TRANSITIONS PATHWAYS AND RISK ANALYSIS FOR CLIMATE CHANGE MITIGATION AND ADAPTATION STRATEGIES

# D4.2: Implications of different “heterodox” mitigation policies: the role of behavioural changes

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# Preface

Both the models concerning the future climate evolution and its impacts, as well as the models assessing the costs and benefits associated with different mitigation pathways face a high degree of uncertainty. There is an urgent need to not only understand the *costs and benefits* associated with *climate change* but also the *risks, uncertainties and co-effects* related to different *mitigation pathways* as well as *public acceptance* (or lack of) of low-carbon (technology) options. The main aims and objectives of TRANSrisk therefore are to create a novel assessment framework for analysing costs and benefits of transition pathways that will integrate well-established approaches to modelling the costs of resilient, low-carbon pathways with a wider interdisciplinary approach including risk assessments. In addition *TRANSrisk* aims to design a decision support tool that should help policy makers to better understand uncertainties and risks and enable them to include risk assessments into more robust policy design.

# PROJECT PARTNERS

| No | Participant name | Short Name | Country code | Partners' logos |
|---|---|---|---|---|
| 1 | Science Technology Policy Research, University of Sussex | SPRU | UK | |
| 2 | Basque Centre for Climate Change | BC3 | ES | |
| 3 | Cambridge Econometrics | CE | UK | |
| 4 | Energy Research Centre of the Netherlands | ECN | NL | |
| 5 | Swiss Federal Institute of Technology (funded by Swiss Gov't) | ETH Zurich | CH | |
| 6 | Institute for Structural Research | IBS | PL | |
| 7 | Joint Implementation Network | JIN | NL | |
| 8 | National Technical University of Athens | NTUA | GR | |
| 9 | Stockholm Environment Institute | SEI | SE, KE | |
| 10 | University of Graz | UniGraz | AT | |
| 11 | University of Piraeus Research Centre | UPRC | GR | |
| 12 | Pontifical Catholic University of Chile | CLAPESUC | CL | |

# Executive Summary

Mainstream literature on climate change concentrates overwhelmingly on technological solutions for this global long-term problem. Research effort has focused primarily on how the portfolio of existing and future technologies can contribute to meet the world's energy demand over the next century and, at the same time, limit GHG emissions so that they are consistent with a stabilisation of temperature change below 1.5 – 2 ºC (IPCC 2014). According to the IPCC (2014, page 89), the mitigation effort needed is so great that changes in human behaviour will be necessary on top of technological solutions: "The existence of limits to adaptation suggests transformational change may be a requirement for sustainable development in a changing climate — that is, not only for adapting to the impacts of climate change, but for altering the systems and structures economic and social relations, and beliefs and behaviours that contribute to climate change and social vulnerability."

Generally, as the limited studies in literature so far shows, a change towards climate friendly behaviour by citizens could have a significant impact on GHG emissions. This report focuses on the potential climate mitigation by behavioural change in the European Union covering many behavioural options in food, mobility and housing demand, not only in the energy domain, and uses an Integrated Assessment model (GCAM model) that can capture the direct and indirect implications of behavioural change in terms of emissions.

Our results indicate that modest to rigorous behavioural change could reduce per capita footprint emissions by 6% to 16%, out of which one fourth would be reduced in regions other than the EU itself. These GHG savings within the EU itself represent emission sectors that are among the most difficult to be mitigated with a carbon tax. Therefore, these 4.5% to 12% of domestic GHG savings would yield a 13.5% to 30% reduction in policy costs.

The other 1.5% to 4% of non-domestic GHG emission savings are predominantly realized by freeing up cropland for forests, grasslands, pasture lands and biomass production. By having a significant impact in the reduction of global agricultural land pressure, the modelled behavioural change in (mainly) the food sector could reduce global staple crop prices by up to 5% compared to their projected price paths.

Finally, many of the modelled behavioural options would also yield co-benefits such as monetary savings, positive health impacts or animal wellbeing. In practice, it has proven easier to convince consumers to adapt climate-friendly behaviour when the co-benefits are more significant. However, in order to convince an increasing amount of consumers to adopt the modelled behavioural changes, it is essential to significantly improve climate change awareness.

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# 1 EC SUMMARY REQUIREMENTS

## 1.1 Changes with respect to the DoA

There are no major changes to the overall deliverable in respect to the Grant Agreement. We have, however, added “the role of behavioural changes” to the title, as we decided to place greater emphasis on behavioural changes as part of different mitigation portfolios than originally planned. The behavioural change focus stemmed from a literature review, which found that behavioural change was an important mitigation action that had been under studied.

## Dissemination and uptake

This Deliverable is a ‘work-in-progress’ document. As such it will not be made public (without the permission of the authors) in its current form until either, a) papers stemmed from part of the Deliverable are published or, b) the end of the TRANSrisk project.

## 1.2 Short Summary of results (<250 words)

Mainstream literature on climate change concentrates overwhelmingly on technological solutions for this global long-term problem, while a change towards climate friendly behaviour by citizens could also significantly reduce GHG emissions. This paper focuses on the potential climate mitigation by behavioural change in the European Union covering many behavioural options in food, mobility and housing demand using an Integrated Assessment model (GCAM model), capturing both their direct and indirect implications in terms of GHG emissions. Our results indicate that modest to rigorous behavioural change could reduce per capita footprint emissions by 6% to 16%, out of which 4.5% to 12% would be reduced within the EU and one fourth outside (predominantly by reducing land use emissions abroad). The domestic emissions savings would contribute to reduce the costs of achieving the internationally agreed climate goal of the EU by 13.5% to 30%. Finally, many of the modelled behavioural options would also yield co-benefits such as monetary savings, positive health impacts or animal wellbeing.

## 1.3 Evidence of accomplishment

This deliverable.

# 2 INTRODUCTION

Mainstream literature on climate change concentrates overwhelmingly on technological solutions for this global long-term problem. Research effort has focused primarily on how the portfolio of existing and future technologies can contribute to meet the world's energy demand over the next century and, at the same time, limit GHG emissions so that they are consistent with a stabilisation of temperature change below 1.5 – 2 ºC (IPCC 2014). For example, Pacala and Socolow (2004) showed that there is already a portfolio of measures that, if implemented, can deliver a significant reduction of emission during the first half of the century. Fifteen different measures were proposed in that influential paper to reduce GHG emissions (1 GtC/year per each option), among them switching coal plant to wind or nuclear power, efficiency improvements in cars or $CO_2$ capturing options). Only one of these measures was a behavioural-based solution: reduce the use of vehicles from 2 billion 30-mpg cars from 10,000 to 5000 miles per year.

The mitigation effort that will be needed is so great that more changes in human behaviour will be necessary. According to IPCC (2014, page 89), "The existence of limits to adaptation suggests transformational change may be a requirement for sustainable development in a changing climate — that is, not only for adapting to the impacts of climate change, but for altering the systems and structures economic and social relations, and beliefs and behaviours that contribute to climate change and social vulnerability."

Apart from a handful of papers focusing on the housing and mobility demand (Dietz et al 2009, Gifford et al 2011a) as well as food demand (Bajželj et al 2014), the total mitigation potential due to behavioural action has received little investigation. Dietz et al (2009) use a behavioural approach to examine the achievable near-term reductions by altered adoption and use of available technologies in US homes and non-business travel. They found 17 household action types in 5 behaviourally distinct categories by use of data on the most effective documented interventions that did not involve new regulatory measures. According to this study, the US could save an estimated 123 million metric tons of carbon per year in 10 years (20% of total household direct emissions or 7.4% of US national emissions), with little or no reduction in household well-being. However, this study focuses primarily on solutions with implications for the energy sector, which represents the largest share of greenhouse gas emissions (70% of all GHG emissions). In contrast, Bajželj et al (2014) use a global land-system model to estimate the impact of changing food demand on greenhouse gas emissions. They show that a demand side reduction, such as reducing food waste and adopting a "healthy" diet, could more than offset the projected increase in GHG emissions from the agricultural sector due to global population growth.

Generally, as the limited studies in literature so far shows, a change towards climate friendly behaviour by citizens could have a significantly negative impact on GHG emissions. Apart from that, many of these options usually have negative monetary costs and in some cases imply significant health co-benefits (WHO 2003). However, there are several psychological barriers to behavioural change (Whitmarsh 2009), even if the individual´s welfare effect is positive (Gifford 2011b). Public policies might therefore be necessary to stimulate certain behaviour.

This report focuses on the potential climate mitigation by behavioural change in the European Union[1] that goes beyond the study by Dietz et al (2009) as: a) it covers many of the options in food, mobility and housing demand, not only in the energy domain; and b) it uses an Integrated Assessment model (GCAM model) that can capture the direct and indirect implications in terms of emissions[2]. These options will be described in detail in section 3.2.

These mitigation impacts will be presented relative to the socioeconomic baseline scenario and the EU NDC-scenario, representing the promised emission targets by the European Union in advance of the UNFCCC COP21 conference in Paris. These scenarios will be explained in detail in section 3.3. A discussion of the results per behavioural option will be provided in section 4 and three different "behavioural mitigation" profiles will be described to give an indication of the total potential that behavioural changes could contribute towards climate change mitigation.

The results of this report will focus on per capita GHG emissions savings due to behavioural change- with the recognition that some people will change their behaviour more easily than others. Factors like income and household size (Poortinga et al 2004) and social influences (Staats et al, 2004) are of high importance, among other factors. By focusing on the positive question on to which extend climate-friendly behaviour can contribute to climate mitigation, we mainly skip the normative question on how to convince people to adapt their behaviour for further research, although we discuss the literature on this topic briefly in section 5.1.

[1] We focus on the EU-27, so excluding Croatia which joined the EU in mid-2013. The reason behind this is that the GCAM model does not yet include Croatia in the modelled EU-region. Croatia represented about 0.83% of total population and 0.33% of total GDP in the European Union in 2015 (source: EuroStat).

[2] A similar objective has been investigated in the 6th (Exiopol project, DIV.2.c) and 7th (CarbonCap project, D6.2) Framework programme of the EC, although these focus on different behavioural options and use a different kind of model to estimate the impacts.

# 3 METHOD

## 3.1 Overview

The method section is structured as following: first we discuss the GCAM model in general and the way it has been applied in our study. We then discuss the assumptions made for each modelled behavioural option. Finally, we discuss the baseline and policy scenario that we run on the background of these options.

### 3.1.1 GCAM Model

This study applies the Global Change Assessment Model (GCAM), an integrated assessment model that links the world's energy, agriculture and land use systems with a climate model. GCAM traces its origin to a model developed by Edmonds and Really (1985) and was previously known as MiniCAM (see Edmonds et al. 1997). It is a community model developed and run at the Joint Global Change Research Institute, University of Maryland. GCAM was one of the four models chosen by the Intergovernmental Panel on Climate Change (IPCC) to create the Representative Concentration Pathways (RCPs) for the IPCC's Fifth Assessment Report (see Thomson et al. 2011).

GCAM is a dynamic recursive economic partial equilibrium model. It is driven by assumptions about population size and labour productivity that determine gross domestic production (GDP) in 32 geopolitical regions, operating on 5-year time steps from 1990 to 2100. The model connects emissions and atmospheric concentrations of GHGs, carbonaceous aerosols, sulphur dioxide, and reactive gases to socioeconomic activities, and provides estimates of the associated climate impacts. An important feature of the GCAM architecture is the terrestrial carbon cycle model embedded within the agriculture-land-use system model. Thus, all land uses and land covers, including the non-commercial lands[3], are fully integrated into the economic modelling in GCAM. This coverage gives GCAM the capability to model socioeconomic preferences and policies that jointly cover emissions in all activities in the energy, agricultural and forestry sectors. These properties make the model suitable for comparing the potential savings of all greenhouse gases from a wide range of behavioural trends in the food, mobility and housing sectors. For more details on the GCAM model see Calvin et al (2011).

