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Corrigendum: Global climate targets and future consumption level: an evaluation of the required GHG intensity

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There is an error in figure 5: for ‘food’ the GHG intensity should be gCO₂/Mcal (instead of gCO₂/kcal). The corrected figure and caption are reproduced below.



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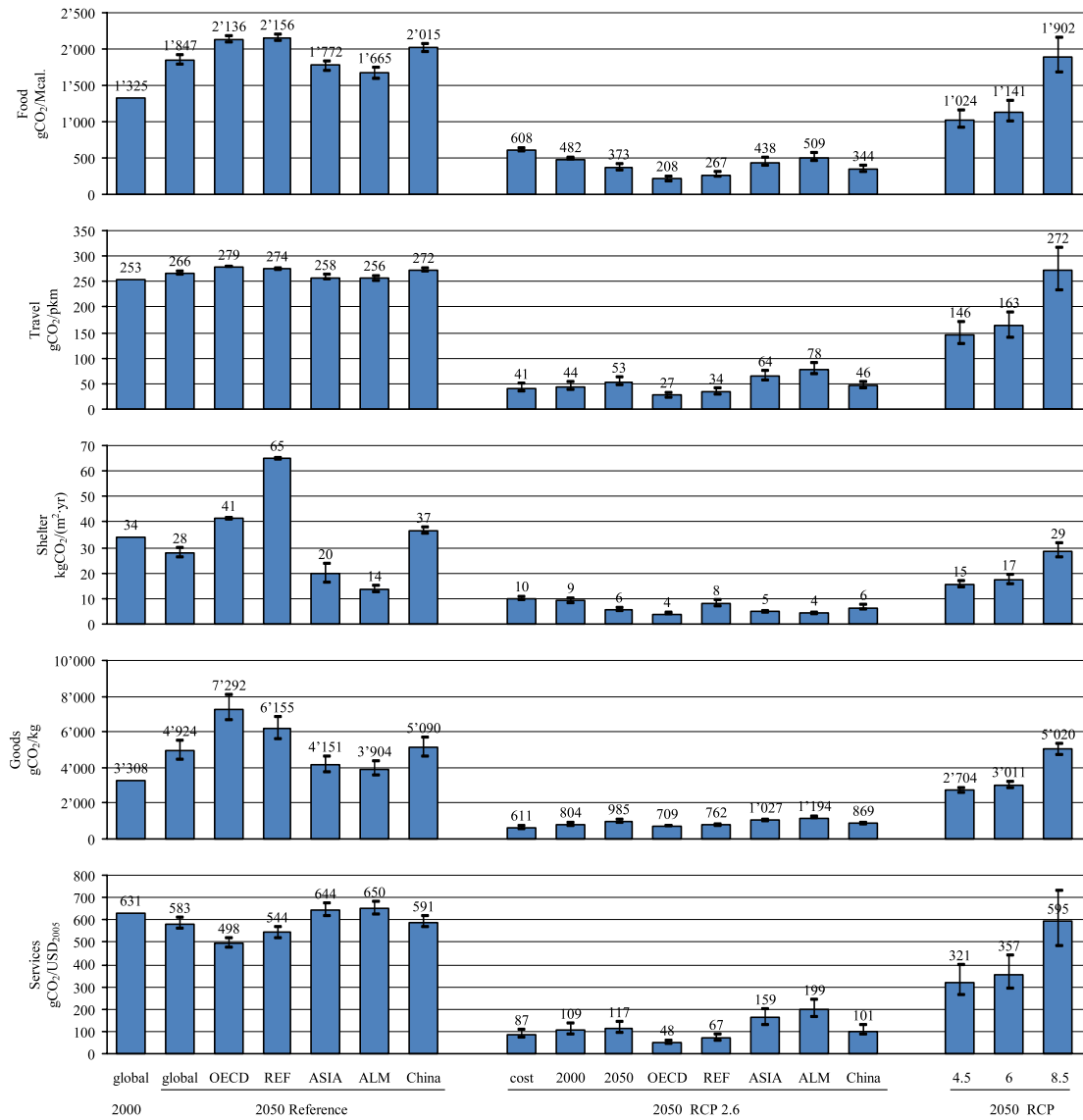


Figure 5. Baseline and target GHG intensity for the five main consumption categories. ‘Global’ refers to the global average. Projections for 2050 are shown for the five main world regions. Target GHG intensities in 2050 for the RCP2.6 are shown for different allocation schemes: same cost of reduction, same reduction from the distribution in 2000 and the same reduction in GHG intensity (2050). The different world regions show the target GHG intensity for same reduction and equal per capita allowance. The GHG intensity for the RCP4.5 to RCP8 uses also the same reduction allowance scheme.

Global climate targets and future consumption level: an evaluation of the required GHG intensity

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Abstract

Discussion and analysis on international climate policy often focuses on the rather abstract level of total national and regional greenhouse gas (GHG) emissions. At some point, however, emission reductions need to be translated to consumption level. In this article, we evaluate the implications of the strictest IPCC representative concentration pathway for key consumption categories (food, travel, shelter, goods, services). We use IPAT style identities to account for possible growth in global consumption levels and indicate the required change in GHG emission intensity for each category (i.e. GHG emission per calorie, person kilometer, square meter, kilogram, US dollar). The proposed concept provides guidance for product developers, consumers and policymakers. To reach the 2 °C climate target (2.1 tCO₂-eq. per capita in 2050), the GHG emission intensity of consumption has to be reduced by a factor of 5 in 2050. The climate targets on consumption level allow discussion of the feasibility of this climate target at product and consumption level. In most consumption categories products in line with this climate target are available. For animal food and air travel, reaching the GHG intensity targets with product modifications alone will be challenging and therefore structural changes in consumption patterns might be needed. The concept opens up possibilities for further research on potential solutions on the consumption and product level to global climate mitigation.


