ENVIRONMENTAL RESEARCH
COMMUNICATIONS

PAPER • OPEN ACCESS

# Current lifestyles in the context of future climate targets: analysis of long-term scenarios and consumer segments for residential and transport

IOP Publishing Environ. Res. Commun. 4 (2022) 095003 https://doi.org/10.1088/2515-7620/ac8c86

Environmental Research Communications



OPEN ACCESS

RECEIVED
8 February 2022

REVISED
29 June 2022

ACCEPTED FOR PUBLICATION
24 August 2022

PUBLISHED
7 September 2022



PAPER

# Current lifestyles in the context of future climate targets: analysis of long-term scenarios and consumer segments for residential and transport

Nicole J van den Berg[1,*], Andries F Hof[1,2], Vanessa J Timmer[1,3] and Detlef P van Vuuren[1,2]

[1] Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, The Netherlands
[2] PBL Netherlands Environment Assessment Agency, The Hague, The Netherlands
[3] One Earth, Vancouver, Canada
[*] Author to whom any correspondence should be addressed.

E-mail: N.J.vandenBerg@uu.nl, A.F.Hof@uu.nl, Andries.Hof@pbl.nl, V.J.Timmer@uu.nl, vanessa@oneearthweb.org, D.P.vanVuuren@uu.nl and Detlef.vanVuuren@pbl.nl

**Keywords:** consumption patterns, consumer segmentation, scenarios, climate change, lifestyles, behaviour change, integrated assessment

Supplementary material for this article is available online

## Abstract
The carbon emissions of individuals strongly depend on their lifestyle, both between and within regions. Therefore, lifestyle changes could have a significant potential for climate change mitigation. This potential is not fully explored in long-term scenarios, as the representation of behaviour change and consumer heterogeneity in these scenarios is limited. We explore the impact and feasibility of lifestyle and behaviour changes in achieving climate targets by analysing current per-capita emissions of transport and residential sectors for different regions and consumer segments within one of the regions, namely Japan. We compare these static snapshots to changes in per-capita emissions from consumption and technology changes in long-term mitigation scenarios. The analysis shows less need for reliance on technological solutions if consumption patterns become more sustainable. Furthermore, a large share of Japanese consumers is characterised by consumption patterns consistent with those in scenarios that achieve ambitious climate targets, especially regarding transport. The varied lifestyles highlight the importance of representing consumer heterogeneity in models and further analyses.

## 1. Introduction

Recent studies have shown that behavioural changes could significantly contribute to climate change mitigation (Grubler *et al* 2018, IPCC, 2018, Van Vuuren *et al* 2018, Vita *et al* 2019, Capstick *et al* 2020, Ivanova *et al* 2020, Akenji *et al* 2021, Costa *et al* 2021). Still, most long-term mitigation scenarios modelled by Integrated Assessment Models (IAMs) focus mainly on technological options to reduce emissions; emission reduction by behavioural change is typically unrepresented (Saujot *et al* 2020). Moreover, the assumptions of quantified scenarios with behavioural changes (van Sluisveld *et al* 2016, Grubler *et al* 2018) are often stylised (van den Berg *et al* 2019, Krumm *et al* 2022). Representation of consumer heterogeneity in IAMs is also limited (De Cian *et al* 2020), and those studies that incorporate consumer segments focus on specific aspects within a sector (Daioglou *et al* 2012, McCollum *et al* 2017, Edelenbosch *et al* 2018). In addition, few scenario analyses take a consumer perspective and account for regions' heterogeneity across consumer segments with different lifestyles and behaviours. Analysing these fundamental differences makes it possible to identify opportunities and barriers in implementing behavioural change options for climate mitigation.

However, consumption-based carbon footprint studies have extensively modelled the impacts of lifestyles among and within countries (Heinonen *et al* 2020). Several studies show that per-capita emissions, lifestyles, and technology use differ substantially among countries (Brizga *et al* 2017, Heinonen *et al* 2020). Significant regional differences are highlighted in recent reports in which potentials for reducing lifestyle carbon footprints in an equitable consumption space are analysed (Lettenmeier *et al* 2019, Akenji *et al* 2021). These reports also show how far off or close regions are to reaching reduction targets. The regional differences are interesting for understanding the varying contexts that affect the feasibility of behaviour changes and for guiding climate strategy and actions that consider these contextual elements. Lifestyles and consumption patterns are also substantially different *within* regions. One way to better understand consumer heterogeneity and real-world opportunities (and barriers) to behavioural change options is to look at current statistics on consumer groups, lifestyles, and emissions. Per-capita emissions differ strongly between income groups (Seriño 2017, Froemelt *et al* 2018, Gore 2020, Nielsen *et al* 2021). The 10% highest income group's per capita emissions is less than half of the top 1% in the EU (Ivanova and Wood 2020). Similarly, residential areas strongly affect per capita emissions (Minx *et al* 2009, Jones and Kammen 2011, Ala-Mantila *et al* 2014, Jones and Kammen 2014, Ala-Mantila *et al* 2016, Czepkiewicz *et al* 2018, Ottelin *et al* 2019, Nissinen and Savolainen 2020, Heinonen *et al* 2013a, b, , , , , ). Other demographic differences and transitions such as age and household composition also affect per capita emissions substantially (Yu *et al* 2018, Koide *et al* 2019). These studies show how different contexts affect consumption patterns and highlight consumer heterogeneity within countries or regions.

