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

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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, Capsick 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 Sluijsveld 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 2021), 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 (Seríño 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 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 insights 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 SI 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 (Daïoglou 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 CO₂ 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 CO₂ emissions by a ratio of 0.78 to match the IMAGE scenario results for comparability. For transport CO₂ 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 CO₂ emissions. The second section focuses on Japan, comparing the decomposition analysis of long-term scenarios to the current CO₂ 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 CO₂ emissions
This section highlights various regions’ current transport and residential CO₂ 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 CO₂-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). |
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 tCO2/capita lower and 0.2 tCO2/capita from consumption changes than the SSP2 Baseline. There is less difference between consumption and technology for transport, as there is a 0.2 tCO2/capita effect from consumption and a 0.2 tCO2/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 CO2 emissions in 2015 between regions, highlighting the extensive range in CO2 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
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 $2^\circ$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 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).
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 tCO2-eq) have per capita emissions which are four times higher than ‘large families, with efficient homes and limited materialism’ (28% of the population with 1.2 tCO2-eq/capita). For transport, ‘small families with very frequent driving and materialistic hobbies’ (0.5% of the population with 10 tCO2-eq/capita) have more than ten times the per capita emissions than ‘large families with limited materialism’ (22% of the population with 0.83 tCO2-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 CO₂ 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 (Hammer 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 CO₂ 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 CO₂ emissions, and it is reasonable that they have room to increase their CO₂ 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.

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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 CO₂ 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 CO₂ emissions. Our multi-regional comparisons show notable differences in CO₂ 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 CO₂ 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.

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Data availability statement

No new data were created or analysed in this study.

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