Keywords: climate policy, climate mitigation target, consumption projections, representative concentration pathways (RCP)

 Online supplementary data available from stacks.iop.org/ERL/8/014016/mmedia

1. Introduction

It is now widely accepted that human activities are a major driver of the observed climate change during the 20th century

and that without radical change, human activities are likely to lead to further climate changes in the future (IPCC 2007b). In the past, IPCC emission scenarios have played a prominent role in describing the relationship between different human development paths and climate change (Girod *et al* 2009, van Vuuren *et al* 2012). For the next IPCC assessment report, the representative concentration pathways (RCPs) have been proposed as a basis for climate research (Moss *et al* 2010,

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van Vuuren *et al* 2011a). These RCPs capture the range of emission projections from literature and can be expected to guide future discussions on climate change. The pathway with the highest emissions, representing a scenario without climate mitigation, is estimated to result in a long-term temperature change of more than 7°C above pre-industrial levels, while the lowest pathway corresponds to the 2°C target set in Copenhagen (Meinshausen *et al* 2011, van Vuuren *et al* 2011b).

In the current debate on international climate policy, the focus is on national (or regional) greenhouse gas (GHG) emission targets related to domestic emissions. For instance, the Kyoto Protocol was formulated in terms of national targets, as are the current pledges under the Copenhagen Accord. Related to this, an increasing number of integrated assessment models have focused on the feasibility and costs of enacting of various climate targets such as those consistent with the RCPs, looking into the consequences for countries or regions or on aggregated production sectors, such as the energy sector (van Vuuren *et al* 2011a).

An alternative perspective to the climate mitigation issue can be gained by analyzing climate policy from the consumption side and evaluating what climate targets imply for product manufacturing and consumption patterns. This is a highly relevant approach for several reasons. It translates abstract climate policy to a more tangible level of implications. This approach also provides a means to encourage engineers to revise and innovate product designs and consumers to consider behavior change in the light of reaching climate targets. Furthermore, it allows for a feasibility assessment of the required emission reductions to be conducted from a new perspective.

Studies addressing this question typically focus on a single consumption category, such as food (Stehfest *et al* 2009), transport (Kyle and Kim 2011, Fulton 2009, Girod *et al* 2012), or shelter (van Ruijven *et al* 2010, Isaac and van Vuuren 2009). Studies that, in contrast, comprehensively evaluate all consumption categories use monetary units to measure consumption levels and do not consider growth in consumption levels (Hertwich and Peters 2009).

While the adoption of climate targets for individuals has been suggested before, this paper makes a unique contribution by discussing the assignment of climate targets (RCP) to five distinct consumption categories, namely food, shelter, travel, manufactured goods and services in 2050. We also consider the expected growth in consumption level. Required GHG intensities for different climate targets are calculated in terms of physical consumption indicators enabling direct interpretation of the outcomes in terms of consumption patterns and product design.

2. Method

Index decomposition is a powerful tool used to analyze changes in emission rates in terms of changes to its underlying drivers. The most well-known example is the IPAT identity (Ehrlich and Holdren 1971). This identity can be described

as:

$$\underbrace{\text{GHG emissions}_c}_{\text{Impact}} = \text{Population} \cdot \underbrace{\frac{\text{Consumption}_c}{\text{Capita}}}_{\text{Affluence}} \cdot \underbrace{\frac{\text{GHG emissions}_c}{\text{Consumption}_c}}_{\text{Technology}}. \quad (1)$$

Here, we use GHG emissions as the impact indicator (I), consumption per capita as the affluence indicator (A), GHG emissions per unit of consumption as the technology indicator (T) and distinguish different consumption categories, *c*. The choice of variables differs to the Kaya identity (Kaya 1990), which refers to income rather than consumption level for the affluence indicator and which decomposes the GHG intensity into energy intensity of consumption and carbon intensity of energy use.

Consistent with other authors applying the IPAT equation to emission reductions, we focus on changing the last term of the equation (see review by Chertow (2000)). For a given emission trajectory consistent with a long-term climate goal, this last term, henceforth referred to as GHG intensity, can be rewritten for different consumption categories and emission target (RCP) as:

$$\text{GHG intensity}_{\text{RCP},c} = \frac{\text{GHG emissions}_{\text{RCP}} \cdot \text{Allocation}_c}{\text{Consumption}_c}. \quad (2)$$

There are various ways to improve the GHG intensity. Although manufacturing improvements clearly have a direct influence, structural changes in consumption pattern like the substitution of more GHG intensive with less GHG intensive consumption (e.g. train instead of car) can also contribute to the attainment of certain intensity goals. In the following section, we first estimate future global consumption patterns and use equation (1) to determine the effect on future consumption related GHG emissions (section 2.1). Next, we address the allocation of the required global level of emissions in order to reach a certain climate goal (section 2.2), which allows in combination with the global consumption projections to determine the GHG intensity targets (equation (2)).

