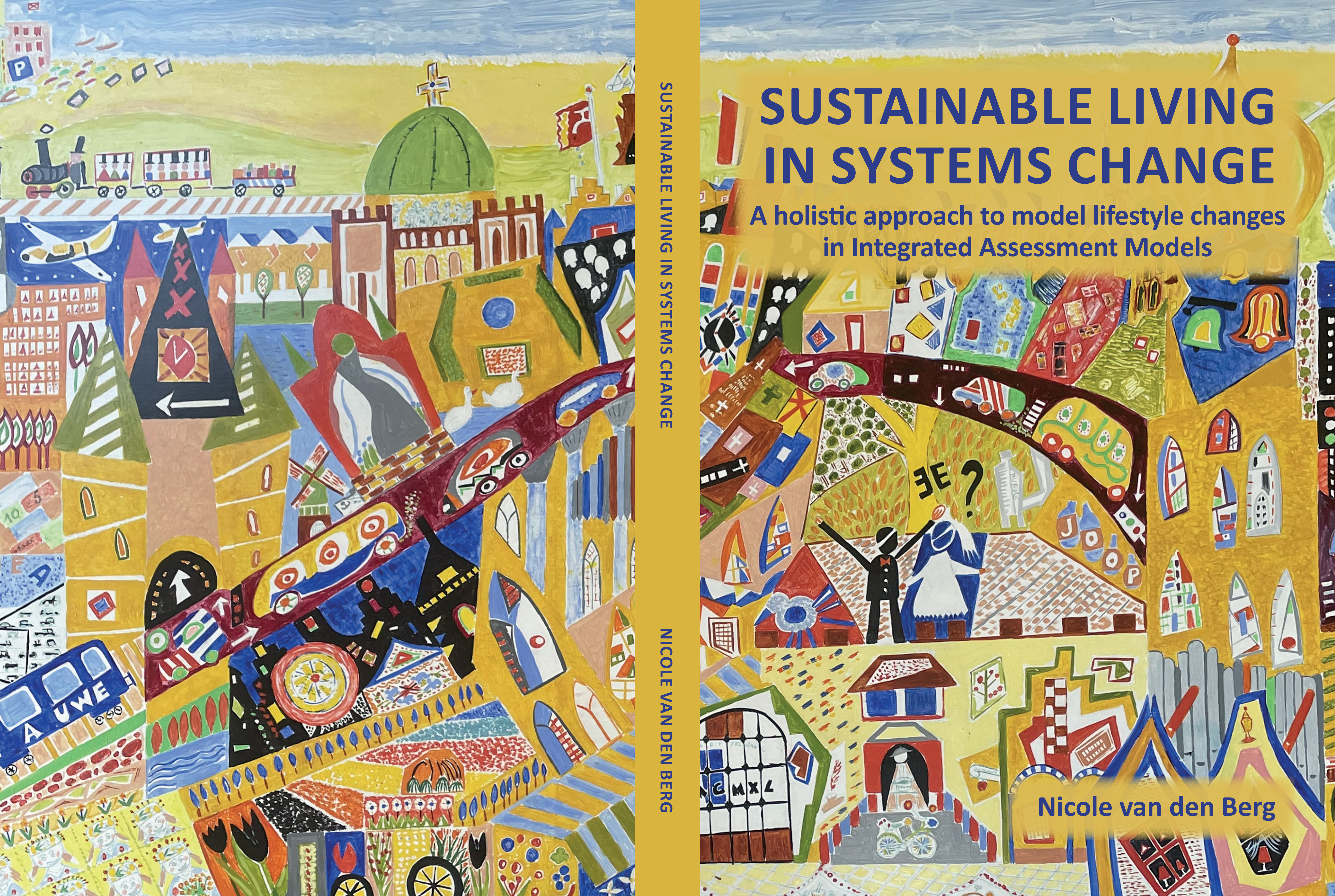


SUSTAINABLE LIVING IN SYSTEMS CHANGE

A holistic approach to model lifestyle changes in Integrated Assessment Models

Nicole van den Berg

SUSTAINABLE LIVING IN SYSTEMS CHANGE
NICOLE VAN DEN BERG

Sustainable Living in Systems Change

A holistic approach to model lifestyle changes
in Integrated Assessment Models

Nicole van den Berg

ISBN: 978-94-6483-110-8
Cover illustration: Wim Boss
Lay-out: Publiss | www.publiss.nl
Print: Ridderprint | www.ridderprint.nl

© Copyright 2023: Nicole van den Berg, The Netherlands

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, by photocopying, recording, or otherwise, without the prior written permission of the author.

Sustainable Living in Systems Change

A holistic approach to model lifestyle changes
in Integrated Assessment Models

Duurzaam leven in systeemverandering:
Een holistische benadering om veranderingen in levensstijl te modelleren in *integrated assessment* modellen
(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de
Universiteit Utrecht
op gezag van de
rector magnificus, prof.dr. H.R.B.M. Kummeling,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen op

vrijdag 30 juni 2023 des middags te 12.15 uur

door

Nicole Jane van den Berg

geboren op 22 maart 1991
te Pietersburg, Zuid-Afrika

Promotor:
Prof. dr. D.P. van Vuuren

Copromotoren:
Dr. V. Timmer
Dr. A.F. Hof

Beoordelingscommissie:
Prof. dr. E.M. Steg
Dr. E. Trutnevyte
Prof. Dr. F. Creutzig
Prof. Dr. H.A. Bulkeley
Prof. C. Wilson

TABLE OF CONTENTS

UNITS OF ABBREVIATIONS

°C	degree Celsius
/capita	per capita
/yr	per year
ABM	Agent-based Model
AFI	Attitude, Facilitators, Infrastructure
ASI	Avoid, Shift, Improve
ASIF*	Activity, Structure/Service, Energy Intensity, Fuel mix
CBCFs	Consumption-Based Carbon Footprints
ESM	Energy System Model
EIO-LCA	Environmental Input Output-Lifecycle Assessment
GHG	Greenhouse Gas
IAM	Integrated Assessment Model
IMAGE	Integrated Model to Assess Global Environment
IPCC	Intergovernmental Panel for Climate Change
LCA	Lifecycle Assessment
MaSTU	Macro-economic Sustainable Time Use
MRIO	Multi-Region Input-Output
NSFIE	National Survey of Family Income and Expenditure
SLIM	Sustainable Living in Models
SSPs	Shared-Socioeconomic Pathways
TTB	Travel-Time Budget
TMB	Travel-Money Budget
TIMER	Targets Image Energy Regional


VICIT
VIM
VIRTVS
BLAUWE

1

INTRODUCTION

1.1. MITIGATING CLIMATE CHANGE REQUIRES CHANGES IN SUPPLY *AND* DEMAND

Anthropogenic greenhouse gas (GHG) emissions have increased considerably since the pre-industrial period, and it has been proved unequivocally that they contribute to climate change (IPCC, 2022). Regarding the physical aspects and its causes, climate change has been studied extensively by diverse research disciplines (Sörlin & Lane, 2018). The growing scientific evidence has been assessed since 1990 in subsequent Intergovernmental Panel on Climate Change (IPCC) reports, supporting the policymaking process. In 1992, countries worldwide agreed to prevent dangerous anthropogenic climate change as part of the UN Framework Convention on Climate Change. Subsequent international negotiations resulted in several international climate agreements, e.g., the Kyoto Protocol in 1997, the Cancun Agreements in 2010 and the Paris Agreement in 2015. The agreements aim to coordinate action among countries to reduce greenhouse gas emissions and, thus, limit the increase in global mean temperature. The most recent agreement, the Paris Agreement in 2015 (UN, 2015), formulates the objective to keep the rise in the global average temperature to well below 2°C, and possibly even 1.5°C, above preindustrial levels. There are various options to reduce emissions to achieve these goals, including improving energy efficiency, increasing the share of renewable energy, carbon-capture-and-storage, and adjusting human activities. Policymakers need information about the probable outcomes of these options, especially in complex systems and if they involve far-reaching implications. Scenarios developed by Integrated Assessment Models (IAMs) provide such insight by exploring different options to achieve stringent climate targets (van Beek et al., 2020; Weyant, 2017).

Mitigating climate change requires changes in various parts of the economy, including how we use and generate energy. Supply changes, such as substituting fossil fuels with renewable energy sources (e.g. solar, wind, hydropower, geothermal and bioenergy), have been explored and considered extensively as options to mitigate climate change. Energy demand solutions, such as reducing activities and efficient and sustainable technology adoption, have been explored less. However, a large body of literature on efficiency improvement via technology change is available. Lifestyle and behavioural changes (e.g. travelling less, healthier diets, smaller homes) affecting demand are often not considered, even though they have increasingly received attention as a possible means to mitigate climate change (Creutzig et al., 2021). Recently, the UNEP Emissions Gap Report and IPCC WGIII added a specific chapter designated for the demand-side mitigation (Capstick et al., 2020; Creutzig et al., 2022). The latter report concludes that "Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end use sectors by 40-70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources" (Creutzig et al., 2022). Therefore, exploring lifestyle changes further is vital to identify strategies for climate change mitigation.

Previous quantitative studies have focused on the impact of different stylised lifestyle options on emissions (Costa et al., 2021; Grubler et al., 2018; Ivanova et al., 2020; van Sluisveld et al., 2016; van Vuuren et al., 2018; Vita et al., 2019). More specifically, model-based scenarios with behaviour and lifestyle changes are often represented via stylised assumptions (e.g. assuming everyone adopts a healthier diet). However, the stylised assumptions could be improved with insights from qualitative disciplines, such as environmental psychology, sociology and social practice theory. Qualitative studies often focus on how lifestyles could change based on motivations and enabling factors (Echegaray, 2021; Green & Vergragt, 2002; Manzini & Jégou, 2003); Mont et al. (2014); (Quist et al., 2001; Quist & Leising, 2016; Schmidt-Scheele et al., 2022). These qualitative studies could complement the quantitative modelling of lifestyle changes for more informed strategies for climate change mitigation.

1.2. WHAT ARE BEHAVIOUR, LIFESTYLE AND CONSUMPTION CHANGES?

Often, the terms lifestyle, behaviour and consumption changes are used interchangeably. However, they are distinct from each other. For this research, lifestyle changes refer to a change in a consistent set of behaviours *across* domains. For instance, a specific lifestyle of a sustainable urbanite (e.g., a minimalist vs. high consumption lifestyle) affects passenger transport and consumer goods behaviours. In contrast, behavioural change is a more specific change *within* each domain. Furthermore, consumption changes are also distinct from behaviour and lifestyle changes. In economics, ‘consumption’ refers to the use of goods and services. Therefore, we define consumption changes as the outcomes of behaviour and lifestyle changes.

There are various interpretations of lifestyle change across disciplines. From the sustainable lifestyles field, Akenji and Chen (2016) define sustainable lifestyles as habits or patterns of behaviour that minimise the use of natural resources and the generation of waste while maintaining a fair and decent living. These actions are embedded in and facilitated by societal institutions, norms and infrastructures that frame individual choices and practices. In scenario modelling, behavioural changes are defined as replacing an activity for a different but relatable service (Samadi et al., 2017). These behavioural changes are distinctly different from efficiency (i.e., provision of the same output with a lower input requirement) and technology substitution (i.e., providing the same output but with a different set of inputs). Lifestyle changes crosscut the typical food, residential and transport domains, where behavioural changes occur. For example, a minimalist lifestyle change is a cross-cutting change that results in behavioural changes in various domains, such as less food waste, smaller living space and no car ownership.

1.3. INTENT VS IMPACT ORIENTATION AROUND BEHAVIOUR AND LIFESTYLES

These contrasting definitions mentioned above highlight the focus on the intent (or motivation) and the impact (or outcomes) of lifestyle changes (Gifford et al., 2011). This focus is highly dependent on the scope, aim and research questions. Predominantly qualitative and social sciences take the intent-oriented perspective, analysing or determining the motivations behind lifestyle changes. This perspective informs us on what, by whom, why, how, and when lifestyles could change. Many disciplines adopt this perspective. However, approaches that quantify lifestyle changes generally have an impact orientation, focusing on the outcomes. Various models, assessments, and analyses investigate the impact of lifestyle changes, each with strengths and weaknesses. The multiple disciplines that adopt intent or impact-oriented perspectives are discussed in the following sections.

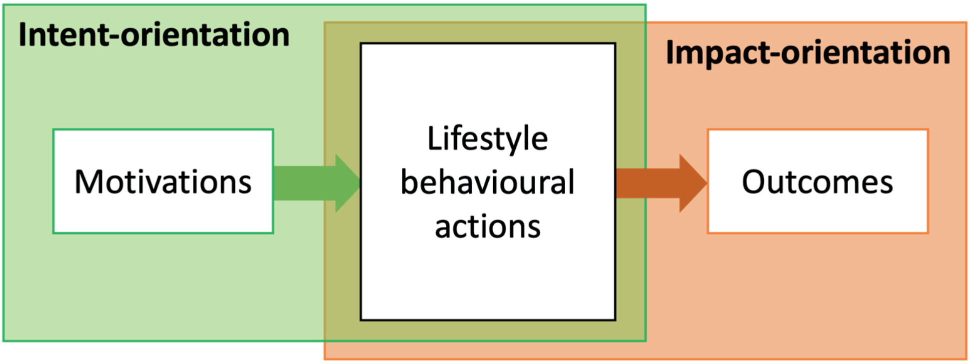


Figure 1-1: A holistic approach representing different orientations around lifestyle and behaviour actions

1.3.1. Disciplines with an intent orientation on lifestyle changes

The disciplines that approach lifestyle changes through intent orientation include (but are not limited to) environmental psychology, sociology, behavioural economics, social practice theory, innovation studies and socio-technical transition studies.

Environmental psychology studies perceived behavioural control, the value-action gap and self-efficacy to help predict behaviour. **Environmental sociology** contributes to understanding behaviours by studying the interactions between societies and their natural environment. Different societies varying in cultures and social norms also vary in their interactions with the environment. Therefore, these disciplines provide insights into the motivations and intentions of adopting certain behaviours and lifestyles (e.g., collective action). Furthermore, **behavioural economics** explores people's bounds of rationality and our susceptibility to nudges influencing our choices (e.g. pre-setting courses of action via default setting). Similarly, by researching what customers want, sustainable marketing helps build and maintain sustainable relationships with customers and the social and natural environment (Mancuso et al., 2021). This can provide a greater understanding of intentions and how to frame lifestyle changes for different people. **Social practice theory** also provides insights into pro-environmental behaviour changes by studying the practice rather than the individuals who perform them. These include routine and everyday social practices such as washing, shopping, cooking, driving or exercising (Giddens, 1984; Hargreaves, 2011).

Innovation studies contribute to understanding lifestyle changes by providing insight into socio-technical change dynamics (Geels et al., 2008). Specifically, strategic niche management is an approach that suggests journeys of sustainable innovation can be facilitated by controlling technological niches (i.e. protected spaces allowing for experimentation and nurturing with the co-evolution of regulatory structures, user practices and technology) (Schot & Geels, 2008). **Socio-technical transition studies** and the multi-level perspective build on these theories and approaches by distinguishing between different analytical levels: the niches, socio-technical regimes (locked in and stabilised on various dimensions) and socio-technical landscape. These transitions provide insights into the evolution of (sustainable) innovations, some staying as niche innovations and others breaking through more widely if the interactions with the other levels create forces on the regime. While these approaches are primarily developed regarding technological innovations, some researchers have applied the multilevel perspective to understand the diffusion of social innovations, for instance, through social practice theories (Hölsgens et al., 2018). Social innovations are distinct from technological innovations as the change is not a new technology but a changing social practice (Howaldt et al., 2015). Therefore, this can provide insights into the transitions of lifestyle changes using the multilevel perspective and strategic niche management theories.

