eq/kg$ -metal − 1.104 $kgCO_2eq/kg$ -glass − 0.104 $kgCO_2eq/kg$	Amount of waste/person/a -cardboard 13 kg -paper 15 kg -metal 5 kg -glass 4 kg	Saarinen 2014 Lounais-Suomen jätehuolto 2017 HSY 2016
Eating all leftovers and not throwing any food away	GHG emissions of a person's food waste: 190 $kgCO_2eg/a$		Häkkinen and Kangas, 2012
Buying half of the clothes second hand	GHG emissions of an average Swedish's fashion purchases: 250 $kgCO_2eq/a$		Roos et al. 2015
Using mobile phone 2 years instead of a year before getting a new one	GHG emissions from production and raw materials of a smartphone: 49.8 $kgCO_2eq$		Ercan et al. 2016
Turning off all appliances when not in use	One person can save approximately 10.3 $kgCO_2eq$		Sitra 2017
Spending 30 min less in a shower weekly	GHG emissions of an average Finnish district heating: 188 gCO_2eq/kWh	Shower consumes water 12 l/min Energy needed to heat 1 l of water: 0.04 kWh/l	Motiva 2018 Turku Energia (n.d.)
Switching to green/nuclear electricity	GHG emissions of an average Finnish electricity production: 164 gCO_2eq/kWh GHG emissions of green/nuclear energy: 0 gCO_2eq/kWh	Energy consumption of 2 persons living in an apartment: 1900 kWh/a Only direct emissions from production phase are considered.	Motiva 2018 Adato Energia 2013
Moving to a smaller apartment	GHG emissions of an average Finnish district heating: 188 gCO_2eq/kWh	An average heating energy consumption of 1980's apartment building: 55 $kWh/m^3/a$	Motiva 2018 Motiva 2016
Replacing old windows with new ones	GHG emissions of an average Finnish district heating: 188 gCO_2eq/kWh GHG emissions of an average Finnish electricity production: 164 gCO_2eq/kWh	New windows are 200 $kWh/m^2/a$ more energy efficient than old ones Area of windows 12 m^2 Energy consumption of producing timber-aluminum framed window (1.2 × 1.2 m) with argon: 4287 MJ Finnish electricity mix used for production Lifespan of windows: 50 a	Motiva 2016 Lumme Energia 2014 Teenou 2012
Talking a friend living in an average detached house into switching to green electricity	GHG emissions of an average Finnish electricity production: 164 gCO_2eq/kWh	Energy consumption of 4 persons living in a detached house: 7300 kWh/a	Motiva 2018 Adato Energia 2013

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