Per capita emissions with detailed impacts from different lifestyles, and IAM scenarios providing a long-term mitigation context, can complement each other well. More specifically, representing heterogeneous consumer segments in long-term mitigation scenarios can provide insights into opportunities and challenges for different consumer segments to reduce emissions. In this paper, we assess whether current statistics on emissions of various consumer groups and regions can provide insight into the feasibility of behavioural changes to reach long-term mitigation targets. First, we provide the context by comparing different regions and their sectoral per-capita emission trends depicted in long-term scenarios (divided into the impact of technology and consumption change) with statistics on current emissions. Secondly, we focus on the case study of Japan, where carbon footprints based on a household data survey have been modelled in detail. We choose this study because it provides comparable data to directly compare with our model-based scenario on sectoral $CO_2$ emissions for different consumer segments (Koide *et al* 2019). Similar comparisons, providing insights into the implications of varying emission levels, can be done for other countries. We apply a decomposition tool, ASIF* (van den Berg *et al* 2021), to explore the contribution of technology and consumption changes to emission trends in the various scenarios. We also compare these long-term scenarios to the current $CO_2$ emissions of multiple regions and diverse consumer segments. This comparative analysis emphasises the diversity of current transport and residential lifestyles and shows which lifestyles align with the Paris Agreement climate objectives. Modellers can also use the consumer groups as input for more heterogeneity in future scenario development within IAMs.

## 2. Methodology

We analyse regional and sectoral per-capita emissions of multiple long-term model-based scenarios. We first apply the decomposition tool ASIF* to highlight the contributions of consumption and technology changes to global and regional changes in per-capita emissions from transport and residential sectors. We then compare the long-term scenarios with the current $CO_2$ emissions of different consumer segments in Japan.

### 2.1. IMAGE integrated assessment model

We used existing long-term scenarios developed by the integrated assessment model IMAGE (Integrated Model to Assess the Global Environment) (Stehfest *et al* 2014). From the 26 regions modelled in IMAGE, we selected a diverse set of regions for comparison to each other and the 'Global' average: 'Japan', Western Europe', 'India', 'Indonesia', 'Russia', 'USA', 'China', 'South Africa' and 'Brazil'. IMAGE models the long-term dynamic changes in land and energy systems by capturing the interactions between various system-dynamic sub-models. One of the submodels, the IMAGE-TIMER energy model, models the energy demand within the transport and residential sectors. Therefore, the scope of this analysis is limited to end-use demand sectors, *transport* and *residential*.

We consider emissions from space heating, space cooling, water heating, cooking, and appliances in the residential sector. We cover passenger transport modes in the transport sector, including aviation (see SI 2). IMAGE calibrates historical sectoral energy use for each energy carrier to the IEA energy statistics. Future $CO_2$ emissions are projected by fuel-specific emission factors used in emission inventories such as EDGAR. The emissions include both direct emissions and, for electricity, hydrogen and modern biomass, indirect emissions. The time, region, and scenario-dependent emission factors of electricity and hydrogen depend on the primary energy mix of electricity generation (see S.I.4). For modern biomass, the emissions include non-renewable energy use for production, conversion (Daioglou *et al* 2015) and land-use change. The emissions from land-use change accounts for the transformation of natural and abandoned agricultural grasslands and land for bioenergy crop production. It accounts for land-use change emissions and the 'foregone sequestration' emissions (Daioglou *et al* 2017). For traditional biomass, we assume that 60% of the biomass is entirely renewable. For the remaining 40%, the carbon content of the biomass (26kg-C/GJ) is used to determine the contribution to emissions.

### 2.2. Long-term model-based scenarios

We begin by focusing on current and depict global and regional per-capita emissions of residential and transport sectors. We analyse the per-capita emissions under three model-based scenarios (see table 1 for details). We chose these scenarios to illustrate how different measures, namely carbon pricing and behavioural changes, contribute to changes in emissions. The three scenarios show 2050 per-capita emissions without additional climate policy (i.e. SSP2 Baseline scenario), with climate policy measures (SSP2 + 2 °C scenario) and with behaviour change and climate policy measures (i.e. Behaviour Change + 2 °C scenario).

### 2.3. ASIF* Decomposition tool

Decomposition analyses provide detailed information on different factors contributing to emissions (Ang *et al* 2003, Edelenbosch *et al* 2017, Chen *et al* 2021). The scenarios are analysed via the ASIF* decomposition tool (van den Berg *et al* 2021). This tool determines which factors contribute to changes in per capita emissions. Two factors, activity and structure/service, relate to consumption, and two other, intensity and fuel mix, relate to technology (see figure 1 and further detail in SI 2(available online at stacks.iop.org/ERC/4/095003/mmedia)). Changes in *activity* refer to the direct changes in consumption (e.g. avoiding kilometres or appliances ownership), *structural* changes in transport refer to shifting transport modes, and *service* change in residential refers to measures such as shifting the thermostat temperature. The technology factor *intensity* relates to the changes in energy use needed for a particular activity (e.g. improving vehicle efficiency). The *fuel mix* relates to emissions per energy used (e.g. changing to renewable energy sources).

### 2.4. Carbon footprints of Japan

Ideally, we would have compared our IMAGE scenarios to the carbon footprints of various consumer segments for multiple regions. However, existing carbon footprint studies differ widely in consumer segments (e.g. income groups, demographics) and scope of emissions, thus reducing their comparability (Heinonen *et al* 2020). Therefore, we decided to focus on one study only. The carbon footprint study analysing Japanese consumer segments (Koide *et al* 2019) was chosen for comparison as its data is transparent and closest to the scope of emissions in IMAGE. This study uses survey expenditure on Japanese households to assess emissions attributed to specific activities via an environmentally-extended input-output analysis. Sectoral $CO_2$ emissions are based on anonymous microdata from the 2004 National Survey of Family Income and Expenditure. The dataset contains detailed information of 47,000 households categorised in 15 consumer segments, distinguished by various sociodemographic characteristics and covering over three hundred consumption categories. Even though the data (Koide *et al* 2019) is comparable with IMAGE output, we had to address some inconsistencies. These inconsistencies result from i) the survey data being filled with estimates and ii) the IMAGE model using different emission factors than the Japanese survey. Therefore, we adjusted the residential $CO_2$ emissions by a ratio of 0.78 to match the IMAGE scenario results for comparability. For transport $CO_2$ emissions, we did not need to adjust the data as it was already consistent with IMAGE. The IMAGE emission data is consistent with Japan's IEA energy use statistics.