*The energy and land use systems*

GCAM contains detailed representations of technology options for each of its economic components with technology choice determined by market probabilistic competition (Clarke and

[3] The land use types in GCAM include: Cropland, Managed Forest, Managed Pasture (Commercial), Unmanaged Forest, Unmanaged Pasture, Grassland, Shrubland (Non-Commercial), Urban land, Tundra, Rock/Ice/Desert (exogenously given, excluded from land competition).

Edmonds 1993). The model produces outputs that include energy and agricultural prices and land use allocation. The model can track not only fossil fuel and industrial emissions, but also emissions associated to land use change.

The GCAM energy system includes primary energy resource production, energy transformation to final fuels, and the use of final energy forms to deliver energy services such as passenger kilometres in transport or space conditioning for buildings. GCAM distinguishes between two different types of resources: depletable and renewable. Depletable resources include fossil fuels and uranium; renewable resources include wind, geothermal energy, municipal and industrial waste (for waste-to-energy), and rooftop areas for solar photovoltaic equipment. All resources are characterized by cumulative supply curves, i.e. upward-sloping supply-cost curves that represent the idea that the marginal cost of resource utilization increases with deployment. Carbon capture and storage (CCS) technology is available for application to large, point-source emission facilities. These include electric power generation, hydrogen production, cement manufacturing and large industrial facilities. A complete documentation of all the technologies in the energy system is provided in Clarke et al. (2009).

The agriculture and land use component[4] is fully integrated into (i.e. solved simultaneously with) the GCAM economic and energy system components. Data for the agriculture and land use parts of the model comprises of 283 sub-regions in terms of land use, based on a division of the extant agro-ecological zones (AEZs). Land is allocated between the various uses based on expected profitability, which in turn depends on the productivity of the land-based product (e.g. mass of harvestable product per ha), product price, and non-land costs of production (labour, fertilizer, etc.). The productivity of land-based products is subject to change over time based on future estimates of crop productivity change. This increase in productivity is exogenously set, adopted from projections from FAO (Bruinsma 2003). GCAM includes several different commercial and non-commercial land uses including ten crop categories[5], six animal categories[6], three bioenergy categories (described below), forests, pasture, grassland, shrubs, desert, tundra, and urban land. All agricultural crops, other land products, and are globally traded within GCAM, whereas animal products are only traded on a regional level.

Bioenergy in GCAM is classified into three categories: traditional bioenergy, bioenergy from waste products, and purpose-grown bioenergy. Traditional bioenergy comprises straw, dung, fuel wood and other energy forms that are utilized in an unrefined state in the traditional sector of an economy. Traditional bioenergy use, although significant in developing nations, is a relatively small component of global energy and, as regional incomes increase over the century, it becomes less economically competitive. Bioenergy from waste products, is a by-product of another activity. The amount of potential waste that is converted to bioenergy is based on the price of bioenergy.

[4] A full description of the agriculture and land use module in GCAM can be found in Kyle (2011) and Wise and Calvin (2011).
[5] The ten crop categories are Corn, Rice, Wheat, Other Grains, Sugar, Root Tuber, Palm Fruit, Fiber Crops, Oil Crops and Other Crops.
[6] The six animal product categories are Beef, Dairy, Pork, Poultry, Sheep/Goat and Others/Fish products.

However, the bioenergy price does not affect production of the crop from which the waste is derived. Purpose-grown bioenergy refers to crops whose primary purpose is the provision of energy. The amount produced of this category depends on the profitability with respect to other land-use options. The productivity of those crops is based on region-specific climate and soil characteristics and varies by a factor of around three across the GCAM regions. GCAM considers also the possibility of using bioenergy in the production of electric power and in combination with CCS technologies.

### 3.1.2 Use of GCAM in this project

We have used GCAM for this project in a way that differs significantly from its use in other studies. The model is usually used to test the impact of polices. Since climate policies, energy policies and land policies usually focus on either the price or the production of certain goods, services or gases, demand is indirectly impacted due to a change in prices.

In contrast, we are using it in this project to model preference changes by consumers in two GCAM regions, EU-15 and EU-12[7]. Indirectly, these preference changes will have an impact on prices and production of goods and services, which will have an impact on the production of greenhouse gases. Although we limit the modelling to EU-15 and EU-12, the global impacts of the modelled preference changes will be analysed on a global level in Section 4. For these two regions, we have also developed an independent and interconnected household waste module in order to estimate the impacts of waste recycling by consumers. See section 3.2.3.2 for more details on this module.

## 3.2 The behavioural options

In 2008, the total GHG footprint of the average EU-27 consumer equalled 9.73 tons of $CO_2$ equivalent GHG gases. Food demand contributes to 17% of this footprint, whereas mobility and housing demand contribute respectively to 23% and 29% of per capita footprint emissions (Arto et al 2012). Therefore, this study focuses on the behavioural options within these three end-use sectors: the food, mobility and housing sector. See Table 1: List of behavioural options for the specific options within each sector. These options are chosen for their behavioural aspects. The idea behind the selection of these options is that they are free of charge and can be adopted from one day to another, without the need of personal monetary investments[8]. Whereas some options are mutually exclusive while others might limit the effectiveness of other options. Finally, we will also focus on a ´optimal´ combination of options for each sector to see the total mitigation

[7] EU-15: Germany, UK, France, Italy, Spain, Austria, Netherlands, Belgium, Portugal, Sweden, Denmark, Finland, Greece, Ireland and Luxembourg.
EU-12: Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovakia, Slovenia, Bulgaria and Romania

[8] Some behavioural options, such as public transport commuting, joining a car sharing program and waste recycling might require investment from public or private entities to meet the consumer´s demand.

potential. To clarify what every option includes, and how it is calculated, we will explain each of the options in detail in the rest of this section.

Table 1: List of behavioural options

| Food demand | Mobility demand | Housing demand |
|---|---|---|
| **Healthy diet**<br>**Vegetarian diet**<br>**Vegan diet**<br>**Food waste reduction** | Public transport commuting<br>Carpool commuting<br>Teleworking<br>Urban Cycling<br>Car sharing / Car club<br>Avoid short flights<br>Closer holidays<br>Eco-driving | Reduce heating / cooling<br>Organic waste recycling<br>Paper waste recycling<br>Plastic/metal/glass waste recycling |

Although we calculate all the listed options on an aggregate level, we present them on a per capita level. The reasoning behind this is as follows: while it is implausible that all EU-27 residents take up a specific behavioural mitigation method from today or tomorrow onwards, for every specific individual it is not at all implausible to change his/her behaviour from one day to the next. Also, while some individuals are convinced about reducing their food waste and joining a car sharing program, others might prefer to follow a healthy diet and recycle their waste. Since preferences differ between individuals, we chose to show the mitigation potential and co-benefits on a per capita level.

## 3.2.1 FOOD DEMAND

This section explains how behavioural options regarding food consumption are modelled. See Kyle et al (2011) for the methods and data sources used to model the agricultural and land-use system into GCAM.

### 3.2.1.1 Healthy diet

The assumed average healthy diet is considered to be `healthy' on the basis of nutritional evidence (Simon and Schuster 2001, WHO 2003, American Heart Association 2014). Following Bajželj et al (2014), we respect the dietary preferences in the EU-27, but with some foods that are deemed unhealthy above or below certain levels capped. See Table 2: Healthy diet assumptions for the precise current and assumed healthy diet for both EU-15 and EU-12[9]. The food categories in GCAM do not exactly match with the categories in Table 2: Healthy diet assumptions. Therefore, we

[9] We separate the diet in EU-15 and EU-12 due to their relevant dietary preferences. We use the estimations of Bajželj et al (2014) for West-Europe as a proxy for EU-15 and the estimations for East-Europe as a proxy for EU-12.

made sure that we applied the absolute changes in kcal/person/day of the GCAM food category containing the relevant category of Table 2: Healthy diet assumptions.

Table 2: Healthy diet assumptions

| Food | Current diet [1] | | Healthy diet [2] | Diet change | |
|---|---|---|---|---|---|
| | EU-15 | EU-12 | EU-27 | EU-15 | EU-12 |
| | Kcal / person / day | | | % change | |
| **Vegetables** | 58 | 64 | 136 | 134 | 113 |
| **Fruits** | 91 | 53 | 119 | 30.8 | 125 |
| **Sugar / Sweeteners** | 318 | 308 | 150 | -53 | -51 |
| **Vegetable oils** | 514 | 326 | 360 | -30 | 10.4 |
| **Red meat [3]** | 260 | 180 | 57 | -78 | -68 |
| **Poultry** | 67 | 70 | 70 | 4.48 | 0 |
| **Eggs** | 39 | 48 | 40 | 2.56 | -17 |
| **Dairy** | 391 | 313 | 300 | -23 | -4.2 |
| **Fish [4]** | 56 | 40 | 50 | -11 | 25 |
| **All other food [5]** | 933 | 1209 | 1218 | 30.5 | 0.74 |
| **TOTAL** | 2727 | 2611 | 2500 | -8.3 | -4.3 |

**[1] FAO (2013)**
**[2] Applying caps as interpreted by Bajželj et al (2014)**
**[3] Respecting the cultural red meat preferences between EU-15 and EU-12**
**[4] Due to limitations in global fisheries, these are kept constant at an EU-27 average**
**[5] Respecting the cultural food preferences between EU-15 and EU-12**

*Source: See table*

## 3.2.1.2 Vegetarian diet

A vegetarian diet does not include any meat, but does include dairy products and potentially fish products. We modelled this option by setting all the consumption of the GCAM categories Beef, Pork, Poultry and Sheep/Goat to zero. The reduction of calories will be replaced with the GCAM category MiscCrop[10] (including, between others, all kind of legumes, vegetables, fruits and nuts) until the daily net amount[11] of 2500 calories per person per day is reached.

#### 3.2.1.3 Vegan diet

Different than the vegetarian diet, the vegan diet does also not include dairy and fish products. The modelling method is exactly the same, replacing dairy products with MiscCrop products until the daily net amount[12] of 2500 calories per person per day is reached.

#### 3.2.1.4 Food waste reduction

Since waste is a rather subjective term, there are several approaches to account for food losses. Technically, we could consider food used as feed for animals as food waste, as it involves a loss in final calories for human purposes. Furthermore, we can distinguish waste at the agricultural, postharvest, processing, distribution and consumption levels (Kummu et al 2012, Bajželj et al 2014) and we can further distinguish consumption waste between avoidable, possibly avoidable (that some people eat and some people don´t eat, like bread crusts or potato skins) and unavoidable food waste like vegetable peelings and meat carcasses (WRAP 2008, van Westerhoven & Steenhuizen 2010). Since we are focusing on behavioural mitigation, we will focus solely on avoidable (including 50% of possibly avoidable) food waste on the consumer level.

Estimates from FAO (2011) are used to separate out the percentage of consumption waste from final food demand. Since the food demand estimations in GCAM are also based on FAO data, this seems the most sensible source for making assumptions on food waste. See Table 3: Food consumption and waste in EU-27, 2010 for the assumed food waste in EU-27 for different types of food.

A food waste reduction potentially reduces GHG emissions in two ways: less final food demand leads to less agricultural emissions and less food waste leads to less waste emissions. The latter, however, depends on what happens with the food waste: emission savings of a food waste reduction will be significant if this food waste would otherwise get landfilled, but the net effect would be negative if the food will otherwise be composted and used as a fertilizer, replacing mineral fertilizers (Bogner et al 2007). The current EU-27 recycling rate will be assumed for this behavioural option, unless we estimate the combined effect of Food Waste Reduction and Organic Waste Recycling[13]. More detail on these calculations follow in the section 2.2.3.3 about Waste Recycling.