1.3.2. Disciplines with an impact orientation on lifestyle changes

Disciplines studying lifestyle changes via impact orientation include life cycle assessments, consumption-based carbon accounting, agent-based modelling, integrated assessment, and energy system models.

Life cycle assessments (LCAs) quantify products' and services' economic, social, and environmental impacts over their entire life cycles (Guinée et al., 2002). However, applications of life cycle assessments have also been expanded to lifestyle changes. For example, a recent study proposed a social practice framework to assess the environmental impact of sustainable consumption using LCA (Suski et al., 2021).

Furthermore, **consumption-based carbon accounting (CBCA)** allocates emissions to the end-user, providing insight into the different types of consumers, drivers of change, lifestyles, rebound effects and urban structure–lifestyle relationships (Heinonen et al., 2020). CBCA is generally based on environmental input-output (EIO) analyses, accounting for environmental impacts through supply chains from their origin to final product consumption. Multi-region input-output (MRIO) models have a higher geographic resolution, ranging from country scale to sub-national and regional to the city and intraurban scales (Heinonen et al., 2020). Many IO analyses, combined EIO-LCA analyses, and MRIO models have analysed behaviour and lifestyle changes using the CBCA approach (Heinonen et al., 2020; Ivanova et al., 2020). For example, specific Lifestyle Carbon Footprints have been calculated (Akenji et al., 2021; Lettenmeier et al., 2019) for various regions and analysed in light of 'fair consumption space' assessments to account for equity.

Agent-based models (ABMs) are also often used to analyse behavioural and lifestyle changes, specifically regarding the interactions between agents (Jager, 2021). An early application of ABMs to model behaviours formalised the theory of planned behaviour (Ajzen, 1991) of a fishery socio-ecological system (Ernst, 1999). Artificial agents had differing motivations and decisions, and simulated results showed the comparability of the artificial agents' behaviours to the real people in the system. Since then, many scholars have applied ABMs to the socio-ecological systems (van Voorn et al., 2019). ABMs have also been applied to socio-technical systems, capturing behaviours in the transport sector (Adelt et al., 2018; Kangur et al., 2017; Schröder & Wolf, 2017; Sopha et al., 2017; Urquhart et al., 2019), home energy use (Busch et al., 2017; Friege & Chappin, 2014; Hesselink & Chappin, 2019; Hicks et al., 2015; Mosler & Martens, 2008; Muelder & Filatova, 2018; Sopha et al., 2011), food (Scalco et al., 2019) and other behaviours (Alonso-Betanzos et al., 2017; Bravo et al., 2013; Ernst & Briegel, 2017; Stefanelli & Seidl, 2017).

Box 1. What are Integrated Assessment Models?

Integrated assessment models (IAMs) are computer models that simulate long-term complex interactions between the natural and socioeconomic systems to inform climate policymaking. As shown by the figure below, IAMs generally incorporate a) environmental mechanisms, especially natural vegetation and climate system, and b) societal systems, including households, industries, and infrastructure. The latter also covers the behavioural, economic, and political superstructures that influence decision-making.

A significant benefit of using IAMs is their integration of data and information from multiple scientific disciplines into a sole framework. Therefore, modellers can use IAMs to execute coherent analyses of physical, technological, and social processes for low-carbon transformation pathways (Geels et al., 2016; van Beek et al., 2020).

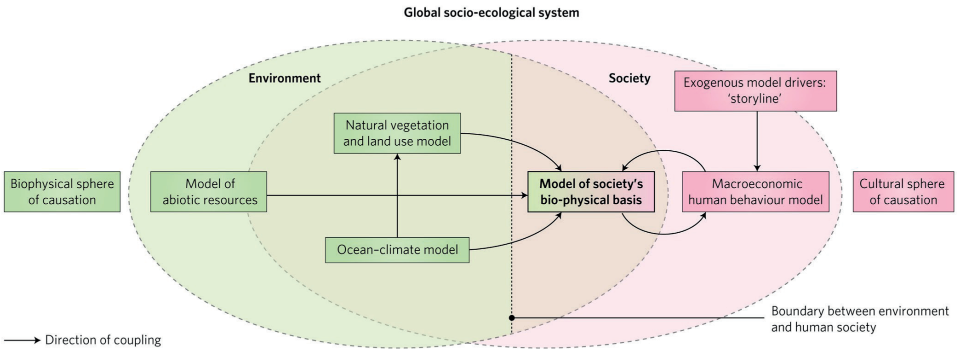


Figure 1-2: General schematic of Integrated Assessment Models (Pauliuk et al., 2017)

There are two distinct types of IAMs (Weyant, 2017):

- Detailed process-based IAMs: more disaggregated models to provide projections of impacts at sectoral and detailed regional levels. Some use economic valuation, while others use projections of physical impacts (e.g., land submerged by sea level rise, crop decline, heat stress-related deaths). Examples include IMAGE, MESSAGEix, GCAM, AIM/GCE, WITCH-GLOBIOM and REMIND-MAgPIE.

- Benefit-cost IAMs: highly aggregated models represent costs of climate change mitigation and aggregate impacts by regions and sectors into a single economic metric. These are also known as policy optimisation models, determining “optimal” climate policies. The costs and benefits of the policies can also be calculated where marginal benefits and costs are not equal. Examples include DICE, FUND and PAGE.

Integrated assessment models (IAMs) (see Box 1) and energy system models (ESMs) have also contributed to understanding the impact-orientation of lifestyle changes via improved model development (Edelenbosch et al., 2018), heterogeneity of actors (Daioglou et al., 2012; Edelenbosch et al., 2018), and the representation of lifestyle changes in scenario development (Chaturvedi & Sharma, 2015; Grubler et al., 2018; Mittal et al., 2017; O'Neill et al., 2017; van de Ven et al., 2017; van Sluisveld et al., 2016; van Vuuren et al., 2018). However, the concept of lifestyles is fundamental for demand-side issues but hard to tame in scenarios, largely due to its complexity (Saujot et al., 2020). Lifestyles depend on economic, psychological, and demographic variables that vary across social and geographical levels and are situated within a nexus between techno-spheres and social lives. This provides challenges to representing lifestyle changes in IAMs. So, why explore lifestyle changes in IAMs? (Saujot et al., 2020) identifies three main reasons:

1) The production of knowledge of quantitative impacts and exploratory pathways. Pathways can be applied to inform decision-makers by contributing to quantifying lifestyle changes for climate change mitigation (i.e., quantitative knowledge) and/or preparing them for heterogeneous future lifestyles (i.e., exploratory).

2) Mediation through participatory approaches.
Pathways can be utilised to support citizen and stakeholder engagement via participatory approaches. Furthermore, they can communicate and disseminate scenario results for dialogue and collaboration between different communities and disciplines.

3) Holistic framing of the possible transitions for policymaking.
Pathways can provide the necessary framing of worldviews associated with sustainable transitions. They can equip policymakers with variables, objects and relations necessary for exerting influence (Beck & Mahony, 2018).

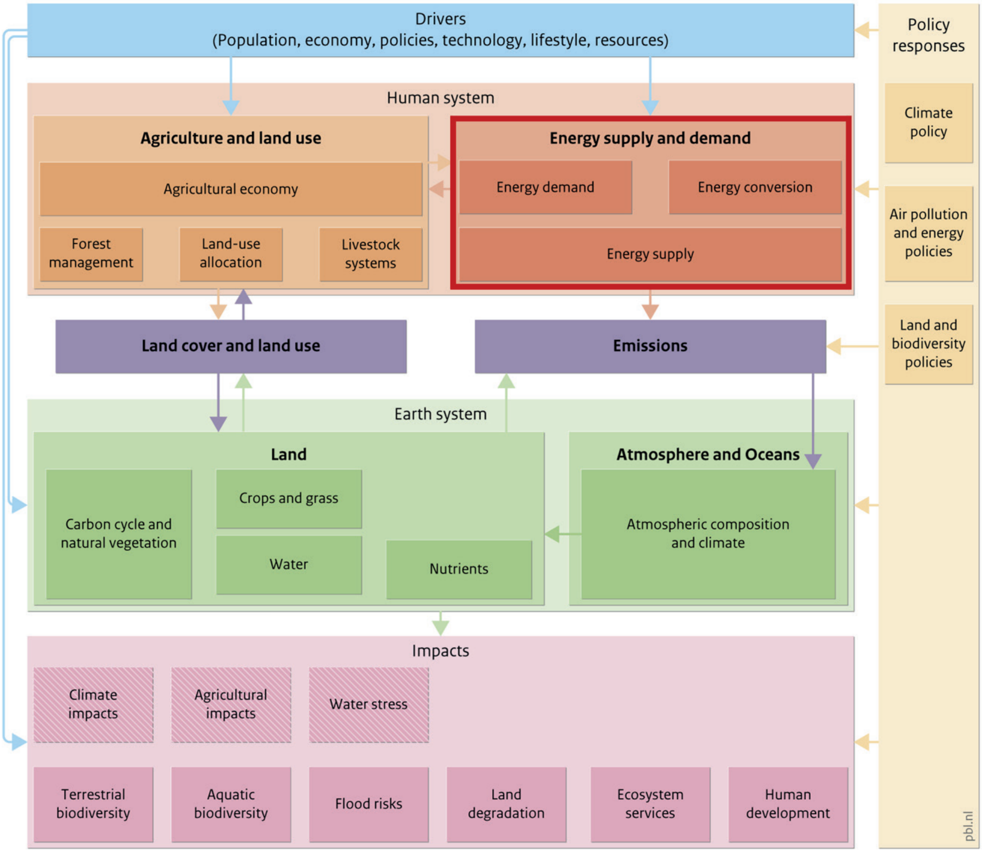


Figure 1-3: IMAGE integrated assessment model, with TIMER energy model shown by red box (Stehfest et al., 2014)

1.4. IMAGE INTEGRATED ASSESSMENT MODEL

This research uses the detailed process-based IMAGE integrated assessment model. IMAGE describes future energy development and land use. The model has been used frequently to calculate greenhouse emission pathways to support climate research and the IPCC assessments. It includes detailed descriptions of future human activities, allowing for explicit descriptions of behavioural changes. IMAGE models the long-term dynamic changes in land and energy systems by capturing the interactions between various system-dynamic sub-models.

Most of the thesis concentrates specifically on energy demand. One of the submodels, IMAGE-TIMER (shown as a red box in Figure 2-3), models annual energy demand and supply of 26 global regions for the sectors industry, passenger and freight transport, residential, services, non-energy and other. The emissions quantified include direct and indirect (i.e. emissions related to electricity use) emissions from energy demand. However, the model does not account for indirect emissions from changes in material demand (e.g. the production of electric vehicles).

In IMAGE, decision-making processes are not explicitly modelled but rather proxies to account for degrees of behavioural variation (van Sluisveld et al., 2016). A multinomial logit function determines the market share of technologies or energy carriers, accounting for preference differences and relative costs per option (Van Vuuren et al., 2011). These preference factors, other than costs, account for government policies and consumer preferences and aim to represent the factors that are difficult to quantify (e.g., the choice to shift transport modes and smaller homes) (van Sluisveld et al., 2016).

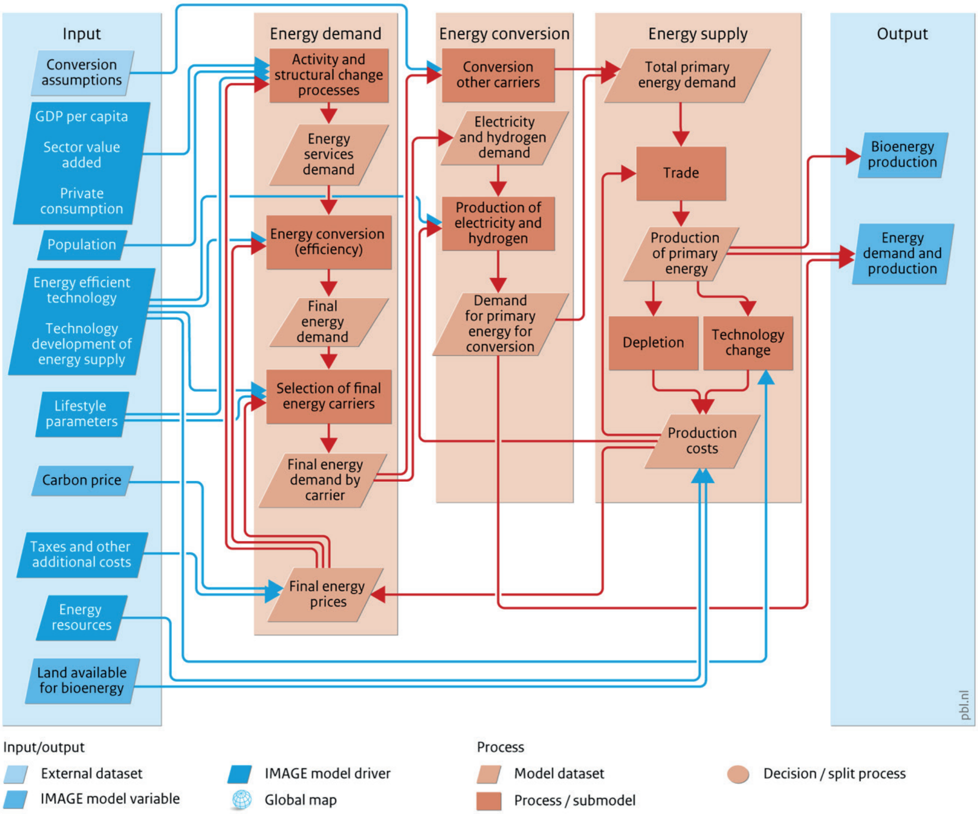
IMAGE accounts for regional diversity by calibrating regional differences in energy demand. For example, there is a stronger preference for car travel in the USA than in Japan, where public transport has a larger share of total passenger transport. Japan also has a significantly lower floor space per capita than the USA, which is accounted for (Daioglou et al., 2012). Details on how behaviours in transport and the residential sectors are modelled are provided below, as these two sectors play an essential role in this thesis.

1.4.1. Travel behaviour and energy demand

IMAGE-TIMER models the travel behavioural actions of scenarios by adjusting inputs and drivers in the TRAVEL model (see Figure 2-5). For example, a sustainable shift in travel mode is implemented by changing the preference factor for travel modes. This affects the Travel Money Budget (TMB)[1] constraint, which adjusts the travel demand for each travel mode, and the Travel Time Budget (TTB)[2], determining the time weight and mode price. For example, several adjustments in the TRAVEL model can be made when implementing behavioural and demand-side changes. For increased public transport use, the preference factor from Inputs and the TTB in Modes can be changed to affect the mode price. The non-energy price of electric vehicle technologies can be changed for a higher electric vehicle adoption, affecting vehicle (perceived) cost and fleet composition.