## 3. Results

The results are separated into two sections. The first section shows the decomposition outcomes of long-term scenarios alongside multiple regions' current per capita $CO_2$ emissions. The second section focuses on Japan, comparing the decomposition analysis of long-term scenarios to the current $CO_2$ emissions of Japanese consumer segments based on the household expenditure data (Koide *et al* 2019).

### 3.1. Impact of consumption and technology changes on emissions in long-term mitigation scenarios

*3.1.1. Global long-term scenarios in the context of current regional $CO_2$ emissions*

This section highlights various regions' current transport and residential $CO_2$ emissions compared to the current global average and the global average in long-term mitigation scenarios. Figure 2(a) shows the transport and residential per-capita emissions in 2015 and how these would change by 2050 in mitigation scenarios due to consumer behaviour and technology changes. The different colours depict different scenarios, and the dashed arrows show the impact of consumption (C) and technology changes (T) on transport and residential per-capita emissions from 2015 to 2050. The solid arrows depict the net effect of dashed lines C and T. It is crucial to

**Table 1.** Scenario descriptions.

| Scenarios | Description |
|---|---|
| SSP2 Baseline scenario | The 'Middle-of-the-road' (O'Neill *et al* 2017) SSP2 scenario assumes current economic and social patterns and trends will continue until 2100, with consumption patterns following GDP trends. It only includes climate policies that are already implemented. |
| SSP2 + 2 °C scenario | The SSP2 + 2 °C scenario includes climate policies (i.e. carbon pricing) to stabilise GHG emission concentrations to 450 ppm $CO_2$-eq by 2100 with a maximum temperature increase of 2 °C in global mean temperature. |
| Behaviour Change + 2 °C scenario | The Behaviour Change + 2 °C scenario also includes climate policies (i.e. carbon pricing) and several behaviour changes to reach 2 °C climate targets within the residential and transport sectors (e.g., transport modal shifts, thermostat adjustments in homes and smaller floor space per capita) (van Sluisveld *et al* 2016). |

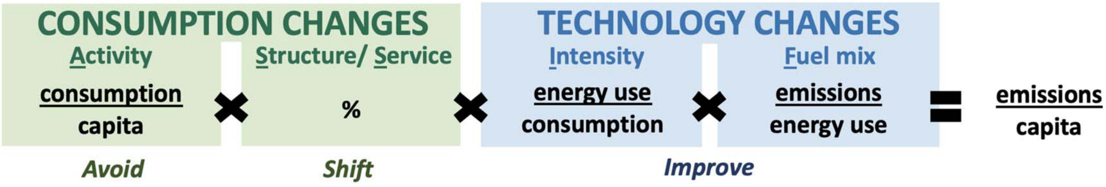


**Figure 1.** ASIF* decomposition tool categorises contributing factors of consumption and technology changes based on the Kaya Identity, with the corresponding ASI behavioural interventions shown in italics. Reproduced from (van den Berg *et al* 2021) © The Author(s). Published by IOP Publishing Ltd. CC BY 4.0.

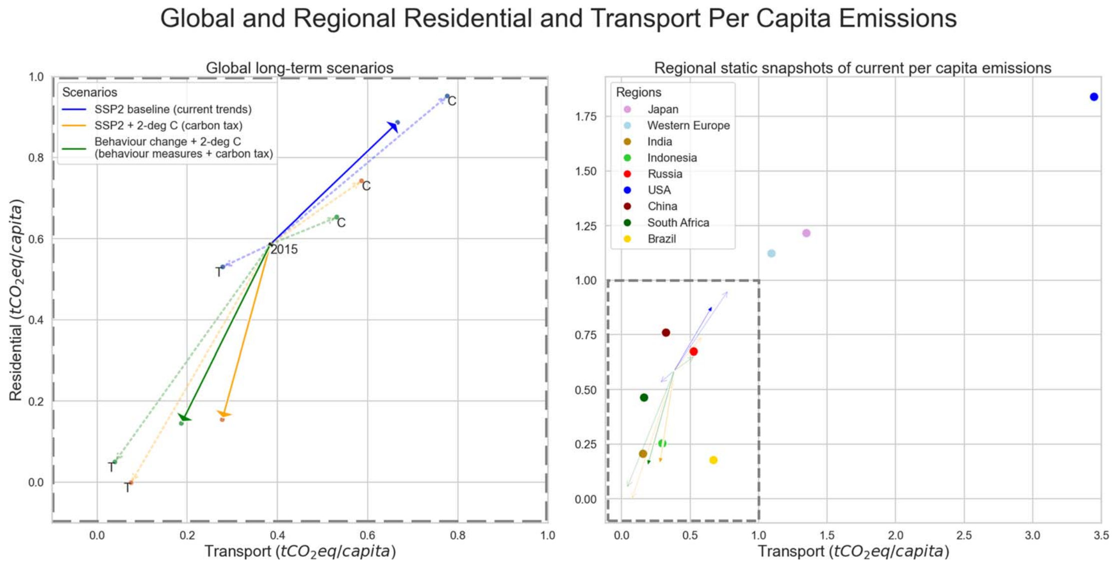


**Figure 2.** (a) Global long-term scenarios and impacts from different types of changes, C = consumption changes (without technology changes), T = technology changes (without consumption changes); 2b) Global long-term scenarios (zoomed-out, as shown by the grey, dotted boxes) in context of regional current per-capita emissions.

remember that the impact of technology change and consumption change are mutually interdependent. For example, if per-capita consumption would not increase, the effect of technology change would be less. The scenarios represent the effects of a carbon tax (SSP2 + 2 °C scenario, shown in orange) and behaviour measures (Behaviour Change + 2 °C, shown in green) compared to no measures when following current trends (SSP2 Baseline, shown in blue). Figure 2(b) shows 2015 per-capita emissions of regions varying in characteristics, namely the USA, Western Europe, Japan, China, South Africa, Brazil, India, Indonesia, and Russia, alongside the global average.