2.1. Future global consumption

Following equation (1), we first project the global population and income until 2050. We then discuss affluence by explaining how income drives future per capita consumption in our model. Finally, we present the assumed reference GHG intensity. For the latter two sections, we provide a more detailed description in the supporting material (available at stacks.iop.org/ERL/8/014016/mmedia).

2.1.1. Population and income. For the baseline scenario, we use the UN medium population projection (UN 2008) and the income projections from the OECD Environmental Outlook (OECD 2012). This scenario is intended to describe future trends in basic drivers of climate change without major

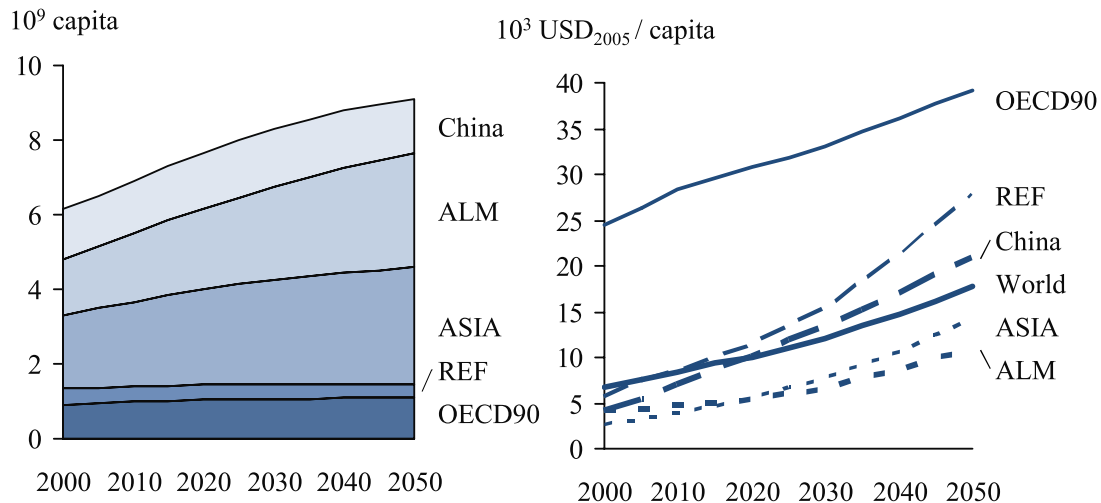


Figure 1. Global baseline population and income projections for OECD90, reforming countries (REF), China, Asia and Africa, Latin America and Middle East (ALM).

policy shifts. Most of the RCPs have used similar assumptions (van Vuuren *et al* 2011a). The corresponding population and income assumptions for five macro regions are shown in figure 1.

Total factor productivity was found to be of critical importance in a review of long-term global GDP projections (Duval and de la Maisonneuve 2010). Since global consumption projections are directly related to GDP, in our analysis, we test the sensitivity of the results against the baseline assumptions by varying annual GDP per capita growth by $\pm 0.5\%$ from baseline values.

2.1.2. Consumption per capita. Where possible, we choose physical instead of monetary consumption indicators since physical units are often easier to interpret, are more directly related to environmental impacts and can capture saturation trends in consumption (Girod and de Haan 2010). We use five broad categories, reflecting basic human needs, namely: food, shelter, travel, goods and services. For each of these five consumption categories, we have selected primary indicators that not only represent the overall consumption levels, but are also relevant for GHG emissions. Secondary indicators are used in addition to the primary indicators to consider changes relevant to GHG emissions within the five consumption categories.

- Food can be measured in calories. However, as most animal products have a much higher GHG intensity than vegan alternatives, the share of animal calories must also be considered (Stehfest *et al* 2009, Wirseniens *et al* 2010).
- Travel is commonly considered in transportation units of passenger distance (passenger kilometers). For GHG emissions, the modal split is also important (see Schafer *et al* (2010)). We therefore distinguish slow public transport (bus/train), cars and high speed modes (high speed train and airplane).
- Shelter can be described by floor space, which relates to living comfort as well as heating requirements (van Ruijven *et al* 2010). For GHG intensity, the necessity

of cooling appliances is also relevant (Isaac and van Vuuren 2009). Auxiliary services related to living spaces, such as lighting or entertainment ICT are difficult to address individually and are therefore considered by the corresponding electricity use (van Ruijven *et al* 2010).

- Manufactured goods comprise such a diverse category that their functionality can hardly be captured by physical indicators. We therefore rely on the weight of goods consumed. However, for the GHG intensity, we will consider an increase in intensity with value and income (Girod and de Haan 2010).
- Services are an equally diverse category. We therefore rely on monetary expenditures in accordance with Suh (2006). In contrast to goods, we have to correct for a decrease in GHG intensity with increasing income (see section 2.1.3).

To project per capita consumption until 2050, we assume that future trends in income, that is, GDP per capita, will drive per capita consumption levels as it has in the past and as is observed in cross regional trends. We therefore gather data on per capita consumption for the different consumption indicators and establish the global income–consumption relationships. The data (figures S1–S5 available at stacks.iop.org/ERL/8/014016/mmedia) shows a considerable variance reducing the model fit for the derived income–consumption relation. However, the resulting trends for food, travel and shelter are similar to representative studies (FAO 2006, Schafer *et al* 2010, Girod *et al* 2013, van Ruijven *et al* 2010). For goods and services, no similar projections were found in literature.