[10] See table A1 in Appendix A for the total list of products that are included in MiscCrop.
[11] Net amount of calories after the subtraction of all producer and consumer food waste
[12] See footnote 5
[13] The combined effect of food waste reduction and organic waste recycling applies to two out of three behavioral profiles in section 3.3.

Table 3: Food consumption and waste in EU-27, 2010

| Food | Total EU-27 Consumption [1] | Total waste [2] | Consumer waste [2] |
|---|---|---|---|
| | Kcal / person / day | % of total consumption | |
| **Cereals** | 1177.4 | 34 % | 22 % |
| **Roots and Tubers** | 135.9 | 52 % | 10 % |
| **Oilseeds and Pulses** | 863.4 | 19.5 % | 3 % |
| **Fruits and Vegetables** | 288.0 | 46 % | 13.5 % |
| **Meat** | 569.7 | 22 % | 10 % |
| **Fish and Seafood** | 180.3 | 31 % | 8 % |
| **Dairy products** | 315.2 | 12.5 % | 7 % |
| **TOTAL** | 3529.9 | 28.1 % | 12.2 % |

[1] Includes all related industry and consumer wastes; FAOSTAT
[2] FAO (2011), "Global food losses and food waste – Extend, causes and prevention.

*Source: See table*

### 3.2.2 MOBILITY DEMAND

This section explains how behavioural options regarding to transport use are modelled. For a detailed documentation on how the transport system is modelled in GCAM, see Mishra et al (2013). The GCAM model uses estimates from the TREMOVE model (EC 2010a) for the base year calibration values in EU-27. Although the data from the TREMOVE model are based on modelled estimates rather than real observations, for reasons of consistency we follow this method by using the same model for more detailed estimates such as the share of urban transport or commuting transport in total transport demand.

#### 3.2.2.1 Public transport commuting

For this behavioural option, we assumed that all commuting transport demand in EU-27 (i.e. from home to work and back) will be met by public transport services (i.e. bus and rail transport). Currently around 20.7% and 17.9% of total passenger kilometres in respectively EU-15 and EU-12 are consumed for commuting between home and work. Of this commuting transport demand, currently only 15.1% in EU-15 and 29.3% in EU-12 is being met by public transport services (EC

2010a). For both geographic areas, we extrapolate the current regional public transport mix (i.e. the share of bus and rail transport) to meet all commuting transport demand from 2015 onwards.

#### 3.2.2.2 Carpool commuting

Similar to the previous option, we focus again on the current shares for commuting transport in EU-15 and EU-12 and assume them to stay the same into the future. Similar to Dietz et al (2009), this behavioural option is translated into numbers by stating a load factor of 2 for every commute car-trip, which is a minimal definition of car-pooling. Current commuting transport demand that is met by public transport and bike/motorbike use is left untouched.

Car trips currently yield around 76.2% of the total commuting passenger kilometres in EU-15, while around 58% in EU-12. Car load factors[14] for commuting transport are currently 1.19 in EU-15 and 1.87 in EU-12, whereas car load factors for all car transport are currently 1.65 and 2 respectively (EC 2010a). Assuming a car load factor for commuting transport of 2 while respecting the share of commuting kilometres in total passenger kilometres (20.7% and 17.9% in EU-15 and EU-12 respectively), we increased the overall load factor for all 4-wheel driven transport modes of 1.85 in EU-15 and 2.05 in EU-12 to model this behavioural option. Finally, in order to model only the emission savings as a result of this behavioural change, we cancelled out any kind of price elastic behaviour in favour of car transport following this adjustment.

#### 3.2.2.3 Teleworking

In order to model the effects of working one day per week from home, we have simply deducted the demand for total passenger transport by one fifth of the total share of commuting transport, i.e. 4.14% in EU-15 and 3.6% in EU-12[15]. This method implicitly assumes that EU-27 citizens currently work 5 days per week away from home.

#### 3.2.2.4 Urban Cycling

There are no easy and straightforward assumptions to make on the potential share for bicycles in total passenger transport. Variable factors like the trip distance and street steepness limit the realistic potential of cycling as an alternative transport mode. According to CBS (2016), the average trip distance for bicycle trips in the Netherlands between 2010 and 2014 was around 3.5 km. Moreover, while the bicycle was the main transport mode for trips up to 5 km, its share was very marginal for trips longer than 5 km. Apart from business trips and emergency services, bicycle use is proportionally distributed between a wide range of travel purposes in the Netherlands. Naturally, also street steepness is an important factor for the cycling potential, explaining (among

[14] The average amount of people carried by one car.
[15] Note that we did not model any changes in heating or cooling demand, assuming that the individual's heating/cooling demand at home and at work will be equal.

other reasons) why cycling is relatively popular in most cities in the Netherlands, Northern Belgium, Northern Germany and Denmark. Because of these facts, we aim to quantify the potential of bicycle usage for any purpose in urban areas only: trips within urban areas are on average quite short and streets within cities are generally flatter than streets outside cities. For non-urban passenger trips, it would be too difficult to generalize the potential for all EU-27 member states.

As a benchmark for the urban cycling potential, we take the urban cycling rate in the Netherlands. According to EC (2010a), slow mode transport (walking and cycling) accounts for 18.9% of total urban passenger transport in 2010, while total urban passenger transport accounts for about 29% of all passenger transport. Assuming the percentage of slow mode transport in urban areas for the whole of EU-27, this comes down to an average share of 5.4% of total passenger transport that would be met by walking and cycling together. GCAM reports the share of walking to account for 1.9% of passenger transport in EU-27 in 2010, so we assume that the potential share of bicycles in total EU-27 passenger demand will be around 3.5%. Note that while we keep the cycling share to 3.5% during all periods for this behavioural option, the walking share is subject to market competition (and decreases rapidly due to an increasing cost of travel time, see also: Mishra et al 2013).

#### 3.2.2.5 Car sharing / car clubs

Over the last decade, car sharing programs have been increasing significantly in popularity in the USA and Europe. Car-sharing is an innovative mobility option that allows individuals to pay for and use automobiles—on an as-needed basis—through membership programs (TCRP 2005). Although users of car sharing programs generally tend to drive less on average compared to car owners, due to the constant (rather than decreasing) marginal costs of driving that are faced in a car sharing program (Chen and Kockelman 2015), we are assuming an equal amount of passenger kilometres driven by cars in this behavioural option. This enables us to solely focus on the environmental benefits of car sharing, would the total amount of driven kilometres stay the same.

Ignoring the behavioural impact of car sharing on transport mode switching, there are two main channels through which car sharing would decrease emissions: lower industrial emissions related with car production and a higher average fuel efficiency due to a faster replacement rate of car-club vehicles compared to privately owned vehicles (Chen and Kockelman 2015). Although the faster replacement rate due to higher utilization rates of car-club vehicles do limit the savings in industrial emissions, the latter does not seem to be cancelled out completely. In other words, intensively used car-club vehicles seem to drive a higher amount of total kilometres during their significantly shorter lifetimes[16].

[16] This could be supported by the argument that due to their intensive usage, car-sharing vehicles need significantly more maintenance over its lifetime. GHG emissions related to maintenance are a lot lower than those related to production of vehicles (own elaboration based on the World Input-Output Database, WIOD)

The calculation used to make assumptions on both effects (based on various references) is as follows. Based on a ratio of 27 members per shared car in the United States, the TCRP report (2005) reports an amount of 14.9 cars to be taken off the road for every car-club vehicle. Applying the ratio of 20 members per shared car in Europe, the estimate for Europe would be 11 cars per car-club vehicle. Correcting this estimate by the 40% reduction in vehicle kilometres of car-share members compared to private vehicle owners, this ratio comes down to 11 x 0.6 = 6.62. Finally, Chen and Kockelman (2015) state that the average privately owned new vehicle is replaced after approximately 6 years, whereas commercial car-club operations replace cars every 2 to 3 years due to more vehicle kilometres and faster wear and tear (Mont 2004). Assuming that the wear and tear to the car and the remaining life time is the same for privately sold second hand cars and those sold by car sharing companies, we can state that a privately owned vehicle has 2 to 3 times the lifetime of a car-club vehicle. Applying a lifetime ratio of 2.5[17], this means that every car-sharing vehicle takes 6.62 / 2.5 = 2.65 vehicles off the production line when assuming that there is no reduction in car use between car owners and car sharers. Furthermore, we assume an energy consumption related to car manufacture of 30 GJ per vehicle (Sullivan et al 2010) and a growing demand for cars proportionally to the growing demand for passenger kilometres in both EU-15 and EU-12. See Table 4: Assumptions made to model car-sharing impact for a summary on the assumptions made for modelling the impacts of car sharing.

**Table 4: Assumptions made to model car-sharing impact**

| Parameter | Source | Value | Multiplier |
|---|---|---|---|
| Vehicles replaced per car-club vehicle in USA | TCRP (2005) | 14.9 | |
| Correction for members per car-club vehicle in Europe | TCRP (2005) | | 20/27 |
| Correction for reduced VKM by car-sharers compared to car owners | TCRP (2005) | | 0.6 |
| Shared vehicle lifetime compared to privately owned vehicle lifetime[18] | Chen & Kockelman (2015), Mont (2004) | | 0.4 |
| Reduction of vehicle production for every car-sharing vehicle | | 2.65 | |
| Manufacturing energy use per vehicle | Sullivan et al (2010) | 30 GJ | |
| Amount of passenger car sales in EU-27 in 2010 (base year) | Oica.net | 13.8 million | |

*Source: See table*

[17] This lifetime ratio is also applied to the assumed vehicle lifetime in GCAM (decreasing from 25 to 10 years), resulting in an increasing average fuel efficiency of cars.

[18] See footnote 6

#### 3.2.2.6 Avoid short flights

The idea behind this behavioural option is to avoid flying whenever there is a 'realistic' travel alternative. With a realistic alternative, we mean another way to get to the desired destination using another transport mode and that does not take more than 10 hours of travelling. To estimate the current amount of avoidable passenger kilometres by plane, we summed all the passenger kilometres on national flights within EU-27 member states[19] and all flights to neighbouring countries (multiplied by half if at least one of the partner countries is a large country such as Germany, France, UK, Italy, or Spain to have a rough estimate of the potentially avoidable flights[20]). We found that about 25% of all passenger kilometres on intra-EU flights are avoidable by these standards, and implicitly assume that it remains 25% until 2050.

As an alternative to flying for medium distance trips, we modelled a new category with 4 possible travel alternatives: coach, train, high-speed-rail and carpooling. Although we copied these transport modes from the original GCAM model, we assume significantly higher speeds for long distance bus, train and car transport (80, 100 and 100 respectively) and a higher load factor for cars[21]. Initially each of these categories take an equal share of the passenger kilometres to be replaced, but the mix between technologies is subject to mode competition as in other GCAM sectors.

#### 3.2.2.7 Closer Holidays

This behavioural option focuses on intercontinental leisure flights. A rough analysis of Eurostat data on intercontinental passenger kilometres from EU-15 and EU-12 shows that respectively 85% and 91.5% of passenger kilometres are for leisure purposes and that the average intercontinental leisure trip by EU-15 and EU-12 consumers is respectively about 5900 km and 2680 km long. Assuming that these estimates will not change until 2050, we modelled this behavioural option in which 50% of all intercontinental leisure trips are replaced by intra-EU trips with an average trip distance of 1000 km. All these replacing intra-EU trips will be performed by intra-EU air transportation.

#### 3.2.2.8 Eco-Driving

Here we focus on the application of "ecodriving" by car drivers. Ecodriving is a term used to describe energy efficient use of vehicles. It is a relatively easy way to reduce fuel consumption

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[19] Although some countries like Germany, France, Spain, Italy and the UK have large distances from one outer point to the other outer point, there are usually good train and bus connections available within the country borders.

[20] i.e. we consider a flight from Brussels to Paris avoidable but a flight from Brussels to Marseille unavoidable. By dividing the number of flights between Belgium and France by two, we hope to have a proper estimate of avoidable flights.