Figure 2(a) highlights the different impacts of consumption and technology change on global per-capita emissions for transport and residential sectors under different scenarios. In the SSP2 Baseline scenario, consumption changes substantially impact increasing emissions, which is only partly offset by technology changes (shown by the dashed lines), resulting in a net effect of growing per-capita emissions between 2015 and 2050 (indicated by the solid lines). In the SSP2 + 2 °C scenario, the carbon tax strongly reduces per-capita emissions through changes in technology, especially in residential. Changes in consumption have relatively less but still considerable impact. For example, technology has a much stronger effect on residential emissions; the SSP2 + 2 °C scenario is 0.5 $tCO_2$/capita lower and 0.2 $tCO_2$/capita from consumption changes than the SSP2 Baseline. There is less difference between consumption and technology for transport, as there is a 0.2 $tCO_2$/capita effect from consumption and a 0.2 $tCO_2$/capita effect from technology changes. In the Behaviour Change + 2 °C scenario, behavioural measures and carbon taxes further reduce per capita transport emissions through changes in consumption.

Figure 2(b) compares the difference in absolute $CO_2$ emissions in 2015 between regions, highlighting the extensive range in $CO_2$ emissions among the regions and their distance from the global average and the 2 °C emission level. A few observations are worth mentioning here. First, the USA has much higher per capita transport and residential emissions than the global average. Japan and Western Europe are also substantially higher than the global average. Second, compared to the global average, China has lower per-capita emissions for

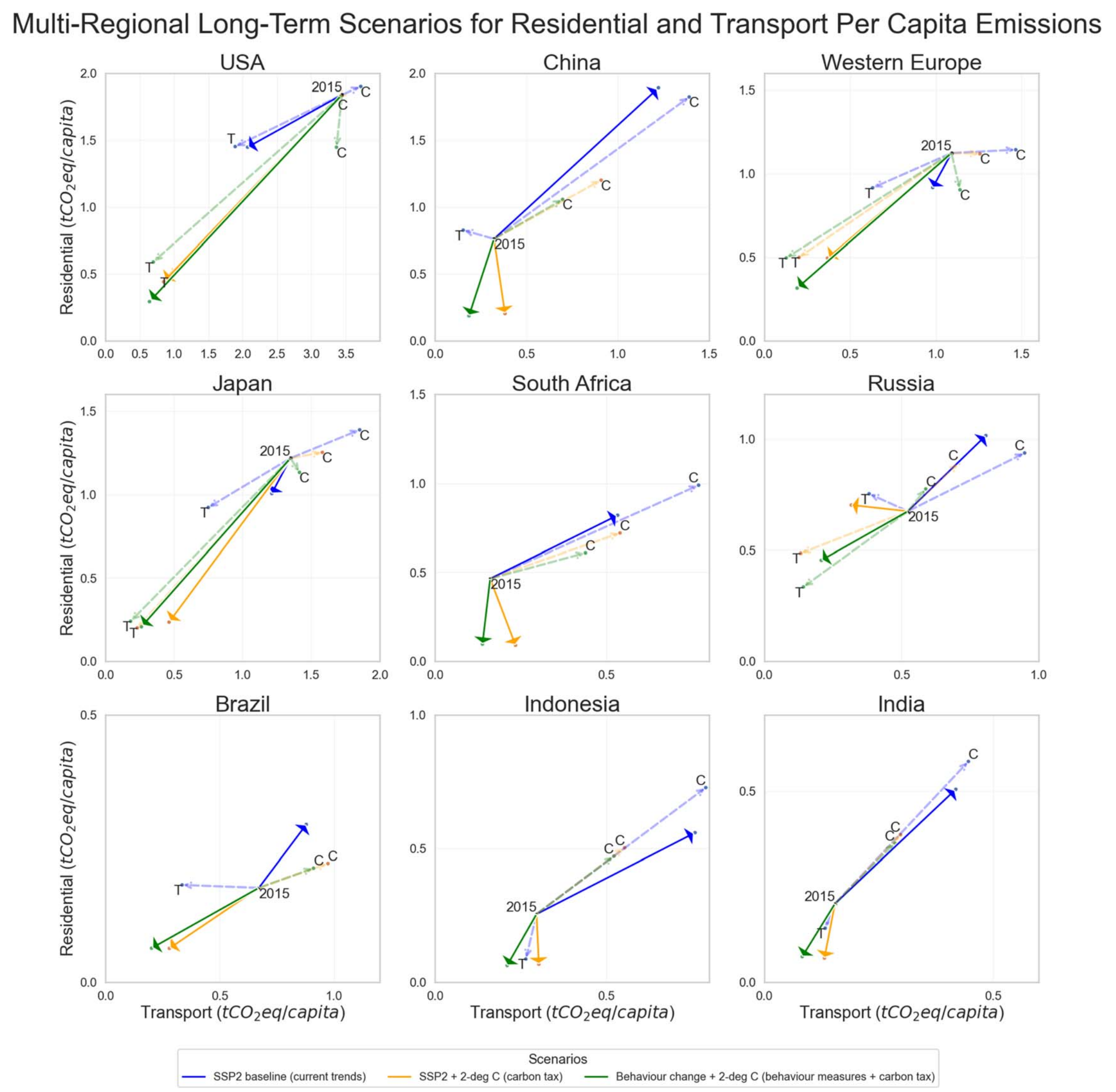


**Figure 3.** Residential and transport per-capita emissions between 2015 and 2050 for a range of regions (i.e. USA, China, Western Europe, Japan, South Africa, Russia, Brazil, Indonesia and India) with various long-term scenarios and impacts from different types of changes, C = consumption changes (without technology changes), T = technology changes (without consumption changes).

transport but higher for residential, primarily in appliance use. This trend is the other way around for Brazil, with relatively high car use. Third, Russia is slightly higher than the global average for transport and residential. Finally, India, South Africa and Indonesia have much lower per-capita residential and transport emissions, close to the global 2050 2 °C per-capita emissions, partly due to lower activity and relatively high use of public transport.