Figure 2 shows the consumption projections to 2050 resulting from the combination of these income–consumption relationships, with income and population projections (section 2.1.1) from 26 world regions. Main trends are an increasing share of animal calories, faster and more energy intensive transport modes, and increased cooling demand in buildings. No saturation in consumption is observed for the distance travelled and electricity use for appliances. The steep increase for services results from the monetary indicator, which does not allow for saturation relative to income.

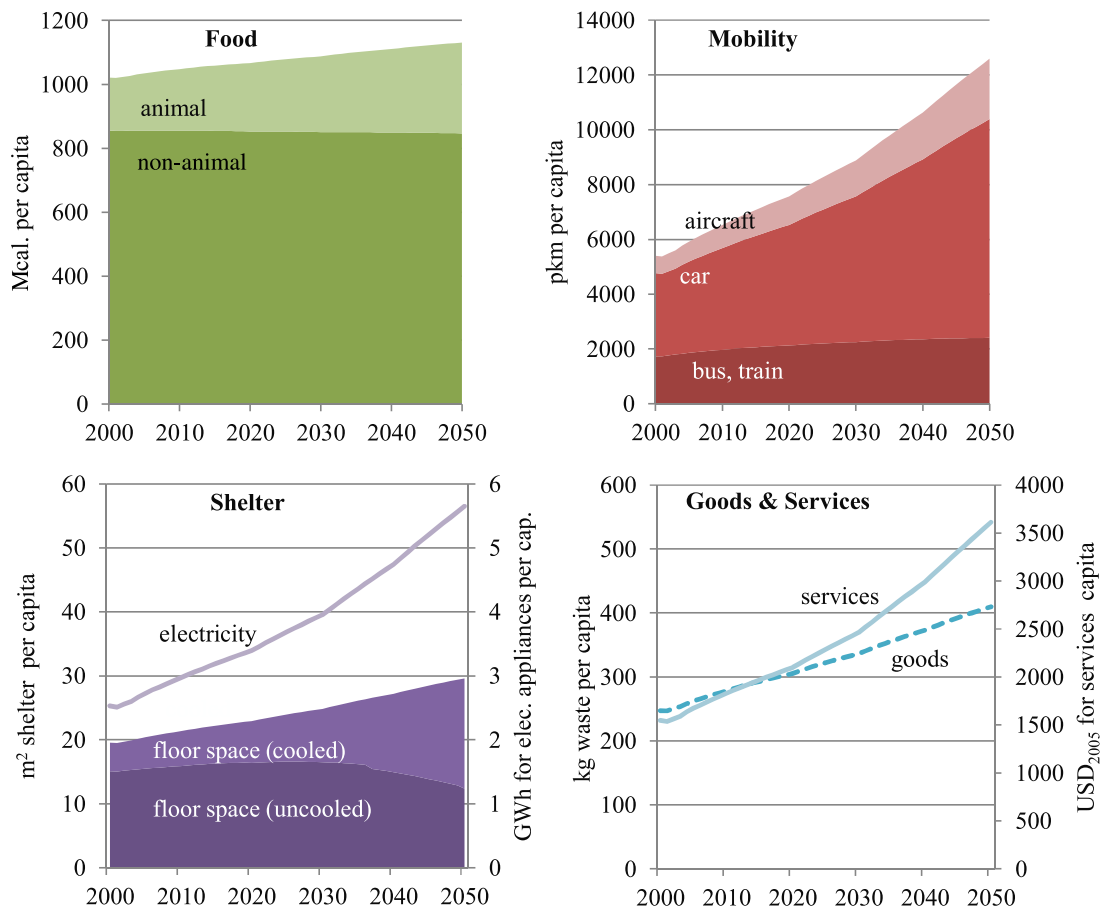


Figure 2. Trends of global average per capita consumption for food, travel, shelter, goods and service from 2000 to 2050. Aggregated from per capita projections in 26 world regions.

2.1.3. Reference GHG intensities. As the goal of this study is to transparently assess the emission intensity changes required for each consumption category in order to achieve global emissions reduction goals, we first assume a situation in which there are no future changes in GHG emission intensities as reference projection. We determine GHG intensities for the reference year (2000) by using consumption related GHG emissions data from Hertwich and Peters (2009). They did not include emissions from land use, land use change, and forestry (LULUCF) due to the difficulty associated with allocating these sectors to economic activities. For the global reference projections the LULUCF emissions are therefore treated separately based on the RCP2.6 data. In contrast to these reference GHG intensities, we will include LULUCF emissions in the target intensities as they are part of the RCP emissions.

2.2. Global emissions and allowances per category

As a next step, we can derive the development of greenhouse gas intensity by relating the consumption levels to emission allowances required to achieve long-term climate goals. Below, we first discuss the so-called RCPs that we will use for this purpose, followed by a discussion of how these emissions can be attributed to the different consumption categories.

2.2.1. Global climate targets in 2050. Table 1 provides a detailed description of the four Representative Concentration Pathways (RCPs) currently used for climate research in terms of radiative forcing, GHG concentration and emission, trend of the emission pathways and projected temperature increase. The RCPs are consistent with the current literature on emission scenarios (van Vuuren *et al* 2011a). In comparison to the 2005 emissions (44 Gt CO₂-equivalent), all RCPs, except RCP2.6, allow a further increase in global emissions in the next four decades. The RCP2.6 represents the category of low emission scenarios consistent with the ambition to maintain global mean temperature increases less than 2 °C (van Vuuren *et al* 2011b) and is fully consistent with the current literature (Rogelj *et al* 2011, Meinshausen *et al* 2011). Still, in reality a range of 2050 emission levels could be consistent with a 2 °C target (Rogelj *et al* 2011) depending on assumptions on technology development and timing of emission reduction.