[1] Travel Money Budget (TMB): refers to the share of income per day spent on transportation

[2] Travel Time Budget (TTB): refers to the time per day spent on transportation



Source: PBL 2014

Figure 1-4: TIMER, the energy demand and supply model in IMAGE

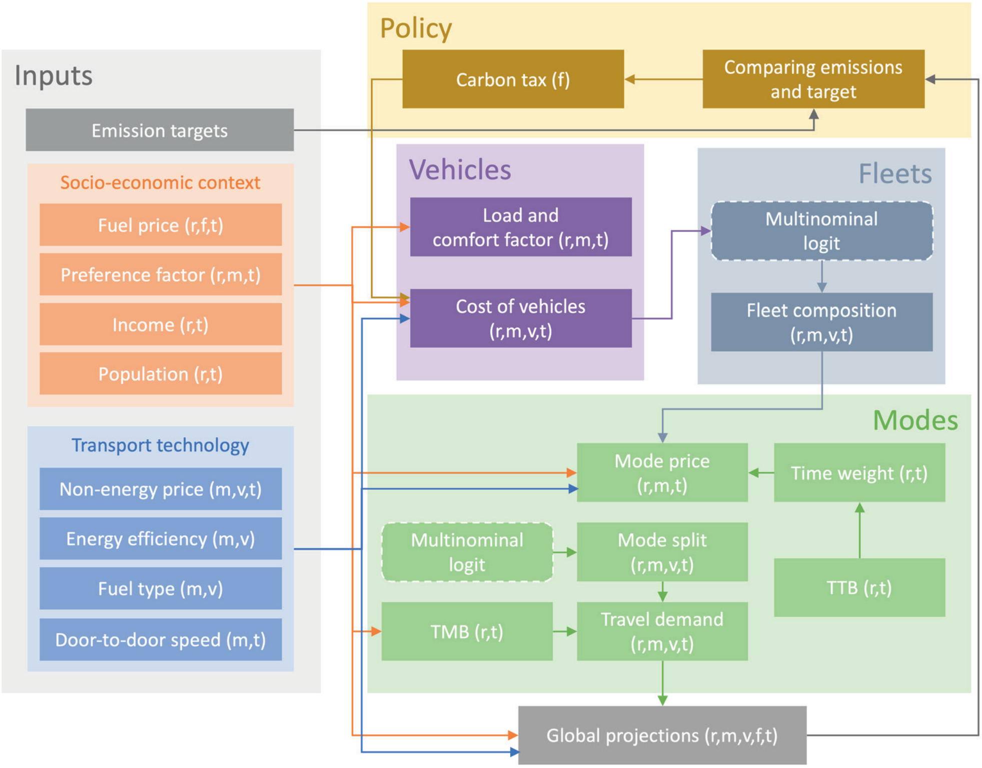


Figure 1-5: TRAVEL model in TIMER-IMAGE with factors dependent on the region (r), travel mode (m), vehicle type (v), fuel type (f) and time (t) (adapted from (Girod et al., 2013)).

1.4.2. Residential sector behaviour and energy demand

IMAGE-TIMER models the residential behavioural actions of scenarios in the residential sector by adjusting variables and parameters (see Figure 1-7) to match the assumptions on adoption rates and speed of transition. Most drivers are defined for income quintiles and urban/rural classes, except for population density and temperature drivers (Daioglou et al., 2012). This allows for a more heterogeneous and equitable representation of lifestyle changes. For example, it is possible to limit the impact of a smaller living space only to groups with already high floor space per capita (i.e. often rural and high-income groups) by implementing an upper cap (i.e. a maximum m^2/capita) rather than a relative reduction. Japan also has a significantly lower floor space per capita than the USA, which is accounted for. Therefore, the cap on living space would have a higher impact in the USA than in Japan. The primary drivers: population, household expenditure, population density, household size and temperature, affect the intermediate drivers: floorspace and electrification. These drivers affect the demand for energy services: cooking, appliances, space heating and cooling, water heating and lighting (Daioglou et al., 2012).

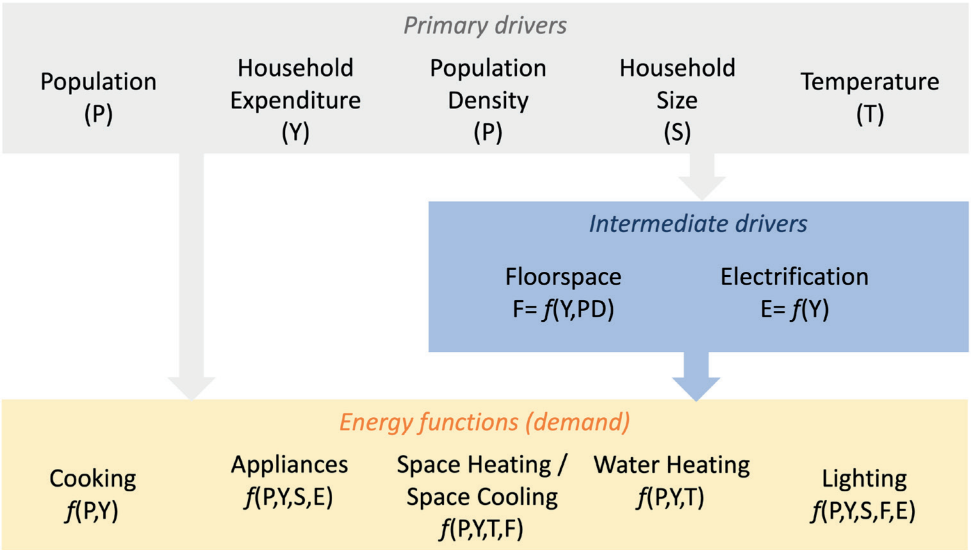


Figure 1-6: Relationship between residential energy functions and drivers (adapted from (Daioglou et al., 2012)).

1.5. CRITICAL METHODS FOR ANALYSIS AND COMMUNICATION OF RESULTS

Various tools can be used to explore possible futures regarding lifestyle and behavioural change. Several tools exist in scenario development and analyses that allow for generating and analysing results. Below, a description of the tools used in this thesis is provided.

1.5.1. Scenario planning

Scenario planning refers to methods for making flexible long-term plans and decisions and identifying innovative responses under conditions of deep uncertainty and complexity (Amer et al., 2013; Volkery & Ribeiro, 2009). Scenario planning can help scenario developers imagine a future and understand the potential implications for decision-making. Via scenario planning, alternative images of the future – the plausible stories of future landscapes – can be created, keeping planners honest about what is uncertain (Schwartz, 2012; Wade, 2012). Scenario planning focuses on what could be possible, not probable or preferable, as it would provide blind spots and cloud judgements and observations. In scenario planning, not one future but multiple futures are explored that differ across critical uncertainties about how the future could unfold. There are different approaches for building scenarios, including the matrix or deductive approach, which was adopted in this thesis (Cairns & Wright, 2017; Chermack, 2011; Konno et al., 2014). Via this approach, scenarios can be arranged in a 2x2 matrix based on two uncertainties (Konno et al., 2014), which can provide contrasting narratives of how lifestyles could change under different circumstances.

1.5.2. Model-based scenario pathways

One of the ways to use a scenario planning approach is via model-based scenario development. Communicating results from IAMs as scenario pathways is a common approach for showing trends over a long-term period. Scenario pathways help decision-makers as they show the relevance of lifestyle change for climate change mitigation. Furthermore, they can communicate and disseminate scenario results for dialogue and collaboration between different communities and disciplines. They can also provide a holistic framing of worldviews associated with sustainable transitions and equip policymakers with variables, objects and relations necessary for exerting influence (Beck & Mahony, 2018; Saujot et al., 2020).

1.5.3. Decomposition analyses

There are numerous decomposition tools to analyse decarbonisation trends in both historical periods and projections. Many use the Kaya Identity (Kaya & Yokobori, 1997) as a basis. The Kaya Identity is an approach to analyse energy-related carbon dioxide emissions based on the IPAT identity (I = P x A x T), where population, affluence (or GDP per capita) and technology represent the contribution to emissions. Examples in the literature that have applied this to model-based scenarios (Edelenbosch et al., 2020; Girod et al., 2014; Pietzcker et al., 2014) often focus on changes in fuel composition and technology - and do not explicitly look at behaviour changes on a per capita level.

There are various types of decomposition analysis for energy and environmental analyses in the literature. Ang et al. (2003) highlight the strengths and weaknesses of several of these methods. In this research, we apply the Sun (1998) method using the n-term decomposition. Sun's method is a so-called *perfect* decomposition as it distributes the contribution from interaction terms to their respective factors, leaving zero residual terms. Moreover, contrary to the other conventional methods (like the Laspeyres Index), Sun's method is robust to factor reordering and time-reversal (Ang, 2004; Ang et al., 2003). Decomposition analyses' results can be effectively visualised as waterfall charts, highlighting the contributions from different factors between two values. This research uses decomposition analyses to highlight the contributions of different factors to emissions over two points in time.

1.6. RESEARCH AIM AND OUTLINE

This research aims **to improve the representation of lifestyle changes in IAMs to advise policymakers on climate change mitigation strategies.** With this aim in mind, the chapters, their research questions, and their analytical focus are presented in Table 1-1. The various chapters focus on the intent or impact of lifestyle changes. In the quantitative analysis, the thesis concentrates on the passenger transport and residential sectors. This research project aims to answer the overarching research question**: "How can IAMs improve the representation of lifestyle changes to show the possible role of lifestyles in climate change mitigation strategies?"**

Table 1-1: Overview of research questions, analytical focus and chapters

#	Research questions	Intent	Impact	Ch.
	How can IAMs improve the representation of lifestyle changes to show the possible role of lifestyles in climate change mitigation strategies?	X	X	all
1	What are key insights from existing literature on different approaches for analysing lifestyle changes?	X	X	2, 3, 5 & 6
2	What is the impact of changes in consumption on emission reductions, compared to technology changes in existing IMAGE lifestyle scenarios?		X	3 & 4
3	How do emissions from current lifestyles compare to the emission levels consistent with climate targets?		X	4
4	What are possible future scenarios towards sustainable living?	X	X	5
5	What are the implications of possible future sustainable living scenarios for emissions?	X	X	6

Chapter 2 provides a multidisciplinary, comprehensive, and comparative overview of research on lifestyle changes, identifies promising approaches, and enhances knowledge on improving representation in IAMs. Taking an **intent** and **impact** analytical focus, the chapter addresses **research question 1**. The chapter highlights and elaborates on the various distinctions, interpretations, and definitions of lifestyle changes from a qualitative and quantitative perspective. Furthermore, it emphasises the importance and the multiple ways of integrating lifestyle changes in IAMs. The chapter also overviews the various lifestyle changes across domains, disciplines, methodologies, and focus. Specifically, the multiple methods for capturing or modelling lifestyle changes are analysed. The chapter recommends and concludes how lifestyle changes and IAMs can be synthesised through promising approaches, interesting entry points, and pitfalls.

Chapter 3 presents a generic decomposition tool for IAM scenarios to analyse the effects of behaviour changes vis-à-vis other measures (such as technology adoption) on transport and residential per capita emissions. Through an **impact** analytical focus, the chapter addresses **research question 1**. The chapter uses literature on decomposition analyses to develop a decomposition tool, adapted from the Sun (1998) method, to separate the effects of consumption and technology changes. Through the application of the tool, we also address **research question 2** by showing the different contributions of consumption and technology changes on emission reductions in different scenarios**.**

Chapter 4 assesses whether current statistics on emissions of different groups and regions can provide insights into the feasibility of behavioural changes to reach long-term mitigation targets. Through an **impact** analytical focus, the chapter addresses **research question 2**, showing the per capita emission of different lifestyles compared to climate targets. The abovementioned decomposition tool explores the changes in long-term emissions from consumption and technology changes for various scenarios. Therefore, this chapter also addresses **research question 3**. These long-term scenarios are compared to the current CO_2 emissions of multiple regions and diverse consumer segments.

Chapter 5 and **chapter 6** present novel lifestyle scenarios, named SLIM (Sustainable Living in Models) scenarios, developed with input from multidisciplinary engagements with advisors and policymakers for qualification and quantification scenario development, respectively.

Chapter 5 presents a comprehensive set of scenario narratives that can directly support strategic dialogues and form the basis for model-based scenario analysis. Approaching the scenario narrative development through an **intent** analytical focus from the scenario planning literature, the chapter addresses **research question 1.** By drawing on the contributions from a wide range of advisors and select policymakers, we could gain insights from different approaches to developing the lifestyle scenario narratives. Specifically, the chapter describes the method of scenario narrative development. Furthermore, the narratives are illustrated through summarised figures and tables with detailed descriptions. The narratives are also analysed in terms of their overlaps and divergences. This chapter addresses part of **research question 4**, by addressing how lifestyle changes can change substantially.

Chapter 6 Taking an **impact** analytical focus, the chapter addresses **research question 5** by analysing how the two SLIM scenarios contribute to climate change mitigation**.** The chapter analyses two SLIM scenarios, Pocket Lifestyles and Designed World (based on their contrasting access to structural support and similarity in value systems). More specifically, we analysed the scenarios' emission pathways for passenger transport and residential sectors. The process of quantifying the lifestyles is arguably as important as the impacts of the scenarios. Therefore, the methodology of this chapter elaborately explains the details of the scenario development process. The SLIM scenario narratives are described to form the basis for translating into scenario inputs and quantifying into the IMAGE integrated assessment model. The process's limitations, opportunities, implications, and results are discussed, and the main conclusions are presented. Applying the intent and impact orientations is central for developing the SLIM scenarios, highlighting the usefulness of the combined orientations, and therefore, addressing **research question 1**.

IMPROVED MODELLING OF LIFESTYLE CHANGES IN INTEGRATED ASSESSMENT MODELS: CROSS-DISCIPLINARY INSIGHTS FROM METHODOLOGIES AND THEORIES

Nicole J. van den Berg, Andries F. Hof, Lewis Akenji, Mariësse A.E. van Sluisveld, Vanessa J. Timmer, Oreane Y. Edelenbosch, Detlef P. van Vuuren

“Improved modelling of lifestyle changes in Integrated Assessment Models: Cross-disciplinary insights from methodologies and theories”
Energy Strategy Reviews 26 (2019): 100420

ABSTRACT

Recent studies show that lifestyle changes can provide an essential contribution to achieving the Paris climate targets. While some efforts have been made to incorporate lifestyle changes into model-based scenarios, the attempts are currently very stylised and included exogenously. This paper discusses current efforts to represent lifestyle change in models, and analyses potential insights from relevant scientific disciplines to improve the representation of lifestyle changes in models – including modelling specific behaviour changes, identifying cross-cutting lifestyle solutions, representing the intentions behind the changes and quantifying their impacts. As such, this research attempts to bridge the gap between qualitative and quantitative theories and methodologies. Based on the results of this literature analysis, we recommend defining lifestyle changes more harmoniously, exploring an expanded range of approaches, domains and transformative solutions, adopting a whole-systems approach, and addressing the trade-offs between the use of exogenous inputs and endogenous modelling.

2.1. INTRODUCTION

Scenario analyses show that greenhouse gas emissions need to be reduced drastically to limit the rise to well below 2°C in global mean temperature as per the Paris Climate Agreement (Rose et al., 2017). Integrated Assessment Models (IAMs) are used to explore strategies for climate change mitigation to inform decision-makers. The options considered in these models generally consist of energy efficiency improvements, changes in energy supply (i.e. increased use of renewable energy, nuclear power and carbon-capture-and-storage), reduction of non-CO_2 emissions, and changes in land use. Various studies have attempted to improve the demand-side representation in IAMs, primarily through the representation of efficient technology use. However, there is significantly less focus on lifestyle change modelling due to the topic's complexity and consumer heterogeneity (Edelenbosch et al., 2018; Grubler et al., 2018; van Vuuren et al., 2018). Although assessment reports and other scientific papers highlight the potential of lifestyle change (e.g. related to transport, diet, appliance use, and thermal comfort) to reduce carbon emissions (Clarke et al., 2014; Faber et al., 2012; Hallström et al., 2015), they are modelled via relatively stylised assumptions in scenarios (Anable et al., 2012; Faber et al., 2012; Grubler et al., 2018; Röös et al., 2016; Stehfest et al., 2009; van de Ven et al., 2017; van Sluisveld et al., 2016; van Vuuren et al., 2018). Furthermore, the comprehension of what sustainable lifestyles entail, and the motivations behind them, is limited within IAMs.