### *3.1.2. Multi-regional comparison of long-term scenarios*

The changes in transport and residential per-capita emissions resulting from consumption and technology changes differ considerably between regions (figure 3). When considering only the effects of consumption changes, all regions show increasing per-capita emissions in the SSP2 Baseline scenario. Most regions still show growing emissions in the mitigation scenarios, especially transport.

There is a substantial increase in per-capita emissions in China, South Africa, Brazil, India, Indonesia, and Russia in the SSP2 Baseline scenario. This trend can be explained by the anticipated economic growth in these regions. The decrease in per-capita emissions from technology changes does not offset the increase in emissions from consumption changes. The developed regions (i.e. the USA, Western Europe and Japan) experience a different trend. Since these regions are already highly industrialised, they already had high per-capita emissions in 2015. Therefore, the impact of consumption changes on emission increases is much smaller since most of these increases happened historically. In this case, technology changes between 2015 and 2050 offset the emission increase from consumption changes. In some regions, technology changes lead to residential emission

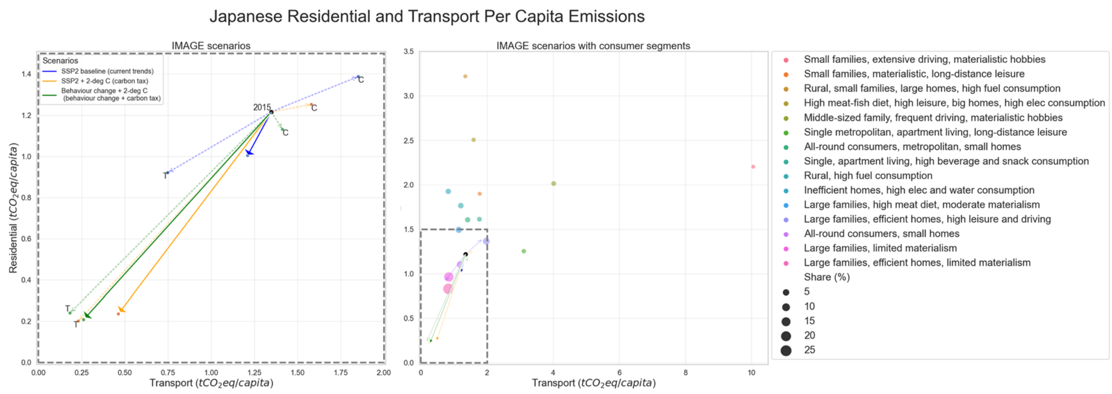


**Figure 4.** (a) Japanese long-term scenarios and impacts from different types of changes, C = consumption changes (without technology changes), T = technology changes (without consumption changes) for residential and transport; 4(b) Comparison of long-term scenarios (zoomed-out, as shown by the grey, dotted boxes) and Japanese consumer segments. Reproduced from (Koide, R. 2019) CC BY 4.0..

increases. This increase is due to more use of inefficient air conditioners and appliances. At the same time, a shift to higher carbon fuels for space heating and water heating causes an emission increase for Russia.

In the SSP2 + 2 °C scenario, all regions still show increasing per-capita emissions from consumption changes in transport, but less than in the SSP2 Baseline. This trend is notable for China. In all regions, the emission reductions from technology changes offset the increases from consumption changes. This offsetting effect is significant in the USA, Western Europe and Japan due to their relatively high per-capita emissions. There is more potential for reduction with higher emissions from both consumption and technology changes.

In the Behaviour Change + 2 °C scenario, consumption changes significantly impact emissions, especially in residential. Therefore, there is less impact of technology changes on emissions needed compared to the SSP2 + 2 °C scenario. In all regions but the USA, consumption changes still have an increasing effect on transport emissions, based on the assumptions in this scenario.

### 3.2. Japanese mitigation scenarios in the context of their current lifestyles

This section compares current Japanese per-capita emissions of different consumer segments to different long-term scenarios. Figure 4(a) shows the average per-capita emissions in 2015 and 2050 under various scenarios. Figure 4(b) compares these numbers with the variation in per-capita transport and residential emissions of consumers in Japan (figure 4(b)).

This comparative analysis shows how far some smaller groups are from a 2 °C lifestyle, while some larger groups are relatively close. For residential, for example, 'rural, small families, large homes, and high fuel consumption' (less than 1% of the population with per-capita residential emissions of 4.8 $tCO_2$-eq) have per capita emissions which are four times higher than 'large families, with efficient homes and limited materialism' (28% of the population with 1.2t $CO_2$-eq/capita). For transport, 'small families with very frequent driving and materialistic hobbies' (0.5% of the population with 10 $tCO_2$-eq/capita) have more than ten times the per capita emissions than 'large families with limited materialism' (22% of the population with 0.83 $tCO_2$-eq/capita). This significant difference between consumer segments highlights which segments have a high potential for reducing emissions and which segments are on track to reach per capita emissions in line with 2 °C. Since income inequality is not that vast in Japan, there is high potential for a shift to lower-impact lifestyles with similar well-being.