2.2.2. Emissions allowance per consumption category. Several approaches may be taken to allocate the emissions to the different consumption categories in order to achieve specific reduction targets; the discussion on allocation is somewhat similar to the one on national emission reduction targets. Obviously, the choice involves political and societal choices. Some options are:

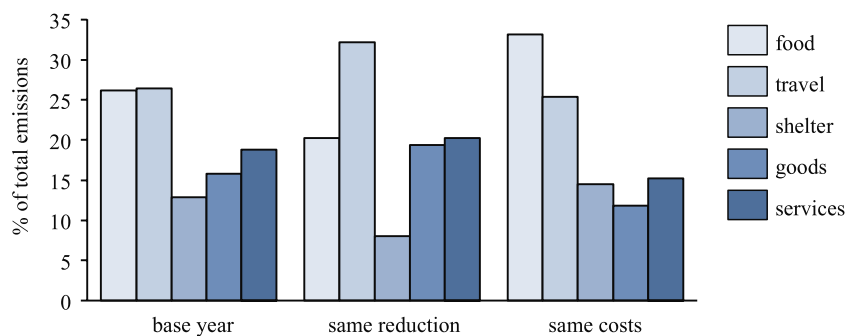


Figure 3. Total global emissions allowance as distributed to consumption categories on the global level accounting for the three different distribution schemes. The ‘base year’ scheme refers to the emission distribution in the year 2000; the ‘same reduction’ scheme assumes the same emissions intensity reduction across all categories; and the ‘same cost’ approach is based on the RCP2.6 (van Vuuren *et al* 2011b) emission projections for 2050.

Table 1. Description of the four IPCC representative concentration pathways (RCP). (Adapted from IPCC (2008).)

Name	Radiative forcing (W m ⁻²)	Concentration (CO ₂ eq. ppm)	Emission pathway trend	Temp. increase in 2100 (° C) ^a	GHG emissions in 2050 (CO ₂ eq.) ^b	
					(Gt)	(t./cap.) ^c
RCP8.5	>8.5	>1370	Rising	~5.2	97	10.6
RCP6	~6	~850	Stabilizing	~3.3	58	6.4
RCP4.5	~4.5	~650	Stabilizing	~2.6	52	5.7
RCP2.6	< 3	>490	Peak and decline	~1.7	19	2.1

^a Meinshausen *et al* (2011).

^b Using the IPCC 100 year global warming potential for carbon dioxide, methane and nitrous oxide (IPCC 2007c).

^c Using the UN medium population projection UN (2008).

- Base year (2000): allocation of emissions to the categories proportional to their share of 2000 emissions.
- Same reduction (2050)⁵: emissions are allocated on the basis of the same relative reduction in each category compared to the corresponding consumption indicator (see section 2.1.2).
- Same costs: this approach assumes that the GHG allowances are set for each industry sector according to the specific mitigation costs. Identical marginal mitigation costs are generally applied when a global emission tax is applied to the integrated emission assessment models. We therefore use the sectoral reduction reported by van Vuuren *et al* (2011b) and adapt them to represent reduction per consumption category. Obviously, this approach includes considerable uncertainties regarding future mitigation costs in the different sectors.

In figure 3, the distribution of emissions allowance across consumption categories following these different allocation rules are shown. The ‘base year’ distribution has the highest emissions in the food and travel categories. The ‘same reduction’ considers changes in consumption levels for the different categories, hence considers a lower growth in demand for food and shelter and therefore allocates more to travel, goods and services. Finally, the ‘same costs’ considers the higher mitigation costs in the agricultural and

transportation sector, leading to higher allowances for food and travel.

3. Results and discussion

3.1. The increasing mitigation challenge

Our results show that, in addition to a growing population and increased total consumption per capita, the structural change toward more GHG intensive consumption like animal calories, aircraft and energy intensive homes and goods presents an important driver for GHG emissions (figure 4). The population growth is higher than its contribution to global GHG emissions because most of the global population growth stems from regions with low income and hence low per capita GHG emissions. The slow-down in the global expansion of agricultural land leads to a reduction of the LULUCF emissions, a trend which is projected by all RCP scenarios (van Vuuren *et al* 2011a). The emissions in 2010 derived by our bottom up-estimate are in line with the RCPs (Meinshausen *et al* 2011), but around 5 Gt CO₂ below the estimates from EC (2011). Latter deviation can be explained by the uncertainty in global GHG emissions especially LULUCF emissions (IPCC 2007a). The global baseline emissions for 2050 are very close to the RCP8.5 (see table 1).

The RCP2.6 scenario requires a decrease in annual GHG emissions until 2050, in order to offset more than a doubling of consumption drivers of GHG emissions (figure 4). Fortunately, GHG intensities are likely to decrease as a

⁵ This method somewhat resembles the Triptych or Sectoral Targets approach (den Elzen *et al* 2008). However, instead of focusing on trends in production-related indicators here we focus on consumption related factors.