[21] We used a load-factor of 2.8, which is the average load factor of trips with BlaBlaCar, one of Europe's biggest carpooling platforms for long distance trips: https://www.blablacar.co.uk/about-us

from road transport so that less fuel is used to travel the same distance[22]. Although training might be necessary, every driver can choose to adapt this driving style, making it purely behavioural. Apart from fuel savings, ecodriving also avoids aggressive driving behaviour and is expected to increase road safety in general[23].

According to the ecoDriver project website, the EU initiative that started in 2010 to promote this fuel-efficient driving style, the long-term fuel reduction due to eco-driving is estimated to be 5%[24]. Following this number, we modelled this behavioural option by increasing the efficiency of all 4-wheel light duty vehicles by 5% from 2015 onwards.

### 3.2.3 HOUSING DEMAND

For housing demand, we build partly on the building sector structure in GCAM (Kyle et al 2010) and for another part on an innovation to the GCAM model zooming in on the municipal waste sector.

#### 3.2.3.1 Reduce heating and cooling

For the effects of a voluntary reduction in heating consumption in the winter season, we assumed a thermostat set-back from the average 21 degrees Celsius to 20 degrees Celsius. Such an indoor temperature change can be easily compensated by wearing extra clothing. To model this change, we simply modified the HDD input (heating degree days) from 4920 to 4625 in EU-15 and from 6311 to 5930 in EU-12, a change that reduces the need for heating in winter by about 1 degree Celsius. Similarly, we changed the CDD input (cooling degree days) from 373 to 328 in EU-15 and from 343 to 302 in EU-12 to model a reduced use of air-conditioning in summer by increasing the target temperature from 25.5 to 26.5 degree Celsius.

#### 3.2.3.2 Waste Recycling

We all produce waste: on average, each of the 500 million people living in the EU throws away around half a tonne of household rubbish every year (EC 2010b). The environmental impacts of this waste greatly varies with how it is treated: while landfilling of waste leads to significant GHG emissions, recycling of waste into new products actually reduces emissions. The treatment of waste greatly depends on whether different types of waste are properly separated by the consumer or whether it is mixed altogether: 92% of all separated waste in EU-27 was recycled in 2010, while only 8% of all mixed waste was recycled in the same year[25]. The other 92% of mixed waste ended up in either landfills, open burning sites or was incinerated with energy recovery, all

[22] http://www.ecodriver-project.eu/
[23] See footnote 20
[24] see footnote 20
[25] Here we are ignoring wooden pellets, which is a significant separated waste stream that usually ends up in waste incinerators.

with GHG emissions as a result. In total 43.6% of all treated waste in the EU consisted of mixed waste of which more than half was generated by households (Eurostat). See Figure 1 for an overview of all waste and recycling streams in EU-27 in 2010.

To model the impacts of waste recycling by consumers, we focus on the three main streams of consumer waste: organic waste, paper/carton waste and non-paper packaging waste (consisting of mainly plastics, metals and glass). In most EU member states, it is possible for households to effectively recycle these types of waste by separating them. For modelling simplicity, we will assume from now that 100% of separated waste actually will be recycled (8% actually ended up between mixed waste in 2010, predominantly separated organic waste in landfills) and that 0% of mixed waste will be recycled (8% of mixed waste was actually recycled in 2010).

Since 66% of household waste ended up between mixed waste in 2010, it is hard to determine the contents of these waste streams. Since we need to know the contents to model the potential emission reductions, we have to make an estimation of these contents. To do so, we looked at the best practice example of waste separation in Europe to gain information about the average household waste streams. According to GAIA (2012), European best example is a door-to-door waste collection program in Usurbil, Hernani, and Oiartzun in the province of Gipuzkoa, Basque Country, Spain. The three towns together represented 33628 citizens with a GDP per capita level close to the EU-27 average. Except for the 20% of waste that was collected from street bins and local street cleaning services, all household waste in these villages was separately collected. The household waste in these villages consisted of 46.8 % organic waste (of which 33.8% food and 13% garden waste), 18.3% paper/carton waste, 32.3% industrial packaging waste (including 14.1% glass and 15.2% plastic and metal) and 2.6% other waste, such as chemicals or minerals

Since all EU-27 member states have a different waste collection scheme with regionally different priorities, we have multiplied the household waste composition as assumed above to the waste totals in every member state and have deducted the separated waste streams from these assumed waste streams. The remaining waste (i.e. the composition after deducting the separated waste streams per member state) is assumed to be the composition of waste within the mixed waste stream. On an EU-27 level, we find 45.6% of all mixed household waste to be organic, 13.6% to be paper/carton, 33% to be non-paper packaging waste and a remainder of 7.8% to be mineral or chemical waste (which we leave out of the model).

For the services and industrial sector (accounting for nearly one third of all mixed waste), waste has traditionally been much better separated. We therefore assume the same mixture of separated waste to hold for mixed waste streams. Finally, we also find about one fifth of the mixed waste in the waste collection industry. This is intentionally separated waste that seems to have a degree of mixture too high to be recycled. Here we simply assume the average assumed waste composition as in the other 80% of mixed waste. The final assumed mixed waste contents in EU-27 are assumed to be 34.3% organic waste, 15.4% paper/carton waste, 31.2% non-paper packaging waste and 19.1% other waste (mainly mineral). Note that we only modelled the non-household sectors to have a full picture on all waste streams. All the behavioural options do apply to household waste only.

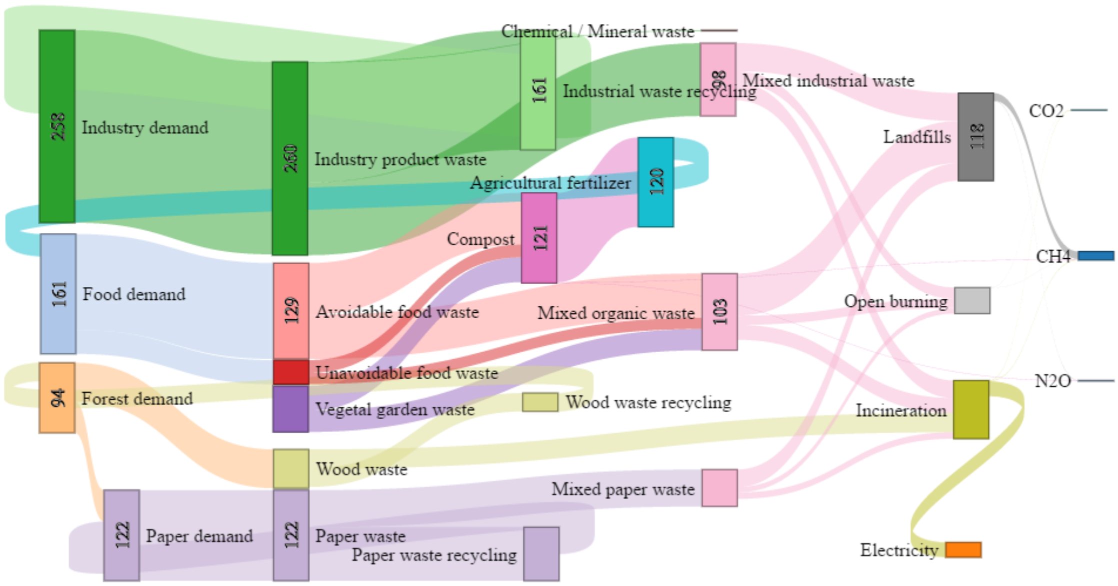


**Figure 1: EU-27 waste and recycling streams in 2010 in million tonnes (based on EuroStat data)**

In total, 89% of all mixed waste in EU-27 was treated within the area[26], with the majority being landfilled (in some cases with methane recovery for biogas production). However, there is an important trend going on in Germany, the Benelux and Scandinavia to incinerate mixed waste, either with or without energy recovery. In the baseline estimates, we assume unchanged shares for landfilling and incineration within the EU-27. However, we will also show the impacts of waste recycling for a scenario in which all mixed waste treatment is converging to incineration, and another one for a scenario in which all mixed waste is landfilled. In our model, we assume that open burning and unmanaged landfilling of waste will be phased out linearly until 2050 and also managed landfilling will be phased out linearly until 2100, following Directive 2008/98/EC on waste management.

For the total emissions from landfilling, we used data from the European Environment Agency (EEA)[27] on landfill emissions on managed and unmanaged landfill sites. Following the IPCC guidelines (IPCC 2006), unmanaged landfill sites have on average 40% less emissions per unit of waste compared to managed landfills[28]. For modelling simplicity, we assume that all landfill emissions in one period are coming from waste that is landfilled in the same period. To fit our modelled waste streams (stemming from EuroStat data) with the EEA landfill emissions data, we

[26] With the other 11% being either exported or simply lost out of sight
[27] http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer
[28] The reason that unmanaged landfills are assumed to yield less CH4 emissions is based on the assumption that these are less dense and more widespread (open garbage field) than managed landfills, such that there is less anaerobic degradation of biogenic sources. Obviously these unmanaged garbage fields have other negative side effects on landscapes and potentially health.

use the methane yields per type of waste stream from EPA (2015). Following the IPCC guidelines, we do not model $CO_2$ emissions from municipal waste management.

### *Organic waste*

Organic waste consists of both food waste and garden waste. Since we have modelled the assumed amount of food waste in EU-27, we assume that all other organic household waste consists of garden waste (the relative share of garden waste is in line with the distribution in our case example as explained in the section above). From 2010 onwards, we assume per capita garden waste to remain constant over time. Food waste consists of unavoidable food waste (which is a by-product of food consumption, predominantly skins and peels of fruits and vegetables, carcasses of pork and chicken, coffee and tea disposals) and avoidable food waste from the production, distribution and consumption of food. We estimated the unavoidable waste stream by GCAM food category by connecting the share of unavoidable waste compared to avoidable waste as reported by Ventour (2008) with our FAO´s (2011) estimates of avoidable food waste by food category. Estimates for unavoidable coffee and tea waste streams (NonFood-MiscCrop) come from Westerhoven (2013). See the assumed estimates in Table 5.

**Table 5: Assumed unavoidable waste streams from different food categories (% of total weight)**

| Cereals | 2.22% | Meat | 13.63% |
|---|---|---|---|
| Oilseeds & Pulses | 3.05% | Fish | 23.44% |
| Fruits & Vegetables | 15.51% | Dairy | 0.46% |
| Rice | 1.67% | Coffee & Tea | 11.06% |
| Root Tubers | 2.08% | | |

*Source: Comparison between Ventour (2008) and FAO (2011), Westerhoven (2013) for Coffee & Tea*

Finally, there are significant potential emissions from organic waste management: landfilling of organic waste results in large amount of methane due to the anaerobic decomposition of organic materials. These are responsible for 2.75% of total GHG emissions in EU-27 in 2010. When incinerated, there will be no methane emissions from organic waste but there will be $CO_2$ emissions, which have a significantly lower warming potential[29]. The energy density of organic waste, however, is very low, so energy recovery from incineration is not very productive. Finally, the preferred treatment for organic waste is to compost it using anaerobic digestion, creating both biogas and a valuable organic fertilizer replacing mineral fertilizers and returning about 15% of the organic carbon contents back into the soil. This is a form of carbon sequestration (IPCC

[29] Since food waste is a renewable source of (potential) energy, CO2 emissions resulting from food waste burning is not counted by the IPCC standards. CH4 emissions due to landfilling are counted, as these would not have been released in a natural situation where the food would degrade aerobically.

2006). Some methane emissions are released in the composting process, but these are limited compared to the methane released with landfilling. In the same way as landfill emissions, we linked data from EEA on composting emissions with EuroStat data on total tonnes composted to estimate the $CH_4$ and $N_2O$ emissions per unit of food and garden waste composted. Finally, we used estimates from Boldrin et al (2010) and Zero Waste Europe (2015) to estimate the total carbon and nitrogen content of both food and garden waste.