For about 50% of the population, those with 'large families, efficient homes and limited materialism', current per-capita emissions are not far from emissions in the 2 °C scenarios by 2050. When only considering transport, 80% of the population is close to a lifestyle meeting 2050 climate targets. These relatively low per capita emissions for Japanese consumers are due to Japan's effective public transport system. Thus, improving infrastructure, technology, and electrification, enables low emissions. Consumer segments such as 'families with inefficient homes, high electricity and water consumption' and 'large families, efficient homes, with high leisure and driving' are in-between the high- and low emitters. Through changes in infrastructure and social norms, those with 'high leisure and driving' could make more use of the public transport system, while those with 'inefficient homes' could invest in sustainable home renovations. Some groups have high emissions only in residential (top-left in figure 4(b)), while others have high emissions in both residential and transport (top-right in figure 4(b)). Due to Japan's already strong public transport system, there is a lower potential for transport emission reduction than residential. A carbon tax would significantly reduce their emissions via technology and consumption changes. Behaviour changes enabled by infrastructure, supportive policy regulations and cultural change would lead to a further decrease, especially in residential per capita emissions.

## 4. Discussion

Most long-term scenario assessments focus on aggregate results (i.e. total $CO_2$ emission pathways). Sectoral emission trends, and the disaggregated results for both transport and residential, allow for a more detailed analysis which can translate to more targeted climate mitigation interventions. The role of differences in regional contexts (e.g. economic development, consumer preferences, fuel availability) on observed differences between residential and transport emissions, for instance, can be analysed in more detail. Furthermore, comparing sectoral per-capita emissions of long-term scenarios with different consumer segments provides insights into which consumption patterns are consistent with long-term climate targets. These insights can guide policy, infrastructural and supportive cultural interventions to enable these low-emission consumption patterns. However, there are some significant limitations of our research.

Firstly, finding comparable data to the long-term scenarios proved difficult. Therefore, we decided to focus on Japan as a case study based on the availability of information and assumptions in the (Koide *et al* 2019) article. As stated in the methodology, many differences among consumption-based carbon footprints reduce their comparability (Heinonen *et al* 2020). For example, a consumer segmentation study by Froemelt *et al* (2018) focusing on Swiss consumer segments would have been very interesting to compare. However, the scope of emissions included differed significantly from both (Koide *et al* 2019) and IMAGE long-term scenarios. Another relevant study by Ivanova and Wood (2020) looked at the carbon footprints of different income groups within EU countries, but the consumer segments would be challenging to compare with the unique Japanese consumer segments (Koide *et al* 2019) (see figure 4 and S.I.5). Furthermore, many carbon footprint studies represent the emissions from the entire life cycle, and it is difficult to isolate only the emissions in the use phase to be comparable to IMAGE and (Koide *et al* 2019).

Secondly, we focused on only the direct and indirect emissions of energy use of passenger transport and the residential sector. In IMAGE, passenger transport and the residential sector are modelled within the IMAGE-TIMER energy model, disregarding upstream and downstream emissions of vehicle production and construction of buildings. For future research, including these emissions of the entire lifecycle could provide a more comprehensive analysis.

Thirdly, we did not consider food and consumer goods, which are also highly relevant to lifestyle changes. In recent studies IMAGE has been used to model material demand (Deetman 2021) and diet change in food demand (Stehfest *et al* 2009, van Sluisveld *et al* 2016). Applying the decomposition tool to these sectors would be valuable for future research.

There is much room for improved lifestyle and behaviour change assumptions in long-term scenarios. The Behaviour Change + 2 °C scenario analysed in this research only indicates the potential impacts of lifestyle changes on climate change mitigation. This limited representation is due to stylised assumptions (e.g. everyone adopts a healthy diet or adjusts their thermostat). To improve representation, social science research on behaviour and lifestyle change can inform IAMs about the types of changes, the extent of change and the speed of transition for more nuanced lifestyle scenarios and more targeted responses.

Adding more heterogeneity to IAMs and long-term scenarios allows a better representation of consumers and lifestyle changes. As our results show, the differences between consumer segments within regions are substantial. To better represent consumers and behaviour change in models, modellers can add different types of consumer segments in IAMs. One option is to add empirical data or use household-specific per-capita emissions, such as the Japanese study used in this research. However, accessing this data for all regions could prove difficult. Furthermore, downscaling and differentiating archetypes from national survey data (Hanmer *et al* 2022) could be an alternative way to add heterogeneity to model-based scenarios. Another option can be to incorporate more generic consumer segments such as the adopter groups based on the diffusion of innovations theory (Rogers 2010). The additional detail per adopter group would allow different market segments and transition speeds to be considered.

A just energy transition is gaining increasing attention and importance within the climate change discussion. Our results emphasise the inequality of $CO_2$ emissions in society, between regions and within regions and raise the question of equity. There is plenty of space for improvement and emission reductions when analysing the high emitters. In contrast, low emitters have limited room to reduce their $CO_2$ emissions, and it is reasonable that they have room to increase their $CO_2$ emissions, especially those under the poverty line. If future scenarios are based on a just transition to reach our climate targets, they should incorporate equity in the assumptions and solutions they reveal.

## 5. Conclusions

This study applies the ASIF* decomposition tool, highlighting underlying changes in transport and residential for multiple scenarios and diverse regions in the context of different consumer segments. Based on our results and discussion, we draw the following conclusions.

**5.1. There is less reliance on technology changes when sustainable consumption changes reduce emissions.**
Per-capita emissions from consumption change increase less drastically with a carbon tax and behavioural measures, so technology changes do not have to offset as much to reach 2 °C climate targets. Therefore, the feasibility of reaching mitigation scenarios increases significantly with lifestyle and behavioural changes, as there is less reliance on technological solutions.

**5.2. In Japan, some large consumer segments are already close to 2050 per capita transport $CO_2$ emissions consistent with a 2 °C climate target.**
Due to Japan's sustainable transport system and consumer preferences, many of the consumer segments in Japan have relatively low emissions in the transport sector. They are thus close to reaching per capita emissions in line with 2 °C. Therefore, the feasibility of behaviour changes for Japan is high for transport, as long as there are no significant shifts between segments. This trend also reinforces the importance of enabling infrastructures for shifting to low emission behaviours. However, for residential, there is more considerable differentiation between groups. These larger differences could affect Japan's feasibility of reaching mitigation targets for residential.