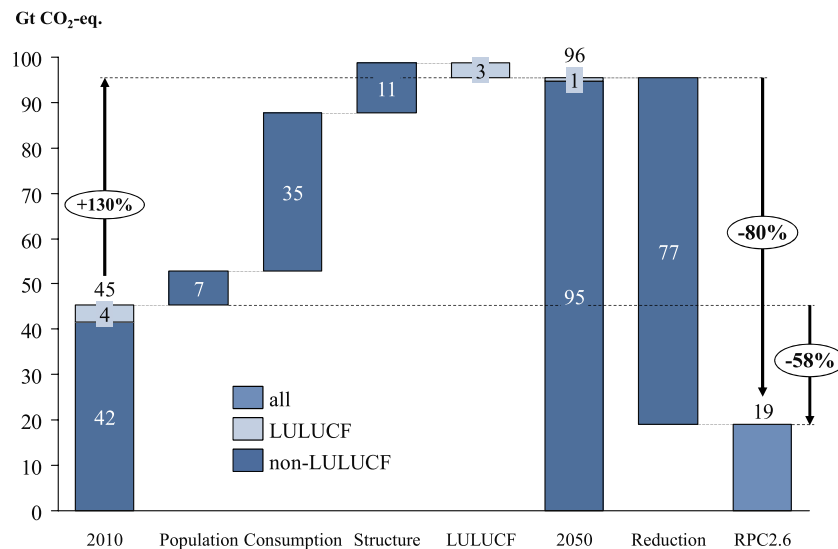


Figure 4. Influence of population growth, increasing consumption levels, structural change in consumption patterns toward more GHG intensive consumption and changing land use (LULUCF) for the reduction of GHG emissions required by 2050 to achieve the 2° climate target (RCP2.6). Non-LULUCF GHG emission are related to changing consumption, LULUCF emissions refer to the CO₂ emissions only and are based on the RCP2.6 projection (van Vuuren *et al* 2011b).

result of increasing energy efficiency even in the baseline scenario. However, by using today’s products as a baseline, the challenge to reduce GHG emissions in line with the 2 °C climate target increases from a factor 3 (58% reduction) to a factor of 5 (80% reduction) as a result of projected global consumption trends. The required 80% reduction is in line with von Weizsacker and Hargroves (2009), who also take both a consumption and product level perspective.

3.2. Climate targets for consumption categories

Climate change mitigation requires a significant reduction of GHG intensities in all consumption categories in order to meet the RCP2.6 emission path. Figure 5 shows the GHG intensities for the baseline and mitigation scenarios. The trend indicates an increasing intensity in the baseline for food, travel and goods due to the increasing share of GHG intensive consumption. For shelter, the GHG intensity decreases because of the increasing share of consumption in countries with moderate temperatures and hence low heating demand.

Regarding the baseline GHG intensities in the five world regions, large differences across the regions are only observed in the shelter category. These variations are due to differing regional climatic conditions which affect heating requirements. Furthermore, high-income regions tend to have higher GHG intensity: for shelter due to higher levels of electrification; for food due to a higher calorific intake and larger share of animal calories; travel due to increased car and air travel; and goods due to more energy intensive materials and manufacturing. The GHG intensity of high-income countries for services, is lower because of the decoupling of GDP and GHG emissions.

For the RCP2.6 target GHG intensities, the influence of the different allocation rules we considered here is small

compared to the required reduction from the baseline GHG intensity. Having the same GHG intensities around the world would result in higher per capita emissions for high-income countries as a direct consequence of their higher consumption levels. Since this might not be acceptable for developing countries, we also evaluate the GHG intensity targets for five major world regions, resulting from equal per capita emission allowance. In this case, high-income regions such as the OECD countries not only start with higher GHG intensity levels, but also have to achieve lower GHG intensity targets.

The target GHG intensities are well below the 2000 and 2050 reference intensities for the RCP4.5 and RCP6 scenarios as well. Conversely, the RCP8.5 scenario allows higher GHG intensities for all consumption indicators compared to the 2050 reference scenario values.

These GHG intensities have several policy implications. In order to attain the 2 °C target respectively reduce emissions to 2.1 tCO₂-eq. per capita by 2050, the international community will have to develop policies that promote products and consumption patterns close to or below the indicated climate targets. While a carbon tax provides an efficient tool to achieve emission reductions, it is clearly not currently politically feasible to set taxes at the required level. Policies will also have to explicitly set emission targets or minimum standards for products for instance as is already the case for vehicles in the European Union (2009) or California (2009).

If equal per capita emissions allowances are the goal, even stricter product emission targets would result for high-income countries. Hence, in comparison to other regions, OECD countries would have to reduce GHG emission intensities to even lower levels while starting from a higher intensity. However, this results in a challenge for international trade. Even if embodied emissions are taken into account as suggested by Peters and Hertwich (2008), high-income