This behavioural option assumes that all organic waste from households will be separated by the consumer, and therefore composted rather than landfilled or incinerated.

### *Paper/carton waste*

We have separated paper waste, since nearly every EU member state offers the possibility to recycle paper and carton waste. Since paper products are made from pulp, which is obtained from forest products, the GCAM model will be helpful in calculating the emissions related to paper waste recycling. Like food and garden waste, paper waste is organic and therefore leads to methane emissions when landfilled. However, the rate in which one ton of paper waste produces methane is only about one fourth compared to that of food waste (EPA 2015). When incinerated, paper products can yield significant energy recovery due to an energy density that is more than twice that of food and garden waste. Finally, recycling of paper waste leads to significant GHG savings: producing new paper out of recycled paper reduces the amount of energy needed for paper production by 40% (EIA 2006). However, with about 80% of the extra energy needed coming from biomass (black liquor) due to the high amount of wood waste in these production locations (Table 17 in AF&PA 2009), paper production from pulp consumes the majority of the biomass energy in the EU-27 energy mix for industrial products.

This behavioural option assumes that all consumer paper waste will be recycled and used for producing new paper. Note that in 2010, EU-28 was the region with the highest amount of paper waste recycling globally (68%; EDPR 2015), so extra gains for recycling will be limited.

### *Plastic/metal/glass waste*

Although industrial products such as plastic, metal and glass do not emit GHG emissions when landfilled, they do emit other pollutants, which are currently not modelled within GCAM. These pollutants are also emitted when incinerated, along with $CO_2$. Glass and metal waste might also lead to health damages or complicate the whole waste collection procedure by cutting into garbage bags due to their sharp edges. Incineration with energy recovery from predominantly plastic waste is interesting due to its high energy density: around 50% higher than paper waste and 4 times that of food and garden waste. Plastic, metal and glass waste however is generally valuable when recycled: compared to producing new products, using recycled plastic, metal or glass reduces industrial energy use by 70%, 60-95% and 5-30% respectively (the Economist 2007). Given the average mixed waste composition in the EU-27, we have estimated that the average tonne of recycled industrial products saves about 30% of industrial energy compared to making the same final industrial products from virgin material (Zero Waste Europe 2015). It is important to note is that the majority of savings comes from recycling metal waste, which saves 60% to 95% (for aluminium) compared to making these products from virgin materials.

This behavioural option assumes the recycling of all plastic, metal and glass waste by consumers. We assume the composition of this category (i.e. the relative amount of plastics, metal and glass) will stay the same over time.

## 3.3 Baseline emissions and comparison

To compare the impacts of these behavioural mitigation options, we use a baseline scenario with no climate policy and another scenario with a climate policy based on the Nationally Determined Contribution (NDC) of the EU during the COP21 conference in Paris.

### 3.3.1 Baseline scenario

As we apply the GCAM model to estimate the impact of all behavioural options discussed in section 2.2, we broadly follow the GCAM 4.2 reference scenario as our baseline scenario, apart from some specific adaptations:

- The GDP and population parameters of both scenarios are based on the SSP2 (Middle of the Road) storyline in O´Neill et al (2014). See Figure 2: Carbon emissions in EU-27 region until 2050 (Authors' own estimates) for the per capita emissions in both scenarios, which yields higher $CO_2$ emissions in the EU-27 than the GCAM reference parameters do.
- We included the waste management model as explained in section 2.2.3.2 in the baseline run, in order to compare the impacts of waste prevention and recycling by consumers.

As in the GCAM reference scenario, there are no climate policies in this scenario. See Figure 2: Carbon emissions in EU-27 region until 2050 (Authors' own estimates) below for the estimated GHG emissions in the baseline scenario of this project.

### 3.3.2 Climate policy scenario

Since a future without climate policy seems an unrealistic starting point, certainly after the UNFCCC Paris Agreement in 2015, we also present the baseline model as described in the section above with a climate policy that follows the NDC promise of the EU in this agreement[30]. In this scenario, the EU NDC is reached through the implementation of an GHG emissions cap for the

[30] The EU NDC comes down to a 40% reduction of carbon emissions in 2030, 60% in 2040 and 80% in 2050 compared to carbon emissions in 1990. http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx

region[31]. See Figure 2: Carbon emissions in EU-27 region until 2050 (Authors' own estimates) for the estimated GHG emissions in the EU-27 following to the EU NDC-scenario.

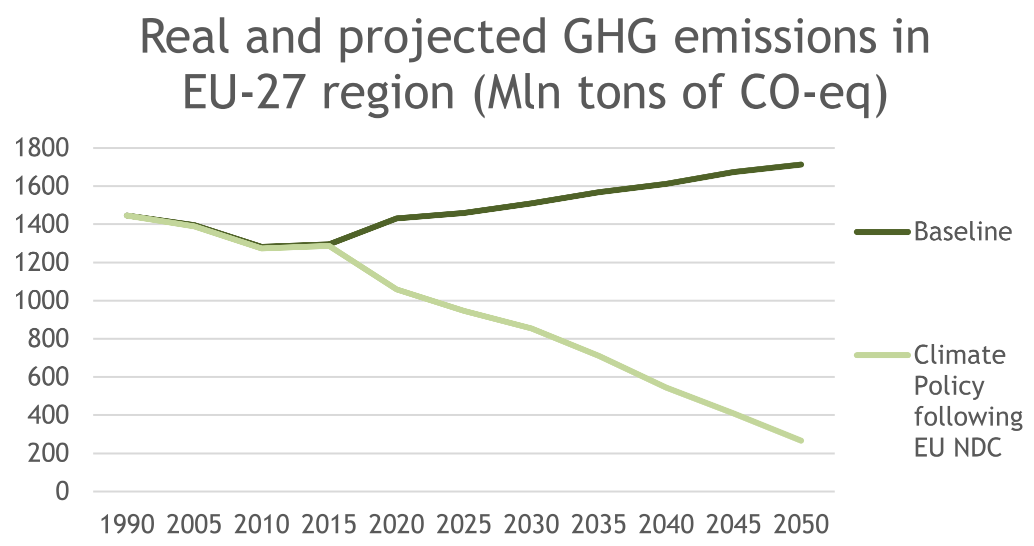


Figure 2: Carbon emissions in EU-27 region until 2050 (Authors' own estimates)

Apart from the GHG emissions in EU-27 itself, and from a consumption-based approach, European citizens are also responsible for a significant amount of GHG emissions in other parts of the world through consumption of imported goods. Similarly, other regions are responsible for GHG emissions inside EU-27. Some of the behavioural mitigation options have a very significant impact on GHG emissions in other parts of the world, and so reduce the total carbon footprint without contributing towards the EU-27 emission targets, as these are not attributed as EU-27 emission savings in the UNFCCC framework. However, since the main focus of this deliverable is the per capita emission saving due to behavioural change, it should not matter whether these savings take place in his/her house, in a neighbouring country or on the other side of the world. Therefore, we count the total per capita emission savings (regional and global) for every behavioural option and, to have some kind of reference point, compare those to per capita EU-27 emission saving targets based on the EU NDC.

[31] GCAM uses a carbon tax (with appropriate multipliers for non-carbon GHGs) to reach the GHG emissions cap in the most efficient way.

# 4 RESULTS

## 4.1 Overview

After running all of the behavioural mitigation options described in section 2.2 using the GCAM model, this section shows the results in terms of GHG emissions and put these in perspective. See Table 6 for an overview of the total per capita GHG emission savings related to the baseline emissions for the period 2011-2050, assuming that these behavioural options would be adapted immediately[32]. Apart from these savings, it shows the share of Fossil Fuel & Industry (FFI) $CO_2$ emission savings within the total GHG emission savings. Finally, the table also shows the share of emissions that are saved domestically within EU-27. All other emission savings have been realized in other regions in the world.

Some of these behavioural options would imply monetary savings for the consumer (see section 4.7 on co-benefits for details on this). Literature suggests that these monetary savings will yield rebound effects, decreasing its effectiveness on total emission savings (Druckman et al 2011, Grabs 2015). The final rebound effect depends on where the monetary savings are spent on. The lower the GHG intensity of the re-spending of savings, the lower the rebound effect of behavioural change. In some cases, re-spending could even save more emissions, if they are invested in for example rooftop solar installations or electric vehicles to replace their previous vehicle. Since we did not model any rebound effects, we implicitly assume that the re-spending of eventual savings have a negligible GHG intensity on average. Given the intrinsic motivation that is necessary to adopt green behaviour, the assumption that this intrinsic motivation will extend to eventual re-spending of savings seems reasonable.

## 4.2 Discussion of individual results

### 4.2.1 Food demand

As Table 6: Overview of GHG emission savings per behavioural option shows, behavioural change in the demand for food leads to very significant GHG emission savings. For example, adopting a healthy diet would reduce accumulated per capita GHG emissions between 2011 and 2050 by 5.27%, only 4.55% of these GHG emission savings are fossil fuel related $CO_2$ emissions and 58.91% of these emission savings will occur within the EU. Fossil fuel related $CO_2$ emissions only accounts for a very marginal share of all food-related emission savings. Instead, methane emission savings from the livestock industry, abated nitrogen oxides from soil utilization and negative land use change emissions due a decreasing land pressure from the agricultural system add up to the gross

[32] Since the first model gives projection from 2015 onwards, in this case "immediately" means from 2015 onwards.

of the GHG savings due to behavioural change in the food sector. The majority of emission savings for each of the options is due to land use change (i.e. avoiding deforestation), mainly outside of the EU.

**Table 6: Overview of GHG emission savings per behavioural option**

| Behavioural option | Avoided GHG emissions: | | |
|---|---|---|---|
| | Total 2011-2050 | % $CO_2$ (FFI) [1] | % Domestic [2] |
| ***Food demand:*** | | | |
| **Vegan diet** | -8.18% | 3.56% | 66.14% |
| **Vegetarian diet** | -6.99% | 4.66% | 50.98% |
| **Healthy diet** | -5.27% | 4.55% | 58.91% |
| **Food waste reduction** | -2.38% | 3.13% | 49.45% |
| ***Mobility demand:*** | | | |
| Public transport commuting | -0.73% | 93.05% | 86.17% |
| Carpool commuting | -1.16% | 92.26% | 89.34% |
| Teleworking | -0.25% | 92.32% | 89.06% |
| Urban Cycling | -0.60% | 92.81% | 89.30% |
| Car sharing / Car club | -1.06% | 87.25% | 89.63% |
| Avoid short flights | -0.47% | 93.18% | 88.06% |
| Closer holidays | -0.49% | 93.39% | 88.92% |
| Eco-driving | -0.59% | 92.25% | 89.35% |
| ***Housing demand:*** | | | |
| Reduce heating / cooling | -0.60% | 88.73% | 89.04% |
| Organic waste recycling | -1.09% | 8.05% | 93.57% |
| Paper waste recycling | -0.56% | 86.23% | 125.90% [3] |
| Plastic/metal/glass waste recycling | -1.66% | 93.93% | 92.89% |

[1] Fossil Fuel & Industry: Includes all $CO_2$ emissions related to fossil fuel use, but no $CO_2$ emissions from land use change

[2] Share of emission reductions within EU-27 region

[3] Since this option reduces $CO_2$ sequestration from foresting i.e. increases GHG emissions in other regions (by reducing demand for forest products), more than 100% of emission reductions occur in the within the EU-27.

*Source: Authors´ own estimates*

It is important to keep in mind that a combination of food waste reduction with either of the diet changes strongly diminishes the impact of a food waste reduction. This is due to the fact that the majority of emissions in the food sector comes from meat consumption, and if less meat is consumed less is wasted as well.