**5.3. Heterogeneous consumer segments within and between regions show diverse lifestyles and contexts that affect $CO_2$ emissions.**
Our multi-regional comparisons show notable differences in $CO_2$ emissions and consequent pathways to 2 °C across transport and residential, from different consumption patterns and contextual factors affecting technology. Our within-region comparison for Japan shows significant differences in consumer segments, primarily in residential $CO_2$ emissions, due to Japan's sustainable transport system in Japan. The diversity sheds light on high emitting behaviours and guides targeted interventions for achieving high-quality lives with lower emissions in equitable ways. This diversity also highlights the importance of accounting for heterogeneity in scenario analysis, development and modelling.

## Acknowledgments

The authors of this research are grateful for the financial support received from the KR Foundation.

## Data availability statement

No new data were created or analysed in this study.

## ORCID iDs

Nicole J van den Berg https://orcid.org/0000-0002-2884-7399
Andries F Hof https://orcid.org/0000-0002-7568-5038
Detlef P van Vuuren https://orcid.org/0000-0003-0398-2831

## References

Akenji L, Bengtsson M, Toivio V, Lettenmeier M, Fawcett T, Parag Y, Saheb Y, Coote A, Spangenberg J H and Capstick S 2021 *1.5–Degree Lifestyles: Towards A Fair Consumption Space for All*

Ala-Mantila S, Heinonen J and Junnila S 2014 Relationship between urbanisation, direct and indirect greenhouse gas emissions, and expenditures: a multivariate analysis *Ecol. Econ.* **104** 129–39

Ala-Mantila S, Ottelin J, Heinonen J and Junnila S 2016 To each their own? The greenhouse gas impacts of intra-household sharing in different urban zones *J. Clean. Prod.* **135** 356–67

Ang B W, Liu F and Chew E P 2003 Perfect decomposition techniques in energy and environmental analysis *Energy Policy* **31** 1561–6

Brizga J, Feng K and Hubacek K 2017 Household carbon footprints in the Baltic States: a global multi-regional input–output analysis from 1995 to 2011 *Appl. Energy* **189** 780–8

Capstick S, Khosla R, Wang S, van den Berg N, Ivanova D, Otto I M, Gore T, Corner A, Akenji L and Hoolohan C 2020 Bridging the gap–the role of equitable low-carbon lifestyles *UNEP Emission Gap Report 2020. UNEP* 62–75