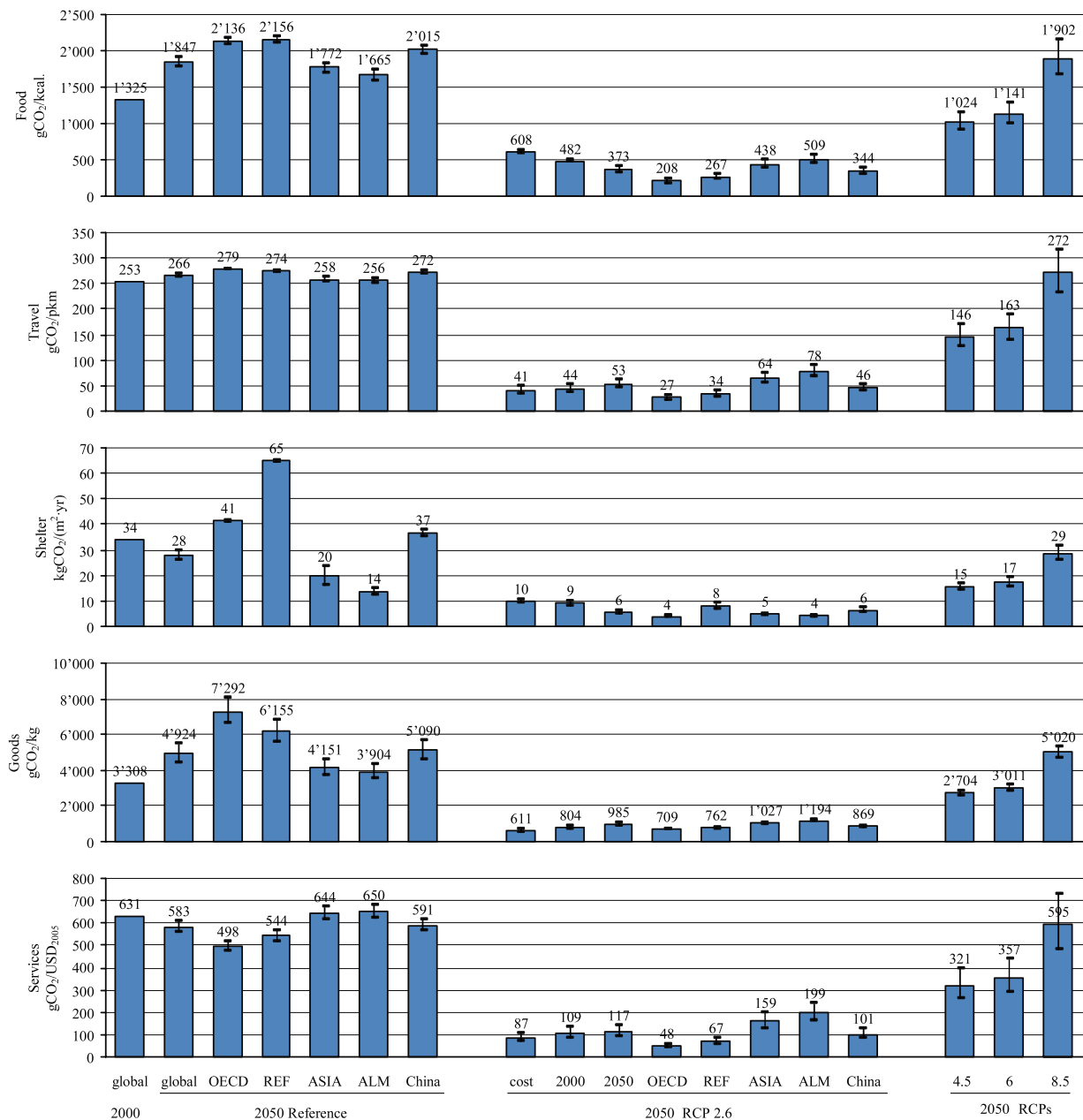


Figure 5. Baseline and target GHG intensity for the five main consumption categories. ‘Global’ refers to the global average. Projections for 2050 are shown for the five main world regions. Target GHG intensities in 2050 for the RCP2.6 are shown for different allocation schemes: same cost of reduction, same reduction from the distribution in 2000 and the same reduction in GHG intensity (2050). The different world regions show the target GHG intensity for same reduction and equal per capita allowance. The GHG intensity for the RCP4.5 to RCP8 uses also the same reduction allowance scheme.

regions would have to impose GHG emission intensity requirements on imports from low-income countries since these countries’ average products would not meet the product climate targets in the high-income regions, even if they meet the targets of the producing countries.

3.3. Feasibility of climate targets consumption level

The climate targets on consumption level enable a discussion of the feasibility of achieving RCP2.6 (table 1) by product modification or shifting consumption to alternative products. Reductions in energy-related GHG emissions in the industry

and power sectors are achieved at relatively low costs and are therefore projected to decrease to nearly zero by 2050 in the RCP2.6 scenario (van Vuuren *et al* 2007). We will therefore focus on the emissions from the non-industry-and-power sectors, since those are the most challenging from a climate mitigation cost perspective.

3.3.1. Food. In the RCP2.6 scenario, the main reduction is obtained by the projected increase in crop yields and the reduction in emissions per unit of food produced (end of pipe reductions for non-CO₂ gases) (Lucas *et al* 2007). The main challenge is, of course, related to the GHG emission intensity

of animal calories. This can be approached in two manners. In the first, animal calories are replaced by vegetable calories processed in such a way that they resemble characteristics of animal-based food (e.g., tofu, wheat gluten). In the second approach, emissions from animal calories are reduced by switching sources from cattle and sheep to poultry, fowl and pork (Carlsson-Kanyama and González 2009). An alternative to this approach includes more radical product innovation such as *in vitro* meat production, leading to a reduction in GHG emissions of animal calories by 80–95% (Tuomisto and de Mattos 2011).