For policymakers, choosing between various policy options requires information about the probable outcomes of these decisions, especially in complex systems with far-reaching implications. As is demonstrated in the fifth IPCC Assessment Report (with influence on the Paris Climate Agreement (Clarke et al., 2014)), IAMs have a considerable impact on mitigation analyses by showing suitable options to achieve stringent climate targets (Weyant, 2017). However, it also implies that the focus on, or exclusion of, specific options in IAMs, can have consequences for the information on mitigation action provided to policymakers.

These two observations highlight the need to better understand behaviour change and lifestyle-focused solutions within global, model-based scenarios. Other disciplines have paid considerable attention to consumer behaviour. For instance, the field of Sustainable Lifestyles focuses on the more qualitative perspectives on this topic and has great potential in strengthening the understanding of the drivers behind behaviours. Within this context, this paper aims to enhance the knowledge of how to improve the representation of lifestyle changes in IAMs, by providing a multidisciplinary, comprehensive and comparative overview of research on lifestyle changes in different disciplines and identifying promising approaches.

Due to the differences in perspectives on lifestyle changes across disciplines, common misunderstandings can readily occur. Therefore, essential concepts must be defined carefully. As such, in Section 2.2, various distinctions, interpretations and definitions of lifestyle changes are elaborated to highlight differences and similarities among different fields and disciplines. Furthermore, this section explains the methodology of the systematic literature search. Section 2.3 emphasises the need to incorporate lifestyle change options within IAMs while noting the different ways to integrate them. Section 2.4 provides an overview of the different types of lifestyle change, distinguishing between domains, disciplines, methodologies and focus, and presents the results of this overview. Furthermore, this research analyses the various methods used to integrate or model sustainable lifestyles by drawing from the literature review, from both the intent- (i.e. motivation) and impact orientation (i.e. outcomes). In Section 2.5, we made recommendations and conclusions based on the opportunity to synthesise lifestyle changes into IAMs by highlighting promising approaches, pitfalls and interesting entry points from this literature analysis.

2.2. DISTINCTIONS AND METHODOLOGY

To adequately review the literature, a comprehension of the various perspectives on lifestyle change is required. Different interpretations of lifestyle change are first discussed, followed by an explanation of the literature search methodology and the review assessment.

2.2.1. Important distinctions and concepts

For the aim of this research, a definition of lifestyle changes is needed that is relevant for implementation in IAMs. IAMs are used to make assessments by comparing different options regarding prices/costs and the service provided. Changes in costs can thus lead to substitution among available options. For instance, for any given electricity demand, the model could compare the costs of providing this electricity from wind power, a coal-based power plant or an alternative coal-based power plant with carbon capture and storage. Based on their relative costs and the required satisfaction of policy targets, the models determine the market shares for each of the above technologies, allocating larger market shares to low-cost options. A similar approach can be used to prioritise efficiency investments. In such cases, IAMs can be used to compare options that represent high- and low-CO_2 technologies, as long as the service they provide can also be easily compared (van Sluisveld et al., 2016). Although IAMs often aggregate the representation of demand more than supply. Nearly all models include efficiency improvement, which assumes the adoption of an efficient technology/products (e.g. fuel-efficient vehicles), and technology-substitution, the use of different inputs (e.g. less CO_2-intensive fuel usage).

However, measures that would lead to radically different levels of service output are more challenging to represent in a similar context – as they would require a statement of differences in service level in the same monetary terms (i.e. costs). For instance, analysing decisions to travel less is more difficult on a like-to-like basis compared to the previous examples. In the literature in general (even beyond modelling), there is often an underrepresentation of possible ways to reduce emissions with measures leading to other services (e.g. driving less or taking public transport instead of the car if this leads to longer travel times) (Gifford et al., 2011).

Consistent with the discussion above, modellers make a clear distinction between efficiency, technological substitution and lifestyle change, which can be defined as follows (Samadi et al., 2017):

- efficiency represents the provision of the same output with a lower input requirement (e.g. using a more efficient car);
- technological substitution means providing the same output – but using a different set of inputs (e.g. wind power versus a coal-fired power plant);
- lifestyle change replaces the output for a different (but relatable) service (e.g. travel less).

It is vital to discuss the difference between these types of changes, how other disciplines treat these distinctions, and how they relate to different domains (discussed in Section 2.2.1.1). A second relevant distinction is that of motivation and outcomes. Models distinguish between autonomous changes (included in factors that change over time) and specific choices based on costs. They typically represent the latter as a response to price changes that denote a generic ‘climate policy’. Therefore, while models represent policies as a cost increase of options that lead to climate change, this price increase could also represent other forms of climate policy, such as regulation or information. However, many choices are made based on non-monetary factors that could also influence greenhouse gas emissions. For that reason, there is also a critical second dimension - that of intent- (or motivation) versus impact-oriented (or outcomes) perspectives of behaviour change (discussed in Section 2.2.1.2). A final aspect requiring clarification relates to the domains of lifestyle changes, i.e., food consumption, household energy choices, transport and consumption of goods (discussed in Section 2.2.1.3). This paper focuses on the behavioural aspects of consumer end-use (i.e. consumer *behaviour* and *lifestyle changes*) and not on representatives of businesses or institutions.

2.2.1.1. The role of avoid, shift and improve

By building on the distinction of *efficiency*, *technological substitution* and *lifestyle change* defined in Section 2.2.1, we compare them to related distinctions in the literature (see Figure 2-1). For instance, Samadi et al. (2017) make a similar distinction between *efficiency*, *consistency* and *sufficiency*, respectively, and defined it as follows: “efficiency is an option in which the input-output relation is improved . . . consistency aims at fundamental changes in production and consumption by substituting non-renewable resources with renewable resources . . . [and] sufficiency is linked to the level of demand for goods and services". This distinction also overlaps with the distinctions of the avoid-shift-improve (ASI) framework (Creutzig et al., 2018): *improve* matches with *efficiency* and *technological substitution* (i.e. *consistency*), while *shift* and *avoid* corresponds to *lifestyle change* (i.e. *sufficiency)* (see Figure 2-1). This multidisciplinary paper highlights similarities and differences between the terminology used across the different disciplines and emphasises potential overlapping theories. This approach allows for easier identification of which theories from other disciplines IAMs can utilise. Many models can distinguish between these different types of changes; in reality, this difference is not always clear-cut. For example, electric vehicle adoption could be considered a purely technological substitution (i.e. *improve*) if the consumer has short commutes and sufficient infrastructure. However, in other contexts, with inadequate infrastructure, electric vehicle adoption *could* be considered a lifestyle change (i.e. shift) as the service provided is different and, therefore, not directly comparable. For example, fossil fuel-based vehicles offer more service in terms of range than electric cars, making the latter less attractive to car owners (Edelenbosch et al., 2018).

Food-related lifestyle changes are difficult to categorise, as they have indirect emissions and are less related to technology, but also because it is heavily dependent on the type of food. For example, organic food might improve some environmental impacts (impacts associated with fertiliser use and pollution). Still, it could also sometimes lead to increased impacts (land use and associated greenhouse gas emissions). Therefore, for categorisation, we assume that the lifestyle changes can be either positive or negative impact depending on the context (see Figure 2-1). A sustainable and healthy diet could be both a *shift* towards alternative proteins and an *avoid* because it requires the consumption of fewer calories (and in some contexts more). Therefore, the context surrounding the lifestyle changes is vital in determining its ASI category, whether it has positive or negative impacts and consequently for identifying suitable interventions. For decreased complexity in ASI categorisation, this paper assumes contexts in which lifestyle changes lead to positive environmental impacts. In other words, *if* a lifestyle change *would* have a positive environmental impact, *where* would it be categorised?). Context-dependencies may include regional differences, infrastructure, cultures, norms, values and domains. This ASI distinction hence becomes useful in determining the levels of the types of lifestyle change, especially for those represented in IAMs. Figure 2-1 is adapted from the ASI framework (Creutzig et al., 2018), the efficiency, consistency and sufficiency definition (Akenji & Chen, 2016) and categorised in line with the IAM terminology. The range of these different lifestyle changes in the various categories and domains is particularly relevant for IAMs and highlights where different actions or products lie within this range.

Based on these distinctions from the different terminologies, a definition suitable for the implementation of lifestyle changes in IAMs is:

Lifestyle changes are the changes that lead, or aim to lead, to the avoidance, shift and in some cases, improvement (depending on the context) in energy service demand, irrespective of their intent.

For this research, we will continue using the ASI distinction, as it offers more categories related to lifestyle changes, compared to the other distinctions (see Figure 2-1). Even though we consider both *efficiency* and *technological substitution* within the *improve* category, it is essential to note that they do have different characteristics.

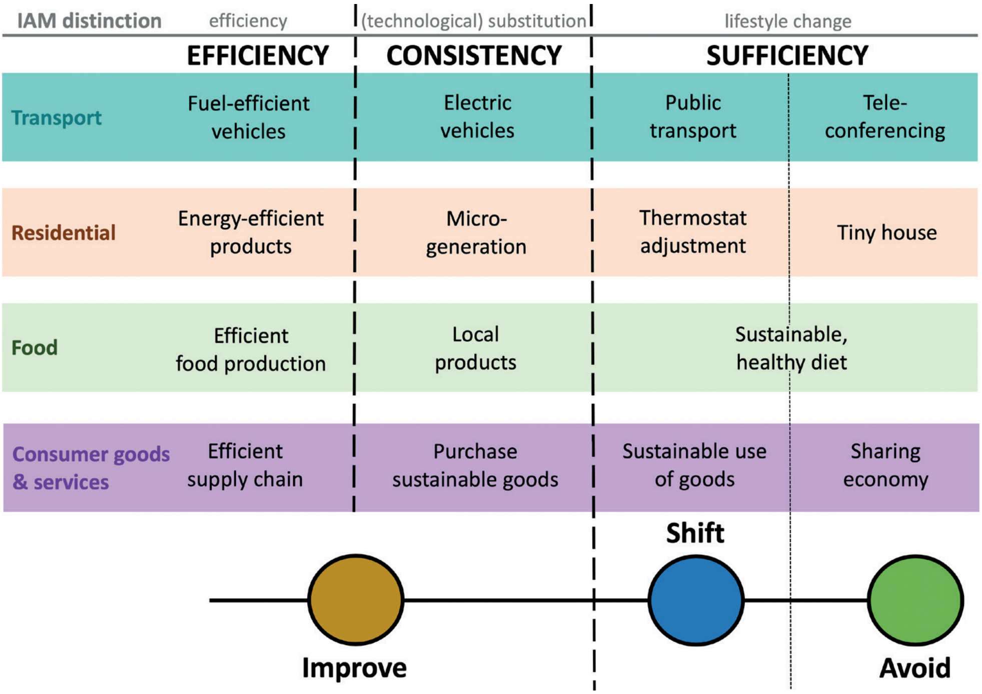


Figure 2-1: Different types of behaviour changes are represented with examples in the domains relevant for IAMs (i.e. transport, residential, food and consumer goods and services) based on the distinctions between IAM distinction, 'efficiency', 'consistency' and 'sufficiency' by Samadi et al. (2017) and the 'avoid-shift-improve' framework by Creutzig et al. (2018).

2.2.1.2. The role of intent and impact

A more effective analysis of the types of lifestyle changes requires an understanding of the motivations behind them, and the effects they have (see Figure 2-3). The latter has been the predominant focus of IAMs so far, yet, a better understanding of the motivations is necessary to improve the representation of lifestyle changes in IAMs substantially. Gifford et al. (2011) explain the differences between intent- and impact-oriented behaviours as follows: "Intent-oriented behaviour that focuses on the consumer's intention, and impact-oriented behaviour that focuses on the behaviour's environmental impact, do not always overlap." Some disciplines tend to focus on the motivation for change, such as 'sustainable lifestyles', 'psychology', 'behavioural economics', 'sociology', and 'philosophy'. These disciplines focus on the decision-making process of changes in behaviour (intent-oriented behaviours; see relevant quotes in the Supplementary Information). Other disciplines, such as 'industrial ecology' and 'energy modelling' (including IAMs), focus on the quantification of environmental impacts (impact-oriented behaviours). For example, consider flying from Amsterdam to New York for a vacation instead of taking a train to a closer destination. From an intent-oriented perspective, understanding the reasons, function and thought-processes for the journey constitutes the primary focus. From an impact-oriented perspective, however, the impacts and effects of that journey are of central interest. Both the intent- and impact-oriented behaviours depend heavily on the context or region in which lifestyle changes take place. This system perspective could be particularly useful for IAMs. If the models would adequately represent the intent-oriented behaviours, and quantify the impacts of these behaviours, they could quantify a change in behaviour based on both the motivation- and outcome potential. Therefore, it is vital to consider *both* these perspectives (to a certain degree) to get a full picture.

Furthermore, environmentally-friendly actions are often not motivated by environmental concerns; for example, vegans often eat plant-based foods for health rather than ecological reasons. Usually, only a weak association between pro-environmental behaviours and environmental attitudes is observed (Gifford et al., 2011). In addition to differences in intent, there are also differences across disciplines in describing the intention of behaviour. For example, psychology focuses on personal psychological reasons while sociology would describe the cultural and social reasoning. The intent- and impact-oriented behaviours illustration in Figure 2-2-3 highlights how these different perspectives construct a systems-perspective. Essentially, when a behavioural action occurs, there is motivation (i.e. intent-oriented behaviour focus) behind that action and an outcome following that action (impact-oriented behaviour focus). The distinction is one of the lenses through which the literature is analysed (see results in Section 2.2.3).

2.2.1.3. Different domains of lifestyle change

IAMs treat energy and land use demand in detail. From a consumer behaviour perspective, consumption can be divided into four domains: 1) transport, 2) heating, cooling and appliance use in residential homes, 3) food and 4) the use of goods and services. Both the residential and transport domains are mostly related to "direct" emissions during the use phase. However, for food and consumer goods and services emissions are mostly generated in the production phase. Still, consumer behaviour can strongly influence demand for food, goods and services. For example, buying fewer goods by reusing, repairing or sharing, or purchasing sustainably-produced goods would be represented in the consumer goods and services domain (Akenji & Chen, 2016; GLAMURS, 2016; P. Vergragt et al., 2016). As stated by Grubler et al. (2018) “consumer goods are not an end-use service per se, but provide for cooking, lighting, hygiene, entertainment, communication and other useful services principally within the home”.

There are also connections *between* the domains. For instance, leisure-related changes could influence all categories. Sustainable lifestyles literature and other empirical studies often identify leisure as a domain on its own. However, in the analytical context of models, if models defined leisure as a separate domain, it would overlap with the four domains identified above. Furthermore, other changes *within* domains could also be cross-cutting. For example, washing clothing at lower temperatures to increase the lifetime of clothing (*consumer goods and services* domain) also leads to a lower residential electricity demand (residential domain). As the above examples make clear, the categorisation of domains for lifestyle changes is heavily dependent on the service defined for the action. The distinction between different domains is one of the lenses through which the literature is analysed (as is highlighted in Figure 2-2-3 in Section 2.2.3 and results illustrated in Figure 1-2-4 in Section 2.4.1).