Chen H-H, Hof A F, Daioglou V, de Boer H S, Edelenbosch O Y, van den Berg M, van der Wijst K-I and van Vuuren D P 2021 Using decomposition analysis to determine the main contributing factors to carbon neutrality across sectors *Energies* **15** 132
Costa L, Moreau V, Thurm B, Yu W, Clora F, Baudry G, Warmuth H, Hezel B, Seydewitz T and Ranković A 2021 The decarbonisation of Europe powered by lifestyle changes *Environ. Res. Lett.* **16** 044057
Czepkiewicz M, Heinonen J and Ottelin J 2018 Why do urbanites travel more than do others? A review of associations between urban form and long-distance leisure travel *Environ. Res. Lett.* **13** 073001
Daioglou V, Doelman J C, Stehfest E, Müller C, Wicke B, Faaij A and Van Vuuren D P 2017 Greenhouse gas emission curves for advanced biofuel supply chains *Nature Climate Change* **7** 920–4
Daioglou V, Van Ruijven B J and Van Vuuren D P 2012 Model projections for household energy use in developing countries *Energy* **37** 601–15
Daioglou V, Wicke B, Faaij A P and Van Vuuren D P 2015 Competing uses of biomass for energy and chemicals: implications for long-term global $CO_2$ mitigation potential *Gcb Bioenergy* **7** 1321–34
De Cian E, Dasgupta S, Hof A F, van Sluisveld M A, Köhler J, Pfluger B and van Vuuren D P 2020 Actors, decision-making, and institutions in quantitative system modelling *Technol. Forecast. Soc. Change* **151** 119480
Deetman S P 2021 *Stock-Driven Scenarios On Global Material Demand: the Story of a Lifetime* (The Netherlands: Leiden University) https://hdl.handle.net/1887/3245696
Edelenbosch O, McCollum D L, Pettifor H, Wilson C and Van Vuuren D P 2018 Interactions between social learning and technological learning in electric vehicle futures *Environ. Res. Lett.* **13** 124004
Edelenbosch O Y, McCollum D, van Vuuren D, Bertram C, Carrara S, Daly H, Fujimori S, Kitous A, Kyle P and Broin E Ó 2017 Decomposing passenger transport futures: comparing results of global integrated assessment models *Transportation Research Part D: Transport and Environment* **55** 281–93
Froemelt A, Dürrenmatt D J and Hellweg S 2018 Using data mining to assess environmental impacts of household consumption behaviors *Environmental Science & Technology* **52** 8467–78
Gore T 2020 Confronting carbon inequality: putting climate justice at the heart of the COVID-19 recovery.http://policy-practice.oxfam.org.uk/publications/confronting-carbon-inequality-putting-climate-justice-at-the-heart-of-the-covid-621052
Grubler A *et al* 2018 A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies *Nat. Energy* **3** 515–27
Hanmer C, Wilson C, Edelenbosch O Y and Van Vuuren D P 2022 Translating global integrated assessment model output into lifestyle change pathways at the country and household level *Energies* **15** 1650
Heinonen J, Jalas M, Juntunen J K, Ala-Mantila S and Junnila S 2013a Situated lifestyles: I. How lifestyles change along with the level of urbanisation and what the greenhouse gas implications are-a study of Finland *Environ. Res. Lett.* **8** 025003
Heinonen J, Jalas M, Juntunen J K, Ala-Mantila S and Junnila S 2013b Situated lifestyles: II. The impacts of urban density, housing type and motorisation on the greenhouse gas emissions of the middle-income consumers in finland *Environ. Res. Lett.* **8** 035050
Heinonen J, Ottelin J, Ala-Mantila S, Wiedmann T, Clarke J and Junnila S 2020 Spatial consumption-based carbon footprint assessments-A review of recent developments in the field *J. Clean. Prod.* **256** 120335
IPCC 2018 Global warming of 1.5 °C. An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways *The Context Of Strengthening The Global Response To The Threat Of Climate Change, Sustainable Development, And Efforts To Eradicate Poverty* ed V Masson-Delmotte *et al* Accepted
Ivanova D, Barrett J, Wiedenhofer D, Macura B, Callaghan M W and Creutzig F 2020 Quantifying the potential for climate change mitigation of consumption options *Environ. Res. Lett* (https://doi.org/10.1088/1748-9326/ab8589)
Ivanova D and Wood R 2020 The unequal distribution of household carbon footprints in Europe and its link to sustainability *Global Sustainability* **3** e18
Jones C and Kammen D M 2014 Spatial distribution of US household carbon footprints reveals suburbanisation undermines greenhouse gas benefits of urban population density *Environmental science & technology* **48** 895–902
Jones C M and Kammen D M 2011 Quantifying carbon footprint reduction opportunities for US households and communities *Environ. Sci. Technol.* **45** 4088–95
Koide R, Lettenmeier M, Kojima S, Toivio V, Amellina A and Akenji L 2019 Carbon footprints and consumer lifestyles: an analysis of lifestyle factors and gap analysis by consumer segment in japan *Sustainability* **11** 5983
Krumm A, Süsser D and Blechinger P 2022 Modelling social aspects of the energy transition: What is the current representation of social factors in energy models? *Energy* **239** 121706
Lettenmeier M, Koide R, Toivio V, Amellina A and Akenji L 2019 *1.5-Degree Lifestyles: Targets and Options for Reducing Lifestyle Carbon Footprints.* (Hayama, Japan.: Technical Report. Institute for Global Environmental Strategies)
McCollum D L, Wilson C, Pettifor H, Ramea K, Krey V, Riahi K, Bertram C, Lin Z, Edelenbosch O Y and Fujisawa S 2017 Improving the behavioral realism of global integrated assessment models: An application to consumers' vehicle choices *Transportation Research Part D: Transport and Environment* **55** 322–42
Minx J C, Wiedmann T, Wood R, Peters G P, Lenzen M, Owen A, Scott K, Barrett J, Hubacek K and Baiocchi G 2009 Input–output analysis and carbon footprinting: an overview of applications *Economic systems research* **21** 187–216
Nielsen K S, Nicholas K A, Creutzig F, Dietz T and Stern P C 2021 The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions *Nat. Energy* **6** 1011–6
Nissinen A and Savolainen H 2020 Carbon footprint and raw material requirement of public procurement and household consumption in Finland-Results from the ENVIMAT-model
O'Neill B C *et al* 2017 The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century *Global Environ. Change* **42** 169–80
Ottelin J, Heinonen J, Nässén J and Junnila S 2019 Household carbon footprint patterns by the degree of urbanisation in Europe *Environ. Res. Lett.* **14** 114016
Rogers E M 2010 *Diffusion of Innovations.* (Simon and Schuster)
Saujot M, Le Gallic T and Waisman H 2020 Lifestyle changes in mitigation pathways: policy and scientific insights *Environ. Res. Lett.* **16** 015005
Seriño M N V 2017 Is decoupling possible? association between affluence and household carbon emissions in the Philippines *Asian Economic Journal* **31** 165–85
Stehfest E *et al* 2014 Integrated assessment of global environmental change with IMAGE 3.0 - model description and policy implications *PBL Netherlands Environmental Assessment Agency, The Hague*

Stehfest E, Bouwman L, Van Vuuren D P, Den Elzen M G, Eickhout B and Kabat P 2009 Climate benefits of changing diet *Clim. Change* **95** 83–102

van den Berg N J, Hof A F, Akenji L, Edelenbosch O Y, van Sluisveld M A, Timmer V J and van Vuuren D P 2019 Improved modelling of lifestyle changes in integrated assessment models: cross-disciplinary insights from methodologies and theories *Energy Strategy Reviews* **26** 100420

van den Berg N J, Hof A F, van der Wijst K-I, Akenji L, Daioglou V, Edelenbosch O Y, van Sluisveld M A, Timmer V J and van Vuuren D P 2021 Decomposition analysis of per capita emissions: a tool for assessing consumption changes and technology changes within scenarios *Environmental Research Communications* **3** 015004

van Sluisveld M A E, Martínez S H, Daioglou V and van Vuuren D P 2016 Exploring the implications of lifestyle change in 2 °C mitigation scenarios using the IMAGE integrated assessment model *Technological Forecasting and Soc. Change* **102** 309–19

Van Vuuren D P, Stehfest E, Gernaat D E, Van Den Berg M, Bijl D L, De Boer H S, Daioglou V, Doelman J C, Edelenbosch O Y and Harmsen M 2018 Alternative pathways to the 1.5 C target reduce the need for negative emission technologies *Nat. Clim. Change* **8** 391–7

Vita G, Lundström J R, Hertwich E G, Quist J, Ivanova D, Stadler K and Wood R 2019 The environmental impact of green consumption and sufficiency lifestyles scenarios in europe: connecting local sustainability visions to global consequences *Ecol. Econ.* **164** 106322

Yu B, Wei Y-M, Kei G and Matsuoka Y 2018 Future scenarios for energy consumption and carbon emissions due to demographic transitions in chinese households *Nat. Energy* **3** 109–18