3.3.2. Travel. In the RCP2.6 study by van Vuuren *et al* (2007), the use of biofuels and subsequently, of hydrogen, allows for low GHG intensities in this sector. The electrification of transportation would also facilitate the fulfilment of the target GHG intensity, provided that the electricity comes from renewable energy such as wind and solar (Althaus and Gauch 2011). For trains, even lower emissions can be achieved due to higher efficiency and lower emissions embodied in infrastructure (Spielmann and Scholz 2005). For air travel, the required GHG intensity seems unattainable; electrification is not possible, and hydrogen would be very costly because of the required storage volume and safety concerns (Lee *et al* 2010). Considering the development cycle of about 40 years for airplanes (IPCC 1999), the only realistic large scale technological option for 2050 is blending conventional fossil-based aviation fuels with biofuels. However, besides the limited potential of biofuels, the issue of non-energy related GHG emissions (Kollmuss and Allison 2009) as well as embodied emissions from biofuels (Dornburg *et al* 2010) remain to be solved.

3.3.3. Shelter. In the RCP2.6 study by van Vuuren *et al* (2007), the GHG intensity target value can be reached through fuel switch and efficiency improvements. For new buildings, zero emissions (Marszal *et al* 2011) or net energy production (Bojić *et al* 2011) designs are possible. However because of the lengthy building lifetime of 50 or more years, existing buildings also have to reduce their GHG intensity toward the target value. Buildings retrofitted by combining improved insulation and the use of heat pumps instead of oil heating allow for the required low emission targets to be achieved, but costs and particularly slow retrofit rates remain a challenge to be tackled (Jakob 2006). Other challenges in this consumption category are the relatively low price-sensitivity of households, the lack of finances to cover capital investments and problems related to ownership for rental properties.

3.3.4. Goods. Most of the emissions related to goods stem directly from the industry and power sector. Besides GHG reductions in these sectors, the material composition of goods can contribute to lower GHG intensities. For instance, one kg of textile from jute leads to 3 kg CO₂-eq. whereas cotton emits 26 kg CO₂-eq. (Althaus *et al* 2007). However, the trends go toward increasing emission intensity, e.g., due to an increasing share of IT goods (Hertwich and Roux 2011).

3.3.5. Services. Since it is not the service itself, but the associated goods, buildings, transport and food used when delivering a service that cause the GHG emissions, reaching the GHG intensity goal in this consumption sector includes measures of all other sectors. The US environmental input–output database (Hendrickson *et al* 1998) shows that a shift in expenditure toward labor intensive services results in a reduction in GHG intensities. While the intensity is 830 g CO₂-eq. per USD₁₉₉₈ for hotels, it is 320 g for colleges and universities and only 180 g for doctors and dentists.

3.4. Change in GHG intensity versus consumption level?

So far we concentrated the discussion on the fourth term of equation (1), the GHG intensity of consumption. Reductions can be achieved with changes in GHG intensity of products but also by changing consumption patterns, for instance the reduction of animal calories in diet or change in travel mode split. However, there is no distinguishing aspect between such structural changes in consumption patterns and changes in consumption levels, the third term of equation (1). If we consider income as a proxy for consumption level, a reduction of expenditure for travel and increase in expenditure for service could be defined as a structural change in consumption pattern and therefore be part of the last term of equation (1). An assessment of GHG emissions of Swiss household consumption showed, that without changing the income level a ‘green consumption pattern’ allows GHG emissions 40% below average consumption (Girod and de Haan 2009). In addition, changes on a product level and consumption level are related; since low-carbon options are often more expensive, their purchase reduces overall consumption level (cf. negative rebound (Girod *et al* 2011)). Finally, low-carbon products are rarely identical to their conventional counterparts and may therefore require consumer acceptance (e.g., lower travel distance of electric vehicles).

There is evidence that initiating structural changes in consumption patterns through policy changes is more difficult to achieve than implementing product improvements due to a lack of acceptance for such climate policy measures (Tobler *et al* 2012). The above review of the feasibility of the GHG intensities indicates two areas where changes in consumption trends might still be required to achieve the climate target: meat and dairy (animal calories) consumption and air travel. The assessment of the question if and how much change in the travel and meat consumption is required is also a question of the overall climate mitigation costs and depends not only on the achieved reduction in GHG intensity of these two consumption categories, but also on the emission reductions in the other consumption categories as well as the baseline development.

4. Conclusion

This study evaluated the climate mitigation challenge from a consumption perspective, providing a somewhat different perspective on the mitigation challenge than the usual national- and production-oriented perspectives. Our analysis

suggests that a reduction in GHG intensity of today's products and consumption patterns by a factor of five is required to be in line with the 2 °C climate target and reduce emissions to 2.1 tCO₂-eq. per capita by 2050. Thereby a factor two stems from the projected increase of consumption level driven by growing population and rising income levels. Rising income implies the increased intake of animal-sourced calories for food, as well as increases in air and car travel, cooling demand in shelter and increasingly GHG intensive goods.

Compared to the global average, high-income regions must achieve stronger reductions of GHG emission intensity because of these regions' higher baseline GHG intensity. This is amplified if emissions are allocated equally per capita. In this case, high-income regions must achieve considerably lower GHG intensities as a result of their high consumption level. A per capita allocation therefore also presents a challenge for international trade because products that are consistent with global climate goals in low-income regions have too high GHG emissions for high-income regions.

Comparing the GHG intensity with the available and possible future product modification reveals that in many cases, the climate targets on consumption level can be reached by choosing available products based on low-carbon technology. However, for meat consumption and air travel, reducing GHG intensity in order to achieve the 2 °C climate target is challenging, and therefore the promotion of changing consumption patterns in these categories might be required.

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