2.2.2. Literature search

This paper conducted a literature review to improve the understanding of lifestyle change and sustainable behaviour from different perspectives. Furthermore, it illustrates where overlapping concepts and methodologies lie, and to assess to what extent IAMs can make use of information and apply useful theories from other fields and models. From these distinctions discussed in the previous section, we conducted a systematic literature search by refining the selection process to the articles relevant for this research. The literature search was carried out based on general search terms within article titles, abstracts and keywords, resulting in a broad and diverse selection of publications. We also included other relevant articles outside of the systematic search (see Figure 2-2). We used the search terms and followed the selection criteria (see Supplementary Information) in selecting the relevant articles for analysis. Figure 2-2 illustrates that there is a predominant focus in the literature on the ‘food’, ‘residential’, and ‘transport’ domains modelled commonly in IAMs, in addition to the ‘consumer goods’ domain highlighted in other disciplines or models (Akenji & Chen, 2016). Thirty-three articles focused predominantly on food and diet, sixty-two articles on transport, fifty-nine articles on the residential sector, and four articles have a significant focus on ‘consumer goods’.

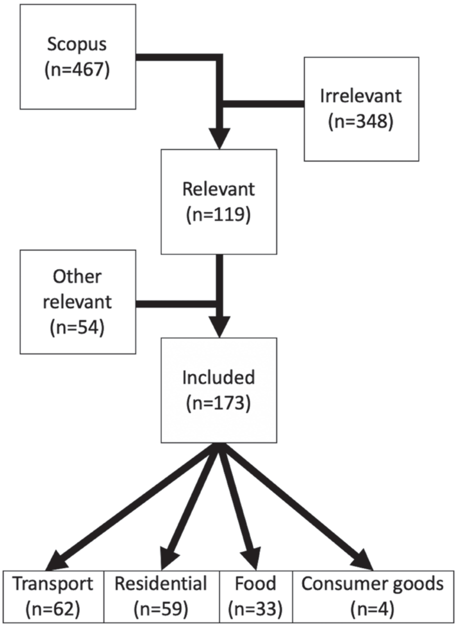


Figure 2-2: Selection procedure and number of articles that focus on domains in the literature.

2.2.3. Approach

This research bases its approach (see Figure 2-3) on the distinction between intent- and impact-oriented behaviours (described in Section 2.2.1.2) in order to capture both the motivations as well as the outcome of behaviours, and analyses these using the ASI distinction (described in Section 2.2.1.1) and different domains (described in Section 2.2.1.3). Looking at both aspects not only improves our understanding of how behaviours can be changed but also which behaviours should be changed. We first unpacked the impact-oriented behaviours and the disciplines that focus on these, such as Industrial Ecology and Energy Modelling (e.g. IAMs), but using a lens of intent-oriented behaviours. We did this by categorising them as 'improve, 'shift' or 'avoid'. After that, we analysed the disciplines focusing on intent-oriented behaviours, with the lens of modelling from the impact-oriented behaviour. We did this by highlighting relevant methodologies and theories for IAMs, and other models, within the categories attitude, facilitators and infrastructure influencing the motivation of behaviours. From this, we gained insights into the possible linkages between these different perspectives. More specifically, we formed concrete recommendations of how IAMs can learn from other disciplines (both qualitative and quantitative) to improve modelling or representation of behaviour.

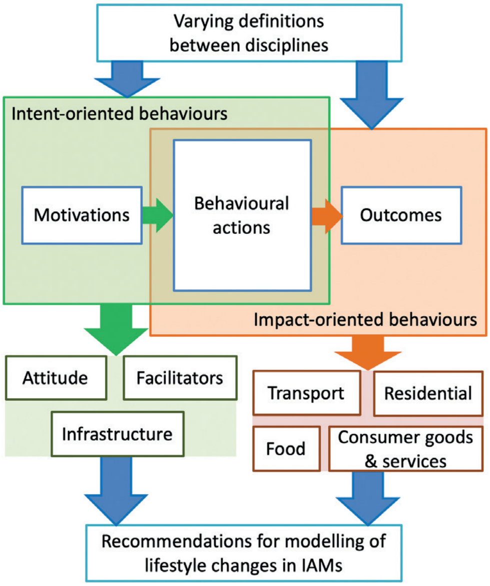


Figure 2-3: Research approach illustrating how the various underlying definitions form the basis for the distinction between intent- and impact-oriented behaviours that frame the structure of the literature analysis, to formulate recommendations.

2.3. IAMS AND THEIR COVERAGE OF BEHAVIOUR AND LIFESTYLE CHANGES

As indicated before, IAMs have primarily focused on technology measures (i.e. improve), and only a few studies have integrated lifestyle change into their models. Mostly, the definition of this lifestyle change is a shift to actions that provide the same outcome (e.g. distance travelled), and less on the avoidance of activities, (e.g. reduced travel) (van Sluisveld et al., 2016). Therefore, there is a noteworthy gap in the representation of lifestyle change within IAMs. To identify promising approaches to addressing this gap, modellers need clarification on the possibilities within IAMs. There are several possible ways of modelling lifestyle changes in IAMs, which are discussed in more detail below:

1. Incorporate changes in lifestyle into narratives, or storylines (e.g. similarly to the Shared-Socioeconomic Pathways), with exogenous representation in IAMs.

2. To a certain degree, lifestyle changes can be modelled endogenously with adjustments of parameters and assumptions within the IAMs.

3. Explicitly model lifestyle changes entirely within the IAMs (e.g. with a whole module focused on lifestyle changes that dynamically responds to other modules).

The use of narratives or storylines is a relatively simple way of improving the representation of lifestyle change in IAMs. This method is not new, but the storylines themselves could be improved significantly in terms of lifestyle changes. More specifically, IAMs could improve the storylines by drawing from qualitative research that specialises in understanding how consumers could change their behaviour over time. A notable example of how narratives have been used to create baseline scenarios is the use of the Shared-Socioeconomic Pathways (SSPs) framework (Bauer et al., 2017). This framework structures the uncertainties around lifestyles and other drivers into five narratives, based on the challenges to mitigation and adaptation. These narratives provide assumptions regarding lifestyles for developing scenarios by IAMs; however, they still only offer a relatively small range of possible trajectories.

van Vuuren et al. (2018) modelled lifestyle changes within a scenario with exogenous inputs, including "less meat-intensive diet (conforming to health recommendations), less CO_2-intensive transport modes (following the current modal split in Japan), less intensive use of heating and cooling (change of 1°C in heating and cooling reference levels) and a reduction in the use of several domestic appliances", among other similar studies (Bijl et al., 2017; McCollum et al., 2017; Stehfest et al., 2009; van Sluisveld et al., 2016). Likewise, van de Ven et al. (2017) modelled behavioural options around food demand, mobility demand and housing demand in the EU specifically, also based on stylised assumptions.

Furthermore, a recent study, by Grubler et al. (2018), represented lifestyle changes within narratives, with a 'low energy demand (LED)' scenario. They illustrated how changes in types of energy service and quantity drive structural change in the supply sector. Also, they concluded that down-sizing the global energy system dramatically increases the feasibility of reaching 1.5°C climate target without relying on negative emissions technologies. They represented lifestyle changes (e.g. how consumers could change the way they use technology) as exogenous inputs. Compared to other optimistic scenarios on world final energy demand, such as the Greenpeace [R]evolution scenario with around 315 EJ/year and SSP1 1.9W/m^2 scenarios with about 425 EJ/year, the LED scenario is considerably more optimistic with around 245 EJ/year. These scenarios are still very stylised and lack qualitative insights on long-term changes and regional differences. Moreover, as information about lifestyle change is often exogenous input to the models, it does not react to changes happening within the models. Therefore, the information is very dependent on external assumptions. The scenarios do, however, illustrate that improving the degree of representation of lifestyle changes in IAMs can lead to promising future scenarios in terms of transformative reductions in GHG emissions.

The second option for better representation of lifestyle changes consists of adjusting parameters and assumptions within IAMs to allow a certain degree of endogenous modelling. This methodology also requires significant insights from qualitative disciplines. For example, qualitative research can help IAMs improve the representation of decision-making processes or heterogeneity of consumers and how they could change. Edelenbosch et al. (2018) made an effort to do this by building on the work of McCollum et al. (2017). They explored a dynamic representation of adopter groups' (Rogers, 2010) behaviour in both technological- and social learning that influences a technological transition to battery electric vehicles (BEVs). This study is limited to this particular case study of the transport sector. Furthermore, other studies, such as van de Ven et al. (2017) and Li (2017) have introduced heterogeneity among decision-making within energy modelling. There are significant limitations for the representation of types of lifestyle changes through this approach. For example, some changes are more difficult to quantify than others (e.g. technology-related lifestyle changes are more straightforward to capture in IAMs than those unrelated to technology). Therefore, there is an opportunity to explore more ways of modelling integrative depictions of lifestyle changes, by learning from qualitative studies allowing for a better representation of lifestyle changes in IAMs.

Thirdly, explicitly modelling lifestyle changes within IAMs is a more challenging approach to represent lifestyle changes. Dynamic modelling requires a detailed understanding of future behaviours and the motivations behind them, and potentially an entire module within the model dedicated to lifestyles to incorporate dynamic interactions with other modules. One example of how this type of approach was applied is the study by Edelenbosch et al. (2018), which modelled changing behaviour endogenously within IAMs by including the dynamics of social learning. Furthermore, this approach could address how consumers respond differently to changes in 2020, compared to 2050 and even 2100. Longer time horizons come with a significant level of uncertainty and thus require substantial inputs from other disciplines to understand how behaviours will change over time and across regions. This approach would be very challenging to implement, as the model dynamically models based on economic and technological factors. Therefore, if models would include social factors dynamically, they would have to be (to a certain extent) translatable to the existing categories within the models. In addition to the difficulty, the approach would allow for a limited range of lifestyle changes representation. This research hopes to gain a better comprehension of how to apply this approach of modelling in IAMs with a higher range of lifestyle changes possible, by drawing on both qualitative and other quantitative disciplines.

2.4. VITAL ELEMENTS OF LIFESTYLE AND BEHAVIOURAL CHANGES ACROSS DISCIPLINES

This chapter explores both quantified impact-oriented behaviours, as well as intent-oriented behaviours by focusing on the drivers of motivations behind these behaviours.

2.4.1. Lifestyle changes across different domains

This section elaborates on the impacts of lifestyle changes, i.e. impact-oriented behaviours (see Section 2.2.1.2). An analysis of these impact-behaviours is discussed below through the lens of the ASI framework illustrated in Figure 2-1 (see accompanying tables in the Supplementary Information for more details). The analysis (see Figure 2-4) highlights the domains relevant for IAMs (as explained in Section 2.2.1.3) as well as the emphasis of modelling behaviour. The overview categorises lifestyle changes in 'avoid', 'shift' or 'improve' (see explanation in Section 2.2.1.1), in their respective domains (see description in Section 2.2.1.3), and what methodologies consider which lifestyle changes. It also emphasises the gaps and resulting opportunities in the quantification of lifestyle changes in IAMs – i.e. in consumer goods and services and food domains, endogenous modelling of 'avoid' category, and cross-domain factors such as time use shifts. The following sections analyse lifestyle changes in their respective domains to highlight the focus in the literature and gaps across domains (see Section 2.2.1.3 on the role of domains).

2.4.1.1. Transport

The *transport* domain has been modelled relatively often with regards to lifestyle changes (see Figure 2-4). Several of the modelled "lifestyle changes" fall outside our definition of a lifestyle change (i.e. *avoid* or *shift*), and constitute a technology change (i.e. improve). In transport, for example, 'choice of vehicles' is an *improve* and not a *shift* or *avoid* lifestyle change, as it is a switch to the same product with different inputs or higher efficiency. As was discussed before in Section 2.2.1.1, this could change depending on the context. Most of the measures modelled are *shifts* towards less intensive transport modes, such as 'public transport', 'carpooling', 'cycling' or 'walking' to the same intended destination. Lifestyle changes in the 'use of vehicles' have been modelled as well and would technically be a *shift* in behaviour within the transport domain. It requires a conscious change in behaviour to shift to eco-driving and maintaining vehicles, but its impact would be quantified at *improve* (i.e. efficiency improvement). The Environmental Input Output-Lifecycle Assessment (EIO-LCA) model is used for analysing lifecycles of products, such as vehicles. Thus, the EIO-LCA model allows for analysing lifestyle changes in the use phase of vehicles (i.e. the manner of driving the car) that affects both the efficiency and the vehicle lifetime. Some of the lifestyle changes modelled in the transport domain are in general (i.e. depending on the context) more transformative than in other domains within the same ASI category. For example, there are notable differences in the *avoid* lifestyle changes, 'reduced travel demand' in transport and 'reduced appliance use' in residential homes (see Section 2.4.1.2). However, in the transport domain, there is less variety in the types of measures found in the *avoid* compared to the *shift* in the transport domain.

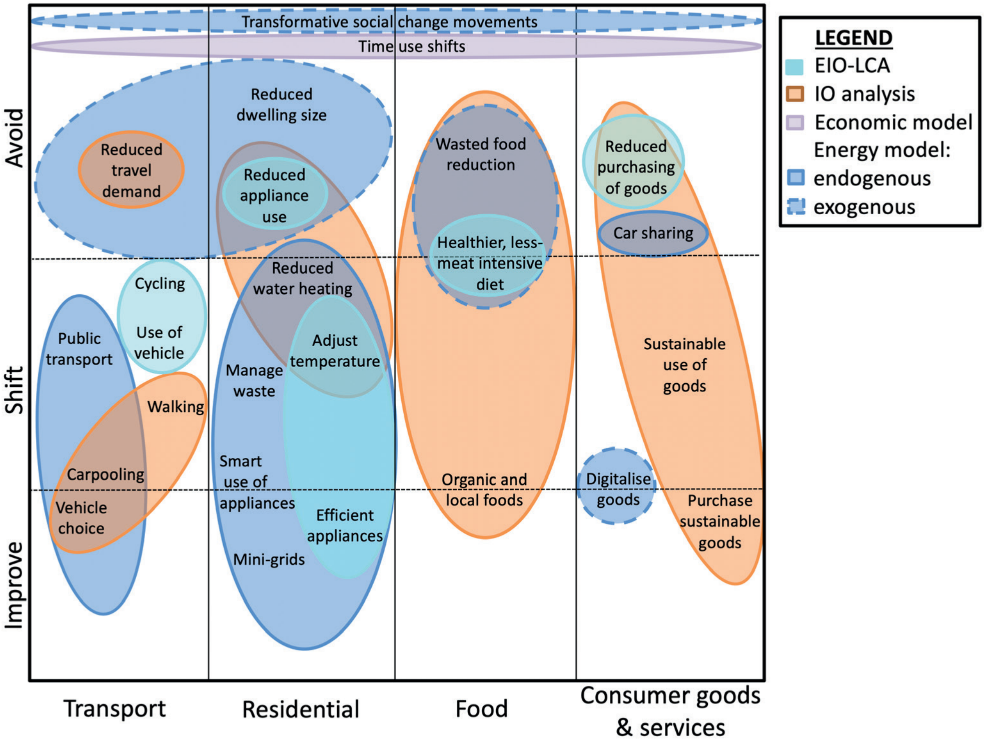


Figure 2-4: Impact-oriented behaviours categorised in relevant domains used in various modelling techniques (x-axis) and as 'improve', 'shift' and 'avoid' (y-axis), namely EIO-LCA (Jones & Kammen, 2011), IO analysis (Bjelle et al., 2018), economic model (Geisendorf & Klippert, 2017; GLAMURS, 2016) and energy models (Girod et al., 2013; Grubler et al., 2018; Stehfest et al., 2009; van de Ven et al., 2017; van Sluisveld et al., 2016; van Vuuren et al., 2018).