### 4.2.2 Mobility demand

In comparison to food demand, behavioural change in mobility demand leads to predominantly domestic $CO_2$ savings. Generally, every option yields $CO_2$ savings due to either a reduction of car or air travel. The fact that not all emissions savings are domestic $CO_2$ emissions has to do with the footprint emissions in other regions related to the production of petroleum products, predominantly from unconventional oil. The only exception regarding the source of emission savings in the transport sector is the behavioural option of car-sharing. This option implicitly suggests that fewer cars are produced, and therefore leads to savings mainly in industrial emissions. However, about 37% of the emission savings due to car-sharing are the result of higher average fuel efficiency due to a higher replacement rate of heavily used shared cars.

One rather surprising result is that commuting by carpooling is more beneficial than commuting by public transport. It is important to keep in mind that we implicitly assumed that the supply of public transport facilities will proportionally increase with higher utilization of public transport. This means that the load factor of every bus and train does not change as a result of higher utilisation, whereas the load factor of cars do change as a result of carpooling. We are aware that this assumption might be subject to debate and that we might expect a higher load factor for trains and buses if more people decide to use them due to economics of density (Caves and Christensen 1988). However, since the spatial dimension is missing in GCAM, it is hard to provide consistent estimates on the extent to which load factors should increase due to higher use of public transport systems.

### 4.2.3 Housing demand

Emissions in housing demand are mainly related to waste recycling: Table 6 shows that reducing heating in winter and cooling in summer has only a marginal effect on total emission savings. The recycling of organic waste leads to mainly methane emission savings due to reduced landfill emissions - the emission savings due to replacement of mineral fertilizers by compost and carbon sequestration by the use of compost does only marginally weigh up against the increased composting emissions. By contrast industrial and paper waste recycling predominantly impact the demand for industrial energy, since it costs significantly more energy to make paper, metal, glass and plastic from raw materials than from recycled materials. This might explain why in many EU member states, recycling rates of paper, plastic, metal and glass are high relative to recycling rates of organic products: the recycled end-product of predominantly paper and metal is significantly more valuable than that of organic waste.

As explained in section 2.2.3.2, we assume that separated waste will always be recycled, whereas mixed waste will always be landfilled or burned. However, there exist technologies that can filter out certain types of waste from initially mixed household waste in order to recycle it. These technologies are already often used, at least for metal waste. The impact of Plastic/Metal/Glass recycling might therefore be overestimated, as a part of these products will anyway be recycled in the future, with or without the contribution of the consumer.

## 4.3 Behavioural profiles

We would like to give an estimate of the total potential emission reduction, but to do this, we cannot simply add up the savings in all categories. Some options are mutually exclusive (such as the diet choices) and other options limit the impact of each other (for example diet change and food waste reduction or carpooling, driving behaviour and teleworking). Therefore, we have described three different profiles of behavioural adapter focusing on climate change mitigation, each with a different mix of behavioural options that are adopted. Following Autio et al (2009), each profile is intended to represent a realistic behavioural style that people can identify themselves with, ranging from a very active to a more passive form of behavioural change. Unlike Autio et al (2009) however, the mitigation effectiveness of each of our behavioural profiles is explicitly modelled. See Table 7: list of behavioural option adopted for each profile for the behavioural options included for each profile.

Table 7: list of behavioural option adopted for each profile

| "Enthusiastic Profile" | "Conscious Profile" | "Convenient Profile" |
|---|---|---|
| ***Food:*** | *Food:* | *Food:* |
| **Vegan diet** | Healthy diet | Food waste reduction |
| **Food waste reduction** | Food waste reduction | |
| | | |
| ***Mobility:*** | *Mobility:* | *Mobility:* |
| **Teleworking** | Teleworking | Carpool commuting |
| **Car sharing / Car club** | Car sharing / **Car club** | Teleworking |
| **Cycling** | Public Transport commuting | Eco-Driving |
| **Public Transport commuting** | Avoid Short Flights | |
| **Avoid Short Flights** | Eco-Driving | |
| **Closer Holidays** | | |
| **Eco-Driving** | | |
| | | |
| ***Housing:*** | *Housing:* | *Housing:* |
| **Less heating / cooling** | Organic waste recycling | Paper/Carton recycling |
| **Organic waste recycling** | Paper/Carton recycling | Plastic/Metal/Glass recycling |
| **Paper/Carton recycling** | Plastic/Metal/Glass recycling | |
| **Plastic/Metal/Glass recycling** | | |

### 4.3.1 Enthusiastic Profile

The enthusiastic adaptor is the typical person that does anything in his/her means to limit the personal footprint. He or she does not eat any meat or other animal products, does not unnecessarily waste any food, does not have a car, uses a bicycle whenever possible or public transport otherwise, applies ecodriving techniques using rental cars when travelling to places impossible to reach without a car, tries to avoids flying by taking alternative transport and by avoiding far destinations, prefers to put some extra clothes in winter or less clothes in summer instead of putting the thermostat or A/C higher and separates all types of household waste.

### 4.3.2 Conscious Profile

The conscious adapter is well aware of all the environmental consequences of his/her actions, but does not want to give up certain basic needs for this. Instead, he or she is the modern metropolitan role model for environmental consumerism. He or she follows a healthy diet, without unnecessarily wasting any food, does not have a car and uses public transport and rental cars to get around (always applying ecodriving), tries to avoid flying when possible but does not want to give up exotic long-distance holidays. Finally, he or she separates all types of household waste.

### 4.3.3 Convenient Profile

The convenient adapter is more or less informed about the environmental impact of his or her actions, but does not want to make significant adaptation to their lifestyle in order to reduce this impact. Instead, he or she adopts some easy forms of green behaviour, such as reducing his or her food waste, carpooling with a colleague to work, applying ecodriving techniques and separating paper and other packaging waste from all other waste.

### 4.3.4 Mitigation by profile

Combining several behavioural options that are discussed in this project can make up to significant mitigation portfolio´s. Table 8: Overview of GHG emission savings per behavioural profile shows that up to 16.24% of emissions can be saved when adopting many behavioural options.

Table 8: Overview of GHG emission savings per behavioural profile

| Behavioural profile | Avoided GHG emissions: | | |
|---|---|---|---|
| | Total 2010-2050 | % CO2 (FFI) [1] | % Domestic [2] |
| **Convenient profile** | -5.89% | 59.38% | 76.40% |
| **Conscious profile** | -11.96% | 35.67% | 71.10% |
| **Enthusiastic profile** | -16.24% | 34.77% | 74.54% |

**[1] Fossil Fuel & Industry: Includes all CO2 emissions related to fossil fuel use, but no CO2 emissions from land use change**

**[2] Share of emission reductions within EU-27 region**

*Source: Authors´ own estimates*

As this mitigation potential through behavioural action is very significant, we can compare it to the total required mitigation promised by the EU in the UNFCCC Paris Agreement. Translating this agreed promise to per capita emissions, about 50 tons of carbon per capita have to be mitigated before 2050 compared to the baseline scenario. This is 39.62% of total emissions in the period 2010-2050 according to the baseline scenario. Figure 3 shows that the carbon reduction per capita due to the adoption of a climate-friendly behavioural profile reaches up to 14 tons of carbon equivalent, or 19 tons if the total footprint impact is counted[33].

[33] Although the figure seems to give slightly higher percentages, it should not be forgotten to subtract the small increase in emissions due to less biomass use from the total emission reduction.

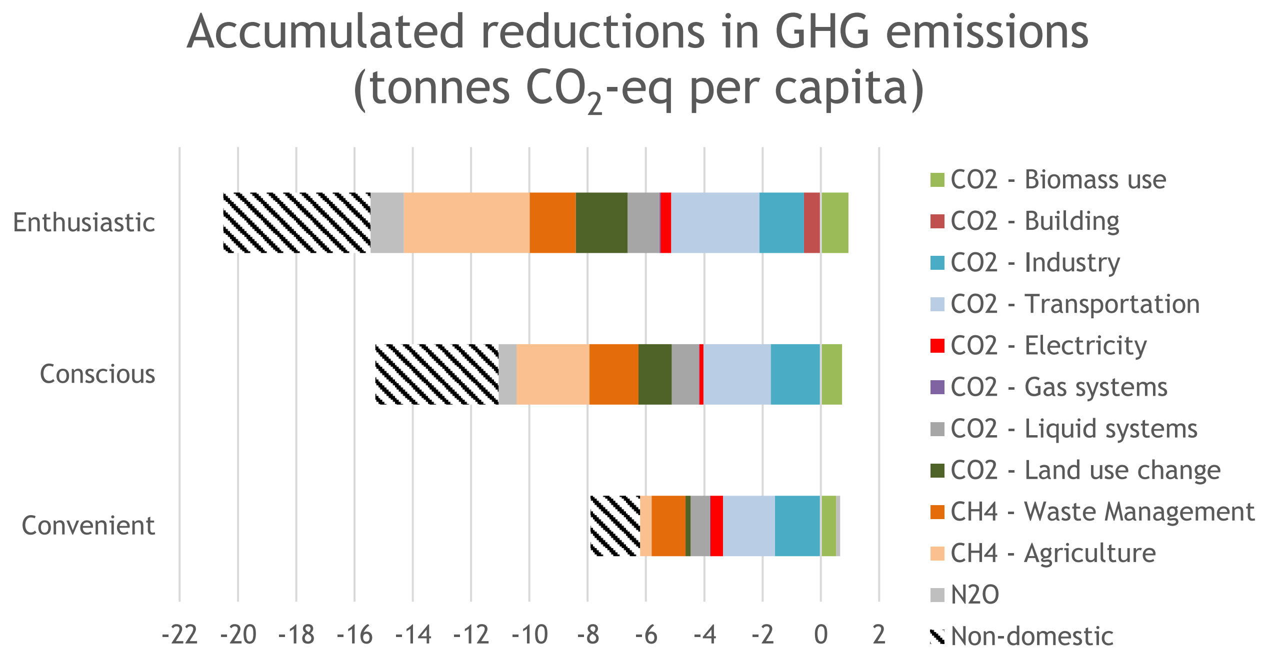


**Figure 3: Per capita GHG emission reduction compared to baseline emissions for the three behavioural profiles. Total savings are split between different domestic sectors and savings outside the EU-27 area.[34]**

An important conclusion to draw from this figure is that significant contributions can be made due to costless behavioural change, up to one third of the total EU mitigation target or over 40% when the total "footprint" impact would count. But even modest behavioural change could mitigate 7 tons of carbon per capita, or 5.5 domestic tons accounting for 11% of the total EU mitigation target.

## 4.4 Sensitivity Analysis on timing of behavioural change

One rather strong assumption of the estimates in this section has been that modelled behavioural change will start immediately, from the very first period after the base year, in this case 2015[35]. Although it is not impossible for any of the behavioural options to start from tomorrow onwards, it might be more realistic to expect a later starting date due to different barriers. Table 9: Avoided GHG emissions per behavioural option or profile dependent on starting year of adoption therefore gives the total emission savings compared to the baseline scenario dependent on when the

[34] The sector "Biomass use" represents the change in biomass use for different end-use sectors. If positive, biomass use has decreased (which automatically leads to decreasing GHG emissions in the intermediate or end-use sectors) and the other way around. This is the way the GCAM model accounts for biomass emissions.

[35] Since GCAM runs in 5-year periods and the base year is 2010, the closest modelling year to the publication of this project is 2015. We are aware that this is effectively in the past, but the idea behind this is that the behavioural option is applied immediately. The 1-2 years of difference have a negligible effect on the total impact of each option.

individual starts to adopt the behavioural change or the portfolio of behavioural changes. Note that in case of a radical land use change, as we see with behavioural change in the food sector, we accounted the full land use savings to the year in which the adaptation takes place, even if the newly planted trees are not completely grown yet.

**Table 9: Avoided GHG emissions per behavioural option or profile dependent on starting year of adoption**

| Behavioural option | Total avoided emissions compared to baseline if behaviour is adopted by year: [1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| ***Food demand:*** | | | | | | | | |
| **Vegan diet** | -8.18% | -7.79% | -7.33% | -6.84% | -6.32% | -5.77% | -5.21% | -4.62% |
| **Vegetarian diet** | -6.99% | -6.70% | -6.37% | -6.03% | -5.66% | -5.27% | -4.87% | -4.45% |
| **Healthy diet** | -5.27% | -5.01% | -4.73% | -4.43% | -4.11% | -3.77% | -3.43% | -3.06% |
| **Food waste reduction** | -2.38% | -2.24% | -2.09% | -1.93% | -1.77% | -1.60% | -1.43% | -1.26% |
| ***Mobility demand:*** | | | | | | | | |
| **Public transport commuting** | -0.73% | -0.65% | -0.59% | -0.51% | -0.42% | -0.32% | -0.23% | -0.12% |
| **Carpool commuting** | -1.16% | -1.12% | -1.04% | -0.91% | -0.74% | -0.56% | -0.39% | -0.20% |
| **Teleworking** | -0.25% | -0.23% | -0.21% | -0.18% | -0.15% | -0.12% | -0.09% | -0.05% |
| **Urban Cycling** | -0.60% | -0.52% | -0.46% | -0.39% | -0.32% | -0.25% | -0.17% | -0.09% |
| **Car sharing / Car Club** | -1.06% | -1.06% | -0.96% | -0.84% | -0.68% | -0.51% | -0.35% | -0.18% |
| **Avoid short flights** | -0.47% | -0.42% | -0.39% | -0.34% | -0.28% | -0.22% | -0.16% | -0.08% |
| **Closer holidays** | -0.49% | -0.43% | -0.38% | -0.33% | -0.27% | -0.21% | -0.15% | -0.08% |
| **Eco-driving** | -0.59% | -0.58% | -0.54% | -0.47% | -0.39% | -0.29% | -0.20% | -0.10% |
| ***Housing demand:*** | | | | | | | | |
| **Reduce heating / cooling** | -0.60% | -0.52% | -0.44% | -0.37% | -0.30% | -0.22% | -0.15% | -0.08% |
| **Organic waste recycling** | -1.09% | -0.93% | -0.80% | -0.67% | -0.53% | -0.40% | -0.27% | -0.13% |
| **Paper waste recycling** | -0.56% | -0.54% | -0.47% | -0.41% | -0.33% | -0.25% | -0.18% | -0.09% |
| **Plastic/metal/glass waste recycling** | -1.66% | -1.46% | -1.27% | -1.08% | -0.87% | -0.66% | -0.46% | -0.23% |
| ***Behavioural profiles:*** | | | | | | | | |
| **Convenient** | -5.89% | -5.48% | -4.99% | -4.41% | -3.77% | -3.09% | -2.41% | -1.68% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Conscious** | -11.96% | -11.19% | -10.28% | -9.28% | -8.21% | -7.06% | -5.89% | -4.65% |
| **Enthusiastic** | -16.24% | -15.18% | -13.93% | -12.55% | -11.08% | -9.54% | -7.96% | -6.31% |

**[1] In the case of land use change emissions, all emission reductions are count to the year the behavioural change takes place, also if the new vegetation is not completely grown yet.**

An important message that can be drawn from this table is that even when individuals start being conscious about climate change, and act accordingly around 2025-2030, solely by costless behavioural change they can mitigate 10% compared to the baseline emissions. This is equal to one fourth of the individuals' share of the total mitigation target in the EU. A second important message is that the choice to change diets or to avoid food waste whenever possible has significant positive instant impacts on the reduction of total footprint emissions, largely due to forestation (or reduced deforestation) in other parts of the world.

## 4.5 Impact on domestic EU Climate Policy

The majority of GHG emission savings due to behavioural change take place in the region itself. As we could see in Table 8: Overview of GHG emission savings per behavioural profile and Figure 3 in section 4.3.4, domestic emissions contribute for around 75% of the total emission savings due to the adoption of different behavioural profiles. As mentioned in section 3.3.2, the European Union submitted an NDC (Nationally Determined Contribution) to the UNFCCC Paris Agreement in 2015, committing itself to significant reductions in GHG emissions - up to 80% by 2050 compared to 1990 emission levels.

There are various ways in which a climate policy can take form. As mentioned in section 3.3.2, we assume a cap-and-trade policy in which the determined carbon reductions as promised in the EU NDC are set and the GHG price in the market is variable. Such a price on GHG gases is expected to impact technology choices such that the necessary GHG emission cap is reached using the least-cost technological options. While there is certainly an overlap between the GHG emission savings due to a cap-and-trade policy and climate-friendly behavioural change, a large part of the GHG emissions that would be abated, by adopting one of the behavioural profiles from section 4.3, would be unabated in case of a cap-and-trade climate policy. The main reason for this is because the sectors that are impacted by the adoption of these profiles are generally the sectors where abatement due to carbon pricing is most complicated.

Table 10 shows an overview on the domestic impact of climate-friendly behavioural change with and without a cap-and-trade climate policy running on the background. It follows from these results that the policy costs related to a climate policy to realize the EU NDC by 2050 could be significantly reduced if the average EU citizen adopted a climate-friendly behavioural profile. Since the sectors targeted by such behavioural change are among the most expensive to be impacted by a climate policy in terms of policy costs, we can see that the impact that adopting a behavioural profile has on policy costs is larger than one would expect from the initial GHG emission savings.

Table 10: Regional impact of behavioural change, climate policy and a combination of both

| Scenario | Accumulated GHG emission savings within EU-27 in 2011-2050[36] | Total policy costs 2020-2050 Trillion € (2010) | Per capita policy costs 2020-2050 € (2010) |
|---|---|---|---|
| **Baseline + Convenient profile** | -4.50% | N/A | N/A |
| **Baseline + Conscious profile** | -8.50% | N/A | N/A |
| **Baseline + Enthusiastic profile** | -12.10% | N/A | N/A |
| **EU NDC** | -39.62% | 1.99 | 3971.6 |
| **EU NDC + Convenient profile** | -39.62% | 1.72 | 3431.0 |
| **EU NDC + Conscious profile** | -39.62% | 1.54 | 3080.9 |
| **EU NDC + Enthusiastic profile** | -39.62% | 1.40 | 2793.2 |

*Source: Author´ own estimates*

## 4.6 Global "footprint" impact

All behavioural options in this analysis have been modelled as consumer side preference changes. Thus, all behavioural change is independent from climate policies, and might be adopted due to environmental awareness as well as monetary, health or animal wellbeing considerations. An important co-benefit of this type of mitigation is that final demand for the polluting good or service has inherently disappeared. In contrast, a carbon tax would simply force demand away by imposing monetary implications. Although a carbon tax might also lead to directed technical change towards less polluting processes and products (Acemoglu et al 2012, Aghion et al 2012), a short to medium term pressure will exist towards consumption of the polluting good or service. In the case of zero or lower carbon taxes in other regions, this pressure will often lead to both industrial and terrestrial carbon leakage[37] (González-Eguino et al 2016).

Although a limited form of carbon leakage might exist in the case of behavioural change through the depressing effect it could have on global energy and food commodity prices, this effect seems hardly visible in the results (see positive emissions in Figure 6). In fact, the results indicate that this effect will be more than offset by the reduced footprint emissions that behavioural

[36] Percentages with respect to baseline emissions, see section 3.1.1
[37] With terrestrial carbon leakage, we mean the relocation of agricultural production due to a land use tax in the policy region.

environmentalism has (see negative emissions in Figure 6). A decreasing demand for food and energy in the EU-27 frees up agricultural land in other regions and avoids emissions related to the mining of energy resources. According to Tukker et al (2016), the EU is currently the only region in the world relying on net embodied imports for all indicators considered, making it highly vulnerable to increasing global competition for the planet´s resources. A reduction in the so-called “footprint” impact of the EU would therefore be important for the region.

Like Bajželj et al (2014) and Alexander et al (2015), we found a strong impact of diet changes and food waste reduction on (mainly) global land use change emissions (Figure 6), land availability (Figure 4) as well as global food markets (Figure 5). Interestingly, as we can see in Figure 4, the reduction of land footprint by EU consumers would not only allow forest, grass, pasture and shrubs to grow back where they used to grow, but also encourage the production of biomass energy due to lower land costs. Consequently, the share of biomass in the global energy mix will significantly grow, crowding out fossil fuel use (see Figure 6). The reducing impact that behavioural change in predominantly the food sector has on global land use also has a significant impact on global food prices. For example, Figure 5 shows that the reduction in agricultural land pressure due to behavioural change in the EU could reduce the global wheat price up to 5% compared to the baseline model, having significant positive impacts on the worlds´ poorest and most vulnerable 20% (Bailey 2011). Similar global price reductions will be realized for corn and other staple foods.

Finally, we also see a small impact of behavioural change on the emissions related with liquids (oil refining) and gas processing. A lower demand for fossil fuels in the EU saves emissions related with the production of these fuels in other regions. Similarly, we also see a saving in $CH_4$ emissions, which are mainly due to a reduction in fossil fuel mining.

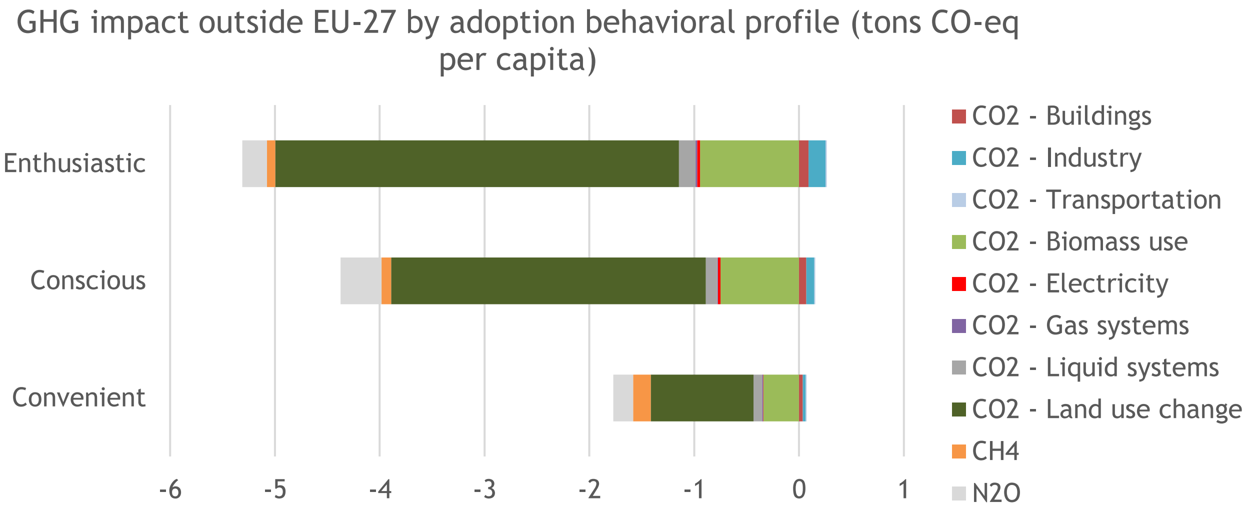


**Figure 6: Footprint impact of behavioural change outside the EU, representing in detail the savings within the non-domestic share from Figure 3.**[38]