2.4.1.2. Residential

The impact-oriented behaviours falling under the *residential* domain vary significantly, and range from heating and cooling, changes in household dimensions, to mini-grids (see Figure 2-4). Most of these lifestyle changes fall somewhere between the *shift* and *avoid* categories since many measures focus on the reduction of energy use. For example, 'adjust temperature', 'reduced water heating', 'manage waste' and 'smart use of appliances' can be considered as *shifts* in lifestyle, as there is no change in function but rather a change in the means to the service. In contrast, 'reduced dwelling size' is categorised as *avoid*, as it is a more radical, one-off decision that reduces emissions in multiple ways over an extended period. 'Purchasing efficient appliances' is efficiency *improvement*, as it requires a decision on a product with the same function, but also in the same way as its alternative. The use of mini-grids is a lifestyle change challenging to categorise in the residential domain, as it can be seen as an *improve* technological substitution but also has *shift* characteristics. This complexity can be due to the relatively high level of investment needed for a mini-grid, the difficulty of implementing it (potentially with the entire community), and intermittency related to the output of the mini-grids. Therefore, these residential measures are more complex to classify within the ASI categorisation, compared to the more-straightforward transport measures.

2.4.1.3. Food

The literature review shows that the *food* domain has a limited variation in the type of lifestyle change, probably since the focus is predominantly on diet change (see Figure 2-4). Furthermore, the disparity between ASI categories is also limited. For example, 'reduced meat-product consumption' would be represented by a *shift* or *avoid* depending on whether the function is calorie intake or meat consumption, respectively. While reducing food waste is categorised as *avoid*, and organic, local foods categorised as *improve* (e.g. when bought in a supermarket), the assumptions and the context heavily influence this categorisation. For example, a 2010-2030 transition from one diet to another is assumed by Stehfest et al. (2009), while others consider a static change (Bjelle et al., 2018). Frenette et al. (2017) assume beef is substituted by less-emission intensive poultry and pork and thus a *shift* lifestyle change. While in the study by Stehfest et al. (2009), beef is assumed to be substituted by plant-proteins (i.e. a reduction in meat) potentially categorised as *avoid*. Therefore, the distinction between ASI categories is far less apparent in the food domain, compared to transport and residential.

2.4.1.4. Consumer goods and services

Few studies within the IAM community have quantified changes in behaviour in the *consumer goods and services* domain (see Figure 2-4). Other approaches, such as input-output analysis (Bjelle et al., 2018) and LCA (Jones & Kammen, 2011), focus primarily on the supply chain of commodities. Consumer goods and services are far less explored than the previously-discussed domains, perhaps because lifestyle changes in consumer goods and services have an indirect effect on energy reduction. The indirect impact is at the production stage or the landfill stage of the lifecycle, or the emissions quantified within other domains. For example, washing at lower temperatures as modelled by Bjelle et al. (2018) focuses on the maintenance of goods (i.e. 'sustainable use of goods') to increase its lifespan (categorised as a *shift*). However, the same action also influences the use of hot water within the residential domain. Furthermore, reduced consumption of goods (i.e. 'reduced purchasing of goods' categorised as *avoid*) is effected by 'reduced dwelling size' (see the residential domain in Section 2.4.1.4 and Figure 2-4). This dynamic interaction can be explained, as a smaller dwelling space reduces the need or possibility for goods to fill that space. Also, useful services, as modelled by Grubler et al. (2018), highlights the value of a shared mobility lifestyle (i.e. 'car sharing'), which could lead to more public transport use and less car ownership (i.e. categorised as an *avoid*). Additionally, the 'digitalise goods' categorised as *improve* could have implications on the number of goods owned and also the efficiency of using those goods. Another *improve* change would be the 'purchase of sustainable goods', with lower emissions in the supply chain but also with extended lifespan. The categorisation of a lifestyle change in a particular domain, is, therefore, significantly dependent on the service defined or the motivation of the action. For example, heating a house or having a spacious house both have a similar measure of output (the motivation, or intent, is discussed in Section 2.4.2). Therefore, we can establish that the impacts of one specific lifestyle change can be quantified in several domains. These interactions make it even more evident why a broader range beyond domains is beneficial.

2.4.1.5. Cross-domain lifestyle changes

This section discusses the categorisation of modelled lifestyle changes that do not fall in any of the domains discussed above (see Figure 2-4). These cross-cutting lifestyle changes often influence other domains indirectly. For example, 'transformative social change movements' modelled by Grubler et al. (2018) would indirectly affect diet, transport, residential and consumer goods and services domains. Including such transformative social change movements in models could potentially have substantial consequences for the feasibility of achieving ambitious climate targets. 'Time use shifts' is another promising entry point for exploring lifestyle changes. For example, the time spent engaging in different daily activities, as this might influence domains like transport and food. For example, working time reduction could result in less vehicular transport and healthier diets, while it will probably increase residential heating and cooling demand. There is a significant focus in the literature to emphasise aspects such as minimalism, slower lifestyles, or healthier work-life balances, which have positive outcomes on climate change mitigation. Some of the articles in this review have explored the concepts of slower lifestyles. For example, GLAMURS (2016) modelled energy use and time use patterns at the macroeconomic level using the Macro-economic Sustainable Time Use (MaSTU) model, allowing for the analysis of both policies and consumer initiatives impacts directed to sustainable lifestyles.

Furthermore, time affluence and time use are essential entry points for sustainability. These aspects are closely related to income and footprints, since there is a societal polarisation between people who have insufficient resources or time and those who do, whether they want it (e.g. more free time) or not (e.g. unemployment) (Moreau et al., 2017). Time use cannot be categorised in any specific domain, as it would have indirect consequences for multiple domains. It is reasonable to categorise these changes as *shifts* between domains but *avoid* within domains. For example, working a day less could result in lower energy demand in transport, but a shift in demand towards residential energy. While it can be interesting to understand the dynamics of the indirect effects of lifestyle changes on various domains, within the review, only a limited number of studies highlight this domain. These are often unmeasurable lifestyle changes in terms of costs or monetary factors, but possibly measurable in patterns of time-use of household members. These concepts are less commonly explored, especially within energy modelling, since they are more challenging to quantify. However, the cross-cutting characteristics can be useful when exploring related ideas, such as, changing the work-life balance and travel patterns. Therefore, they could be vital in understanding the effects of lifestyle changes on climate change mitigation.

2.4.2. Modelling determinants, influencing factors and direct drivers

Other categories modelled or analysed in studies from this review, did not fit the category of impact-oriented behaviours since they only focus on the intentions of consumers, i.e. intent-oriented behaviours. An overview of intentions (or determinants) is shown in Figure 2-5 based on the systematic literature review conducted. The framework by Akenji and Chen (2016) introduces the determinants *attitude*, *facilitators* and *infrastructure* on how to shape sustainable lifestyles, and these are adapted based on this literature review. These determinants help clarify what factors drive sustainable decision-making directly and influence them indirectly, in different disciplines (Figure 2-5). This research also uses these determinants as a lens through which the various lifestyle changes and modelling techniques were analysed (see x-axis in Figure 2-6). As observed in the literature from the review, these are often qualitatively modelled through narratives and storylines (Neuvonen et al., 2014) or quantitatively with heterogeneous consumer groups (Geisendorf & Klippert, 2017; Li & Strachan, 2017; van de Ven et al., 2017) and different demographics (Ala-Mantila et al., 2014; GLAMURS, 2016).

These intent-oriented factors are more novel ways of modelling behaviour in IAMs and are useful in understanding both the intentions and, consequently, the underlying causes of the impacts of behaviours. To expand the range of modelled impact- and intent-oriented behaviour factors, a more qualitative approach can help identify promising methodologies. These factors and the intent-oriented behaviours, already quantified, or incorporated into scenarios (see Figure 2-6 and and details in the Supplementary Information), will be discussed in the following sections and linked with the determinants (see Figure 2-5). A modelling perspective has been used to summarise the literature review, by highlighting already modelled concepts and promising approaches, but also distinguishing the possibility to model them exogenously, partly endogenously or endogenously in IAMs (see y-axis in Figure 2-6).

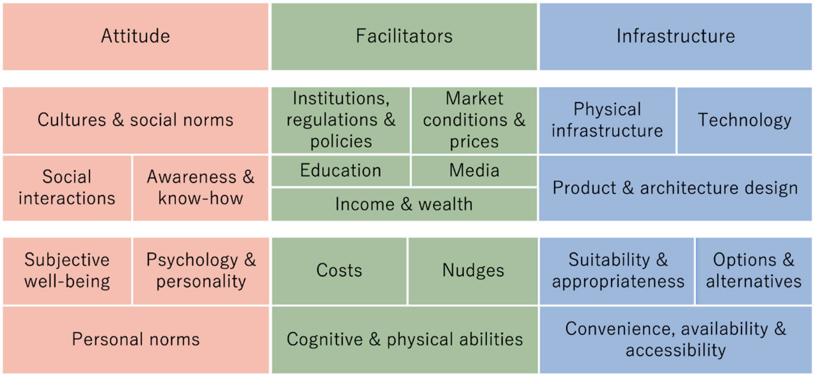


Figure 2-5: Theoretical framework of lifestyles (Akenji & Chen, 2016) adapted for integrating lifestyle changes in IAMs, based on the determinants 'attitude', 'facilitators' and 'infrastructure' which form one of the lenses for analysis of lifestyle changes.

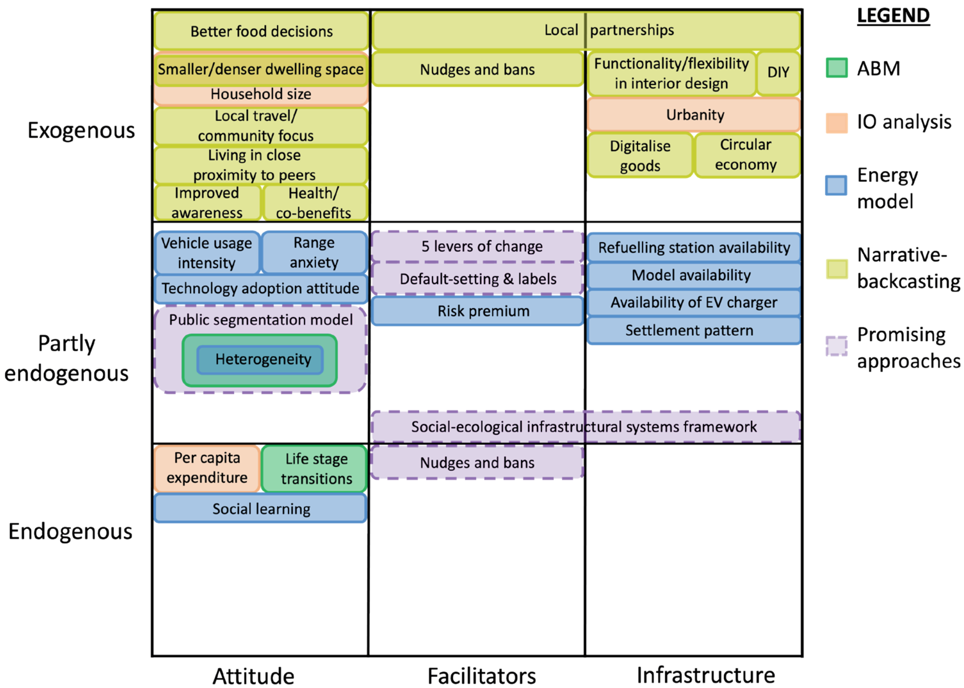


Figure 2-6: Results of intent-oriented behaviours as categorised in determinants 'attitude', 'facilitators' or 'infrastructure' (x-axis), that were modelled/incorporated or showed promise to be included into IAMs, as 'exogenous', 'partly endogenous' or 'endogenous' (y-axis). These models include agent-based models (ABM) (Geisendorf & Klippert, 2017; GLAMURS, 2016; Li, 2017), input-output (IO) analysis (Ala-Mantila et al., 2014), energy models (Brand et al., 2017; Edelenbosch et al., 2018; McCollum et al., 2017; van de Ven et al., 2017), narrative-backcasting scenarios (Neuvonen et al., 2014) and promising approaches (Ala-Mantila et al., 2014; Defra, 2008; Girod et al., 2013; Girod et al., 2014; Ramaswami et al., 2012; Unilever, 2013).

2.4.2.1. Attitude

This section deals with the determinant *Attitude* and discusses the relevant factors (see red boxes in Figure 2-5) with regards to the intent-oriented elements of behaviours (that could be) modelled (see Figure 2-6). There is considerable recognition in the literature of the existence of a value-action gap, a situation where individuals identify with pro-environmental value but do not act accordingly (Babutsidze & Chai, 2018). The Theory of Planned Behaviour from the field of psychology, specifically the Perceived Behavioural Control, similarly highlights the gap between intention and behaviour (Ajzen, 1991), focusing on the perceived difficulty or ease of acting on intentions. To better understand the size of this gap, self-efficacy – the assessment of how well an individual can execute actions to deal with potential circumstances – can help reliably predict behaviour (Cornelius et al., 2014). This section deals with the factors affecting the attitude drivers and influencing factors of lifestyle changes (see Figure 2-5). *Personal values, norms and beliefs* (see Figure 2-5) affect our environmental identity, which in turn affect our awareness of consequences. This *awareness* (see Figure 2-5) shapes our norms and the acceptability in both supply-side technologies and demand-side measures (i.e. behaviour), as illustrated by the Value-Belief-Norm model (Poortinga et al., 2012). Awareness has been highlighted significantly in the literature review as a critical influencing factor and incorporated into scenarios (Neuvonen et al., 2014) (see Figure 2-6).

A distinction can be made between 'compliance' (presenting pro-environmental behaviour when under scrutiny) and 'conversion' (self-sustaining the pro-environmental behaviour) if the goal is to generate sustained change (Dolan et al., 2010). Some authors theorise that reflection, deliberation and elaboration, can contribute to achieving and sustaining change in behaviour (Morris et al., 2012). For example, the 'elaboration likelihood model' (Petty & Cacioppo, 1986) suggests that sustained behaviour change relies on individuals consciously engaging with the subject matter and elaborating on it. However, there is ample evidence from the literature that higher awareness or belief alone is not sufficient to induce change, let alone sustain such change. Such is the basis of the common misconception built into public campaigns, that if consumers receive full-information and know-how, behaviours will change (UNEP, 2015). Among several examples, there are high correlations found between the intention to reduce meat consumption and make thermostat adjustments to less environmentally harmful levels, and little evidence of it happening (Truelove & Parks, 2012).

Some authors have argued the need to look beyond the individual, and focus on collective action or broader *social norms* (Dolan et al., 2010) (see Figure 2-5) to overcome the climate value-action gap and achieve sustained change (Löschel et al., 2017; Obradovich & Guenther, 2016). "Creating sustainable lifestyles requires a change in social norms . . . it means rethinking of ways of living . . . it's about transforming societies to better meet people's needs in balance with the natural environment" (Akenji & Chen, 2016). In this case, mechanisms such as social imitation and collective efficacy might be more predictive of a behaviour related to a collective outcome (Wang, 2018). Collective or social interaction (see Figure 2-5) has, to a certain extent, been modelled through social discounting (Li, 2017), contrasting with individual discounting and endogenously modelled social learning (Edelenbosch et al., 2018) (see Figure 2-6). This social learning can be a promising methodology to incorporate into IAMs to account for differences in social change and individual action. For proper representation of lifestyle changes in IAMs, modellers should account for these social norms influence over behaviour.