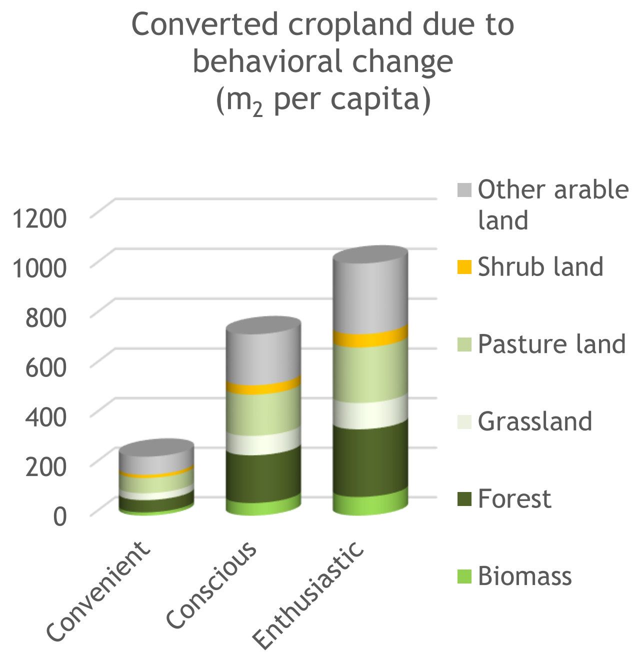


**Figure 4: Per capita amount of cropland that could be diverted into other land uses due to behavioural change in EU-27 (average for period 2010-2050)**

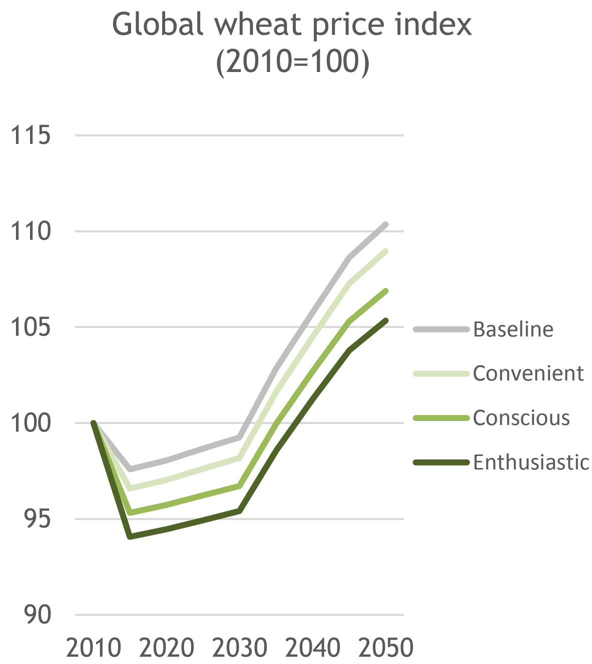


**Figure 5: Impact of behavioural change in EU-27 on global wheat price index**

[38] See footnote 27 for an explanation on the “biomass use” sector.

## 4.7 Co-benefits

Several of the behavioural options discussed have significant co-benefits for either the adopters themselves or society as a whole. What we did not estimate these co-benefits in this analysis, they play an important role in the attractiveness to adopt a certain behaviour.

Table 11: Expected co-benefits of behavioural options gives a brief overview of the potential co-benefits that go along with the adoption of behavioural options.

**Table 11: Expected co-benefits of behavioural options**

| **Behavioural option:** | **Co-benefits:** | | | | |
|---|---|---|---|---|---|
| | **Monetary** | **Own health** | | **Society health** | **Animal Wellbeing** |
| ***Food demand:*** | | | | | |
| **Healthy diet** | | X | X | | X |
| **Vegetarian diet** | | X | ~ | | X |
| **Vegan diet** | | X | ~ | | X |
| **Food waste reduction** | | X | | | X |
| ***Mobility demand:*** | | | | | |
| **Public transport commuting** | | ~ | | X | |
| **Carpool commuting** | | X | | X | |
| **Teleworking** | | X | | X | |
| **Urban Cycling** | | X | ~ | X | |
| **Car sharing / Car club** | | ~ | | X | |
| **Avoid short flights** | | X | | | |
| **Closer holidays** | | X | | | |
| **Eco-driving** | | X | X | X | |
| ***Housing demand:*** | | | | | |
| **Reduce heating / cooling** | | X | | | |
| **Organic waste recycling** | | | | X | |
| **Paper waste recycling** | | | | X | |
| **Plastic/metal/glass waste recycling** | | | | X | X |

| Behavioural option: | Co-benefits: | | | |
|---|---|---|---|---|
| | Monetary | Own health | Society health | Animal Wellbeing |
| X = certain co-benefit<br>~ = dependent on specific attributes | | | | |

We can conclude from

Table 11: Expected co-benefits of behavioural options that most behavioural options yield monetary co-benefits and also either personal of societal health co-benefits. For example, non-meat food products are generally cheaper than meat products and cycling, carpooling and flight avoiding also generally save money just as putting the thermostat to a lower level in winter. Car sharing and public transport systems could save individuals money as well, depending on the specific car share program or public transport operator.

Adopting a healthy diet is by definition good for someone's own health (this diet is taking into account limits to certain foods as indicated by the WHO (2003) and American Heart Association (2014)), whereas the adoption of a vegetarian and vegan diet could be good for one's health as well, depending on the exact diet specifications[39]. Similarly, cycling could be healthy in the sense that it keeps someone fit, but it could simultaneously be unhealthy due to greater respiration of urban air pollution and the increased chance of street accidents (De Hartog et al 2010), whereas Eco-Driving could only decrease one's possibility to be involved in a car accident[40], improving the health impact for eco-driving on average.

Any option that reduces the amount of toxic gases in densely populated areas, generally due to transport, improves society's health by doing so. Furthermore, the recycling of different waste streams improves public health directly if alternatively the waste would have ended up on the streets, but also indirectly if the waste would otherwise be incinerated or landfilled. Both waste management practices release gases that negatively impact public health.

Finally, the reduction of meat consumption, even by a reduction of animal food waste, reduces the amount of animals suffering in animal husbandry industries. This is the major reason why people generally adopt a vegetarian or vegan diet. The recycling of mainly plastic waste also improves animal wellbeing as it prevents microplastics ending up in their food (Derraik 2002).

Another important conclusion is that it is hard to imagine any negative side-effects related to any of the modelled behavioural options with either monetary or health consequences[41]. Because of

[39] A vegan diet with too little protein consumption is for example rather unhealthy.
[40] http://www.ecodriver-project.eu/
[41] Unless a wrong implementation of the option is applied, such as a vegan diet without protein consumption or a suicidal cycling style.

that, the only remaining incentives of why *not* to adopt these behavioural options will be driven by reasons related to convenience or personal preferences.

# 5 DISCUSSION AND CONCLUSION

## 5.1 Discussion and limitations

The main limitation of this study is the absence of agent-based modelling: we could not model the factors that are important to convince people to change their behaviour, nor could we model the indirect rebound effects by the re-spending of monetary savings. In the real world, interaction between individuals is very important for either the stimulation or reluctance of adopting green behaviour. Also, rebound effects of monetary savings can reduce the total effectiveness of green behaviour up to 34% for housing and mobility options (Druckman et al 2011) and 49% for food options (Grabs 2015).

While the scope of this project was to analyse the impacts of preference changes that could contribute to the climate change mitigation portfolio, the normative question on how to change these preferences remains unanswered. Since we are focusing on costless behavioural changes due to preference changes, taxation should not be the way to convince consumers to change their behaviour. Being taxed away from the consumption of a certain good is not the same as a preference change (although taxes can have some signalling effects, reducing the inherent demand for the good). Although recent literature indicates that taxes on unhealthy food products containing a certain amount of fat or sugar, as well as subsidies for healthy food products, have been very effective (Thow et al 2014), such taxes do not necessarily increase consumer welfare (Lusk & Schroeter 2012) if the consumer inherently would have preferred the taxed product.

As taxation is out of the picture, the only remaining option is to convince consumers to change their preferences. Persuasive campaigns against the consumption of meat have been realized by animal protection and food-focused NGOs. According to Laestadius et al (2014), environmental NGO's have however shown little incentives to campaign for a reduction in meat consumption as they appeared to be reluctant to mount campaigns explicitly encouraging personal behaviour change of any type. It makes sense that, when significant co-benefits are related with a certain type of behaviour (see section 4.7), it will be easier to convince consumers to adopt this behaviour. However, it is important for NGO's to keep addressing climate change in the public opinion and to campaign actively to reduce meat consumption, preferably in cooperation with animal protection and food focused NGOs.

In order to persuade consumers to adopt specific climate-friendly behaviour, whether there are significant co-benefits involved or not, public awareness about climate change could be improved. According to Sheppard (2005) for example, realistic landscape visualizations may offer special advantages in rapidly advancing peoples' awareness of climate change, and possibly affecting behaviour and policy, by bringing certain possible consequences of climate change home to people in a compelling manner. He concludes that the persuasive use of visualizations, together with other approaches, may be effective, is justified, and could be vital in helping communicate climate change effectively, given ethical standards based on disclosure, drama, and defensibility.

This and several other techniques to communicate the climate change problem, which are receiving an increasing amount of attention in literature (Moser 2010), will be essential to convince consumers to adopt the behavioural changes discussed in this paper.

## 5.2 Conclusions and policy recommendations

The purpose of this exercise was to show and compare the potential impact of various types of behavioural action on GHG emissions. Whereas literature on the impact of household and transportation sector (Dietz et al 2009) as well as the food sector (Bajželj et al 2014) has confirmed strong potential for behavioural mitigation efforts. Using the GCAM model enabled us to consistently compare behavioural action in the food, transport and household sector together and to create different consumption profiles. Also, unlike Dietz et al (2009), we solely focused on behavioural mitigation efforts that do not require investments in new and cleaner technologies to replace older ones. Therefore, there will be no need for upfront investments to be made by the consumer, which in reality is an important barrier for making energy-saving investments (Costanzo et al 1986). From an analytic point of view, the absence of technology requirements allows us to freely compare and add these results to those of conventional mitigation portfolios that are based on the adoption of cleaner technologies, without overlapping emission savings.

An important effort for this paper has been the implementation of waste streams in the GCAM model. This waste module does not only enable estimates of the direct impacts of waste separation by the consumer, it also measures the co-benefits of waste prevention and other overlapping behavioural options.

A thorough analysis of the results show that costless behavioural change can contribute up to one third of the EU NDC goal from the UNFCCC Paris Agreement, rising to 40% if all footprint emissions would count. However, to achieve this potential, behaviour has to be changed dramatically from tomorrow onwards. But even a more convenient way of behavioural change as well as an average environmentally conscious living style from 2025-2030 onwards could contribute to 14% and 25% of the total mitigation effort respectively (when footprint emission savings are considered).

Another advantage of using the GCAM model for this project is being able to measure the international aspects of domestic behavioural changes. Interestingly, environmentally friendly behavioural change reduces emissions in other regions, which means that the “footprint” effect dominates the “carbon leakage” effect in the case of behavioural change. In contrast, forcing environmentally friendly behaviour with a carbon tax yields some carbon leakage to other regions.

Last but not least, co-benefits of environmentally friendly behaviour are in some cases very significant and could be used to convince citizens to adopt a specific environmentally friendly behaviour. Being a relatively wealthy nation, the EU is characterized by unsustainable average lifestyles, implying that there are a lot of potential gains in behavioural mitigation. Since lifestyle is a relative rather than an absolute term, the adoption of a sustainable lifestyle in developed regions might simultaneously yield a more sustainable lifestyle in developing regions by giving a better example (Lange & Meier 2009). Surely in the case of behavioural options that imply significant co-benefits for the adopter, ´leapfrogging´ of sustainable lifestyle features might be a realistic climate mitigation strategy for developing regions (Schäfer et al 2011). A good example of behavioural change from a developed nation could therefore be of inexpressible value for future climate scenarios.

Currently, policy makers predominantly look at taxes and subsidies in order to provide technological solutions to reach their climate targets. As follows from this analysis, behavioural effects can play a significant role in climate change mitigation portfolio. Therefore, policy makers could include measures in the form of education and awareness programs in order to promote green behaviour by citizens. The policy costs of such measures are usually low compared to the implementation of taxes and subsidies, while Table 10 in section 4.5 shows that the climate policy cost savings are significant. On top of that, they often lead to significant co-benefits in terms of health and land use.

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