It is also essential to recognise individuality (e.g. *personal norms* and identities in society) and therefore capture the heterogeneity of citizens in IAMs, for different types of behaviours (see Figure 2-5). Efforts have been made to incorporate this heterogeneity in energy modelling, to expand the types of consumers beyond the usually-modelled rational actors and free-market economists with cost-optimal decision-making (see *heterogeneity* category in Figure 2-6). Diversity in types of profiles include ‘scientifically-informed’, ‘environmentalists’ (Geisendorf & Klippert, 2017), ‘heterogeneous decisions with social discounting’, ‘heterogeneous decisions with individual discounting’ (Li, 2017), ‘convenient’, ‘conscious’ and ‘enthusiastic’ (van de Ven et al., 2017), and different adopter groups based on diffusion of innovations theory by Rogers (2010), ‘early adopters’, ‘early majority’, ‘late majority’ and ‘laggards’ (McCollum et al., 2017). These methodologies can be expanded to include different consumer segmentation, which further grasp differences in consumer behaviours. An example of this is the evidence-based *public segmentation model* (Defra, 2008) (see Figure 2-6), which aims to offer insights on how to stimulate various options for sustainable living for different segments. Studies that have implemented the segmentation models find inconsistencies between segments dependent on the sector (i.e. between activities, products and services), and therefore this approach would need to be tailored differently based on lifestyle changes in different domains.

Well-being (see Figure 2-5) in the literature is usually associated with indicators that are alternatives to the Gross Domestic Product and aim to better portray social wellbeing, including new definitions of wealth, and new indices for the quality of life (e.g. Happiness Index). Putting well-being central on how to progress would thus necessitate that development of infrastructure, public policy, business strategy and institutional principles and practices are prioritised based upon their contribution to well-being. Some researchers, therefore, argue that *“dynamic models (with long time horizons) would need to consider the issue of influence of the physical and social context on preference formation”* (Mattauch et al., 2014). Thereby, they are highlighting the need for modification of individual preference structures in IAMs resulting from changes in cultural or social norms about what “good life” and well-being signifies (Samadi et al., 2017).

Some studies highlight the focus on well-being as a ‘compelling, pragmatic and positive vision’ on how sustainable behaviour can be adopted without scare tactics or guilt framing and instead with a focus on aspirations and stakeholder values (UNEP, 2011; P. J. Vergragt et al., 2016). Most notably, co-benefits of sustainable behaviour, related explicitly to well-being rather than economic benefits, are a commonly explored concept throughout the literature. There are numerous psychological barriers to changing behaviour, despite the positive subjective well-being effect and welfare. When a particular behaviour type has significant co-benefits (e.g. own health, societal health or animal well-being), it increases the consumers' willingness to adopt this behaviour (van de Ven et al., 2017). These co-benefits can be modelled implicitly in different consumer profiles (discussed in the following paragraph) and in scenarios where health becomes communal issues (e.g. *better food decisions* as illustrated in Figure 2-6). Understanding these co-benefits is the first step into determining how to stimulate and anticipate change (Quam et al., 2017; van de Ven et al., 2017). This focus on co-benefits allows a different framing of behavioural changes, to a more positive and compelling alternative, rather than a sacrificial decision.

Even though there is a tendency for actors located in the same regions to participate in similar mitigation practices, social norms related to sustainable behaviour often vary considerably within and across regions. Researchers speculate this is most likely due to clusters of environmental, social norms within regions (Babutsidze & Chai, 2018). These clusters within the regions are difficult to represent in IAMs, as these models *do* distinguish between regions *but* aggregate at that level, while models would need to represent social norms clusters *within* regions. Some examples from this literature review of differences in regions modelled include settlement patterns (McCollum et al., 2017) and urbanity (Ala-Mantila et al., 2014) (see Figure 2-6). Furthermore, models could better represent different consumption patterns for regions in IAMs and incorporate interventions to promote generational changes within these regions. These changes could require social movements supporting long-term changes in social norms (Stern & Wolske, 2017) (discussed earlier in this Section).

Several articles address these concerns, by emphasising the potential of engaging people based on their stages in life (e.g. teenager, student and parent) (P. Vergragt et al., 2016). For example, during life stage transitions (modelled by GLAMURS (2016) using an agent-based model), or by acknowledging different consumption patterns in different life stages (modelled by Ala-Mantila et al. (2016) using input-output analysis), for understanding possible opportunities for social change (see Figure 2-6). These are novel ways of identifying possible shifts in behaviours, which could be useful for modelling lifestyle changes in IAMs over the long-term with demographic data on different life stages.

2.4.2.2. Facilitators

"*Facilitators* are a set of factors that contribute to the possibility for certain behavioural patterns or a lifestyle to actualise" (Akenji & Chen, 2016) (see green boxes in Figure 2-5). *Public policy, pricing, nudge* techniques can facilitate sustainable lifestyles; and *institutions*, *markets*, *education*, and *media* could influence these techniques. Facilitators are the more relevant determinants from a policy-perspective as they are critical indicators to assess how likely a sustainable lifestyle can be adopted, and which levers can be useful in facilitating lifestyle changes.

Cost (see Figure 2-5) is often assumed to be a dominant motivator and driver for decision-making (GLAMURS, 2016; Moreau et al., 2017), and thus also of lifestyle changes. Macroeconomic variables such as *prices*, *income* and employment (see Figure 2-5) are therefore likely indirectly affect consumer decisions (GLAMURS, 2016). Traditionally, behavioural choices have been modelled by economists by assuming a utility function maximisation that represents their preferences, under rational choice theory (Jackson, 2005). This utility function represents which are the preferred options over others (Mattauch et al., 2014). It is thus commonly assumed that rational actors make up the society, which maximises their gains at the least cost (Webb, 2013). Currently, economic behaviour is often explained through this rational choice approach, for example, in IAMs and other energy models. Consequently, disclosed preferences form the basis of utility-maximisation, often conveying reduced generalised costs, including time (Mattauch et al., 2014; Quinet & Vickerman, 2004; Small et al., 2007; van Wee et al., 2013).

Within the literature, there is quite some focus on Willingness To Pay (WTP), which is a concept where a higher cost is accepted by an individual, relating to a cost-benefit analysis weighing up the costs and the benefits of a decision (Von Borgstede et al., 2013). Concerning environmentally-friendly behaviour, an intention for pro-environmental behaviour could be considered WTP (Ajzen, 1991; Stern et al., 1993); to translate an expression of intent into action by using the appropriate facilitator. Often used facilitators involve costs and mitigation strategies; examples include taxes, subsidies, and deposit-refunds (Akenji et al., 2012; Dubois & Ceron, 2015; GLAMURS, 2016; Hanley & Brennan, 2013; Webb, 2013).

Some argue that mechanisms to foster cooperation should be incorporated into policies to become more effective in mitigating climate change but also account for irrational responses and uncertainty that could potentially inhibit collective action (Raihani & Aitken, 2011). We argue based on the literature review results that Common-Pool Resource (CPR) theory can address the traditionally lacking reflexivity and disorganisation of climate policy, as the design principle of CPR theory can allow for a more comprehensive analysis regarding the effectiveness of policies. For example, design principles can offer an improved analysis of carbon taxes when compared to existing policy analysis, through better monitoring of user behaviour (Lacroix & Richards, 2015).

Some disciplines and theories challenge the above-mentioned rational choice theory based on cost-optimal decision-making, such as behavioural economics, psychology and welfare theory. For example, behavioural economics emphasises the need to understand the bounds of rationality of economic agents. Under the assumption that actors do not necessarily behave rationally, people are susceptible to *nudges* (see both Figure 2-5 and Figure 2-6), a term introduced by Thaler and Sunstein (1999), which could improve decisions about wealth, happiness and health as well as environmental health (see relevant quote in Table S2). Fundamentally, thoughtful architecture can influence choices, through nudges or by steering consumers in a sustainable direction. However, some argue that nudges alone could be ineffective and must be combined with other approaches and incentives to achieve desired outcomes (Thaler & Sunstein, 1999).

This is particularly relevant for IAMs since policymakers have become interested in the concept of nudging. They have become more reluctant to approach lifestyle issues with financial or administrative instruments that are perceived to limit freedom of choice (Backhaus et al., 2012). As discussed in the previous section on Attitude (see Section 2.4.2.1), freedom of choice also highlights the importance of social context, social norms and values. Some interesting nudging-related mitigation strategies are *default-setting and labels* (Girod et al., 2014) and the use of *five levers of change* developed by Unilever (2013) to break or create new habits (see strategies in Figure 2-6). Furthermore, the narrative-based backcasting analysis included policy-driven nudges and bans (Neuvonen et al., 2014) (see Figure 2-6), and therefore has the potential to be either covered in narratives or modelled within IAMs.

2.4.2.3. Infrastructure

"*Infrastructure* refers to socio-ecological interfaces that support consumption activities" (Akenji & Chen, 2016) (see blue boxes in Figure 2-5). There is an emphasis on context-specific conditions in the literature, which highlights the need for specific *appropriate* and *suitable* mitigation measures (see Figure 2-5) to avoid a one-size-fits-all approach (Baiocchi et al., 2015). These measures also relate to the consumer-segmented method and modelling heterogeneity (see Section 2.4.2.1 on Attitude). For example, local GHG emissions drivers can be relevant in specific contexts only. Global models, such as IAMs, are therefore not adapted to understand or model these local emissions drivers, due to the lack of heterogeneity to appreciate specific impacts. By improving infrastructure heterogeneity within the models, they can address these limitations (similar to the those shown in Figure 2-6). Therefore, IAMs could include varied infrastructure between *and* within regions (i.e. rural or urban) based on context-related factors for the various domains. This infrastructure heterogeneity can represent both motivation barriers *and* infrastructural barriers.

Lock-in designs limit and direct the choices available to consumers. For example, mobility *infrastructure* (see Figure 2-5) favours private vehicle use, thereby limiting other options for travel, such as cycling or public transport (Akenji & Chen, 2016). As phrased by UNEP (2015) "it is challenging for consumers to express demand for a product that is not available. It is therefore essential that retailers include more sustainable options in their assortment, and make these options attractive and affordable”.

Therefore, having *options and alternatives* (see Figure 2-5) is vital to ensure that products or services meet consumers’ needs and have minimum environmental impact. The design of products and buildings, for example, influences the level of convenience and options provided to consumers; therefore, *product and architectural design* (see Figure 2-5) is a crucial influencing infrastructural factor. Currently, product design often ensures that replacement is intrinsic within the products (e.g. disposable razors) (Akenji et al., 2012), limiting options for long-term use, recyclability or reparability. Subtle changes in product and infrastructure design can modify consumer behaviour (Unilever, 2013). Therefore, to improve the representation of lifestyle change in IAMs, enablers and lock-in factors for unsustainable and sustainable aspects should also be well represented (Moreau et al., 2017). Narrative-based backcasting by Neuvonen et al. (2014) accounts for these concepts, with functionality and flexibility in interior design, DIY products and circular economy. Furthermore, McCollum et al. (2017) account for *model availability* of light-duty vehicles to determine the likelihood of adoption (see Figure 2-6).

Infrastructure for transportation *convenience, availability and accessibility* are particularly relevant considerations for motivating sustainable behaviour (Lin, 2013). For example, a ‘smaller city block’ system through improved spatial urban planning, enables pedestrians to change direction quickly (Creutzig et al., 2016), a factor that promotes accessibility and convenience (see Figure 2-5). Similar elements have been modelled by McCollum et al. (2017) using an IAM that considers *refuelling station availability* and *availability of EV charger* a factor in the adoption of light-duty vehicles. Therefore, by including these factors, IAMs can improve (partly) endogenous modelling of lifestyle changes, as they offer the context in which behaviour change is possible, or not (see Figure 2-6).

Sometimes the lack of large-scale *infrastructure* (see Figure 2-5) can lead to more sustainable behaviour. For example, in terms of decentralised energy systems in rural environments, small-scale infrastructure improves access to energy sources while also doing it sustainably, with off-grid clean energy sources (Nakata et al., 2011). This bottom-up infrastructure provision is also relevant for stimulating collective action. For example, “sustainable neighbourhoods, communities and cities are emerging through co-creation and participation” that is enabled by public space, buildings and urban infrastructure (Backhaus et al., 2012). There is a trend towards collective action in terms of sustainable living. For example, transition towns or eco-villages (Backhaus et al., 2012), in which they use energy from their own local renewable energy production, requires appropriate energy infrastructure, such as micro-grids. Thus, the inclusion of *local partnerships* (see Figure 2-6) in narrative-backcasting (Neuvonen et al., 2014) and *settlement patterns* modelled in an IAM (McCollum et al., 2017) (see

Figure 2-6) could be relevant factors affecting community-based energy provision, for inclusion in (other) IAMs or domains.

Moreover, a promising approach to capture both the infrastructure and facilitators of intent-oriented behaviours could be through the use of the Social-Ecological Infrastructural Systems (SEIS) framework. This framework can be used to model the voluntary changes among users, and the interactions with policy actors and infrastructure designers/operators (Ramaswami et al., 2012). Due to these overlaps found in both SEIS and IAMs, the approach of modelling the interactions between actors and infrastructure could also be of use to the modelling of interactions of behavioural changes within IAMs (see Figure 2-6).

Lastly, *technological* innovation can enable alternative behaviours (see Figure 2-5). Behaviour theorists emphasise technology's impact on behaviour and innovation's role as the agent of change (Morris et al., 2012). This behaviour could fill a specific niche requirement, but could also spread to replace dominant technologies (i.e. disruptive innovations). Thus, technological innovation goes beyond focusing on the adoption of technologies by assessing *how* they can stimulate sustainable behaviour so that it is *convenient* and *appropriate* for each consumer (see Figure 2-5). Technological innovation has, to a certain extent, been considered in intent-oriented behaviours, through the *digitalisation of goods* in a narrative-based backcasting analysis (Neuvonen et al., 2014) (see Figure 2-6).

2.5. CONCLUSIONS AND RECOMMENDATIONS FOR BETTER-REPRESENTING LIFESTYLE CHANGE IN IAMS

This research discusses how different perspectives on lifestyle changes could be used to adopt a more nuanced and rich approach and representation of lifestyles in IAMs. We conclude that a meaningful way forward is to focus on the differentiation between *avoid*, *shift* and *improve* (ASI framework) and combining both intent- and impact-oriented methodologies while also representing the context and drivers of lifestyle changes. Even though we conducted a systematic review, critical articles may have been overlooked, especially with the ambiguity around the search terms and the variation in terminology between disciplines. Furthermore, due to the broadness of this research and thus limited time to go into detail, the categorisation of lifestyle changes modelled could be improved. Most notably, only a few frameworks formed the lens through which we analysed the literature. However, other frameworks could have yielded different results and relevant outcomes. Based on these conclusions and limitations, the following are recommended actions for, in particular, the IAM community, but also others to undertake:

Harmonise lifestyle change definitions, especially within the IAM community. The ASI framework allows a better, more qualitative, understanding of the variation in change from an impact-oriented perspective, and modelling approaches should distinguish these different types of lifestyle changes. Furthermore, this paper highlights the importance of semantics and how easily terms like ‘lifestyle changes’, ‘behaviour’, ‘consumption patterns’ are used as synonyms, but their meaning can differ substantially between disciplines. To interpret these concepts and guide strategy and action effectively, harmonise these concepts is crucial.

Expand the range of novel modelling approaches. Adopting the ASI framework can be achieved by experimenting with novel approaches to modelling lifestyle changes. This framework has a high potential for modelling lifestyle change endogenously (e.g. by using concepts such as life stage transitions or per capita expenditure). Furthermore, when IAMs cannot model lifestyle changes endogenously, they can still be dynamically represented by coupling IAMs with other models that prove beneficial where IAMs are limited (e.g. agent-based models or input-output analyses). Also, a promising way forward is to expand and strengthen existing methodologies within IAMs that have already proven successful, such as modelling social learning and heterogeneity on the intent-oriented behaviours by drawing from qualitative studies.

Expand the range of lifestyle domains and include cross-domain entry points in IAMs. To cover a broader range of lifestyle changes, IAMs could model additional factors beyond individual domains. A possible starting point could be to focus on cross-domain entry points (e.g. by incorporating shifts in time use patterns, social change movements), which have indirect effects on the traditional sectors in IAMs (such as transport and residential).

Expand the range of transformative solutions modelled. A stronger focus towards transformative solutions (i.e. actions within the *avoid* category), rather than efficiency gains and incremental adjustments, could emphasise the potential of lifestyle changes for climate change mitigation.

Add essential nuanced details to depict lifestyle changes in IAMs. Essential nuanced details allow for more detailed modelling of lifestyle changes with a greater understanding of the intentions from qualitative studies. This approach could strengthen model-based scenarios and thus clarify and improve communication to policymakers. For example, modellers can extend their modelling of ‘shifts to public transport’ to reflect variations in the types of public transportation, the frequency and distance of trips, and the co-benefits (e.g. both environmental and health benefits) that increase the desirability of particular lifestyle changes. Often the concepts, discussed in this research, to improve lifestyle change representation in models challenge the rational choice theory (used within IAMs), so it is critical to adapt models to move beyond this rational choice assumption.

Consider the whole picture, both intent- and impact-perspectives. If IAMs represent both the intent- and impact-oriented perspectives of behaviours, they could address the following questions: 1)

Why do people change their lifestyles? 2) How can we stimulate these changes in lifestyles? 3) Which lifestyle changes are worth changing (i.e. have a relatively high impact)? One perspective without considering the other can result in only communicating half the story. Therefore, this joint perspective would benefit modelling lifestyle changes *and* effective communication to policymakers. Depending on the research question, there can be a skewed focus to either intent or impact. Nevertheless, considering the other perspective is very beneficial to account for the cause-effect relationship. For example, adopting an impact-oriented perspective is anticipated when modelling the outcomes of lifestyle changes, but could be better represented by reflecting on the intent-oriented perspective using storylines.

Strategically address trade-offs between exogenous inputs and endogenous modelling. As can be seen in Figure 2-7, on a scale from *abstract exogenous inputs* to *fully endogenous modelling*, there are trade-offs in terms of both empirical representation and dynamic representation. Using exogenous inputs can cover more of the lifestyle system and lifestyle energy use from empirical studies, and it is easier to implement. Therefore, using exogenous input has a higher potential for empirical representation. However, this approach to representing lifestyle changes lacks a dynamic representation of the uptake of specific lifestyle changes. Examples of exogenous modelling include stylised assumptions and narratives or storylines, and can either be executed ad-hoc (e.g. assumed a less-meat intensive diet (van Sluisveld et al., 2016)) or informed (e.g. narrative-based backcasting analysis (Neuvonen et al., 2014)). Adopting an endogenous modelling approach limits the coverage of the lifestyle change system, but allows a better representation of changes in specific lifestyle choices. For example, consumer segmentation (e.g. adopter groups (McCollum et al., 2017)), can be partially modelled within IAMs, while representing “consumers” reacting to specific lifestyle change options (e.g. through social learning (Edelenbosch et al., 2018)) could be fully endogenously modelled within IAMs. The chosen approach should depend on the research question. For example, for ‘what-if’ types of questions, static modelling with exogenous inputs would be more appropriate. If the main aim is improving our understanding of how a specific lifestyle change option evolves (e.g. increased use of public transit, lower temperature when washing clothing), a more dynamic approach would be more appropriate. Therefore, not one approach is stronger or weaker than the other: each approach has its strengths and weaknesses, and the chosen approach depends on the question put forward.

By following these recommendations, modellers can represent a more effective and fuller approach to lifestyle changes within IAMs. It is a necessary next step to support policymakers and decision-makers in acting to transform lifestyles towards sustainability and to reach our collective climate targets.

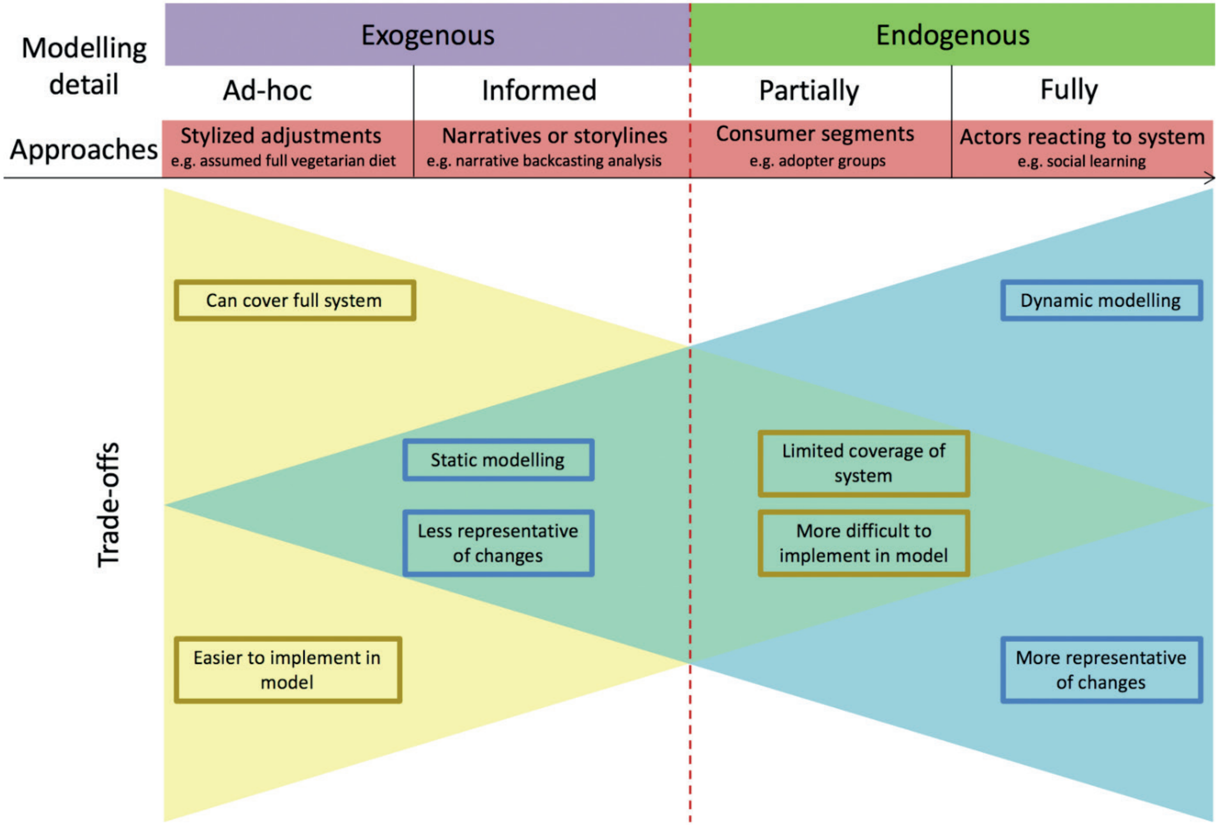


Figure 2-7: Illustration of the trade-offs between exogenous and endogenous. From left to right shows a range of modelling opportunities from exogenous to endogenous. Under exogenous modelling detail, there are ad-hoc (e.g. with stylised adjustments) and informed (e.g. through narratives or storylines) options, while endogenous modelling detail, this can either be partially (e.g. through consumer groups) or fully exogenous (e.g. actors within the model reacting to other model sectors). The yellow triangle represents the trade-offs found when using exogenous inputs, and the blue triangle represents the trade-offs experienced when adopting an endogenous modelling approach.

ACKNOWLEDGEMENTS

The authors of this paper are immensely grateful for the financial support received by the KR Foundation. Also, the research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007–2013)/ERC grant agreement no. 336155 - project COBHAM "The role of consumer behaviour and heterogeneity in the integrated assessment of energy and climate policies".


KAPITTELZAAL
MCMXL

DECOMPOSITION ANALYSIS OF PER CAPITA EMISSIONS: A TOOL FOR ASSESSING CONSUMPTION CHANGES AND TECHNOLOGY CHANGES WITHIN SCENARIOS

Nicole J. van den Berg, Andries F. Hof, Kaj-Ivar van der Wijst, Lewis Akenji, Vassilis Daioglou, Oreane Y. Edelenbosch, Mariësse A.E. van Sluisveld, Vanessa J. Timmer, Detlef P. van Vuuren

"Decomposition analysis of per capita emissions: a tool for assessing consumption changes and technology changes within scenarios" *Environ. Res. Commun*, 3 015004

ABSTRACT

Recent studies show that behaviour changes can provide an essential contribution to achieving the Paris climate targets. Existing climate change mitigation scenarios primarily focus on technological change and underrepresent the possible contribution of behaviour change. This paper presents and applies a methodology to decompose the factors contributing to changes in per capita emissions in scenarios. With this approach, we determine the relative contribution to total emissions from changes in activity, the way activities are carried out, the intensity of activities, as well as fuel choice. The decomposition tool breaks down per capita emissions loosely following the Kaya Identity, allowing a comparison between the contributions of technology and consumption changes among regions and between various scenarios. We illustrate the tool's use by applying it to three previously-published scenarios; a baseline, a scenario with a selection of behaviour changes, and a 2°C scenario with the same selection of behaviour changes. Within these scenarios, we explore the contribution of technology and consumption changes to total emission changes in the transport and residential sector, for a selection of both developed and developing regions. In doing so, the tool helps identify where specifically (i.e. via consumption or technology factors) different measures play a role in mitigating emissions and expose opportunities for improved representation of behaviour changes in integrated assessment models. This research shows the value of the decomposition tool and how it could be flexibly applied for different global models based on available variables. The application of the tool to previously-published scenarios shows substantial differences in consumption and technology changes from CO_2 price and behaviour changes, in transport and residential per capita emissions and between developing and developed regions. Furthermore, the tool's application can highlight opportunities for future scenario development of a more nuanced and heterogeneous representation of behaviour and lifestyle changes in global models.

3.1. INTRODUCTION

Model-based scenario studies are often used to explore different strategies to reach climate goals and assess their respective costs and benefits. These studies typically focus on technological options to reduce emissions, including energy efficiency improvement and substitution to supply-side technologies with less or zero greenhouse gas emissions (e.g., renewables and carbon-capture-and-storage) (van Vuuren et al., 2018). Only a few global modelling studies explicitly explore the potential role of behaviour measures as mitigation options (IPCC, 2014). These studies show that behaviour changes can play a crucial role in reaching long-term climate targets by providing additional options to reduce emissions (Grubler et al., 2018; Lettenmeier et al., 2019; van de Ven et al., 2017; van Sluisveld et al., 2016; van Vuuren et al., 2018). Nevertheless, the range of behaviour measures in scenarios is limited. For example, energy scenarios do not adequately explore sufficiency (Samadi et al., 2017). Thus, a more nuanced approach to behaviour-related scenario development is necessary.

Understanding the role of behaviour change in scenarios can be helpful to understand the possible impact in the future. Behaviour change can reduce emissions by reducing carbon-intensive activities (e.g. travel) or by shifting activities (e.g. from car to public transport). These changes happen alongside technological measures such as energy efficiency improvement (e.g. using more-efficient vehicles) and fuel-switch (e.g. from petrol to electric vehicles).

There are numerous decomposition tools to analyse decarbonisation trends in both historical periods or projections. Many use the Kaya Identity[3] (Kaya & Yokobori, 1997) as a basis. Examples in the literature that have applied this to model-based scenarios (Edelenbosch et al., 2020; Girod et al., 2014; Pietzcker et al., 2014) often focus on changes in fuel composition and technology - and do not explicitly look at behaviour changes on a per capita level. Still, showing the possible contribution of behaviour change in future scenarios offers insights into changes in personal consumption patterns and the activities of our everyday lives. It is, therefore, useful to connect to the studies that focused on individual behaviour and that highlight the role of *avoiding*, *shifting* and *improving* (Creutzig et al., 2018) climate-related activities. Here *avoid* refers to an overall reduction of activity levels, *shift* to an alternative behaviour with lower ecological impact and *improve* to a different way of performing the same activity (Girod et al., 2014; Lettenmeier et al., 2019).

This paper expands on the studies above by developing a tool for decomposing factors of emission changes, measuring impact at an individual level, which is linked to the Avoid-Shift-Improve (ASI) framework. More specifically, our research aim is to present a generic decomposition tool for IAM

[3] Kaya Identity: approach to analyse energy-related carbon dioxide emissions based on the IPAT identity, I = P x A x T, where population, affluence (or GDP per capita) and technology are factors representing the contribution to emissions.

scenarios to analyse the effect of behaviour change vis-à-vis other measures (such as technology change) on both transport *and* residential per capita emissions. Such an analysis can also provide insights into how IAMs can improve modelling of behaviour changes. This decomposition tool is specifically designed to measure the *impact* of behaviour measures and not the *intent* or personal motivations behind them. A different framing is required to conceptualise the intent-orientation of behaviour changes as well as cross-cutting systemic measures (van den Berg, Hof, et al., 2019).

For the decomposition tool, we adapt the *activity*, *modal share (structure)*, vehicle *intensity* and, *fuel mix* (ASIF) framework for the categorisation of transport emissions (Schipper & Marie-Lilliu, 1999) to be more relevant to analyse both transport *and* residential per capita emissions. We replace the term *structure* with *service* for the residential sector. This article will refer to the adapted framework as the activity, structure/service, intensity and fuel mix (ASIF*) decomposition tool. We also align this categorisation with the *avoid*, *shift*, *improve* (ASI) framework (Creutzig et al., 2018; van den Berg, Hof, et al., 2019) to classify behavioural measures. While the critical focus of the paper is on the decomposition tool, we illustrate its use by analysing trends in several existing scenarios for a baseline scenario and two behaviour change scenarios. In the following sections, we first elaborate on the decomposition tool. Second, we apply the tool for a set of previously-developed scenarios for various regions in the transport and residential sectors and third, we discuss the results of the decomposition analyses. Finally, we present our conclusions.

3.2. METHODOLOGY

The ASIF* decomposition tool (see Figure 3-1 and specific details in Table 3-1) distinguishes the contribution of various types of consumption changes and technological changes on changes in per capita emissions. The distinction between these types of changes is essential, as they are characteristically different in several ways. Soft factors, such as habits and social norms, play a more important role in consumption changes than in technology changes. One consumption change factor is *activity*, which refers to the direct changes in energy demand (e.g. *avoiding* kilometres or appliances ownership). Another consumption change factor is *structural* change for transport (e.g. *shifting* transport modes) and *service* change for residential (e.g. *shifting* the thermostat temperature), which also represents a change in energy demand. One technology change factor is *intensity* and refers to the changes in energy use needed for a particular activity (e.g. *improving* vehicle efficiency). Another technology change factor is *fuel mix* and refers to the changes in emissions produced per energy used (e.g. *improving* fuel choice to renewable sources).

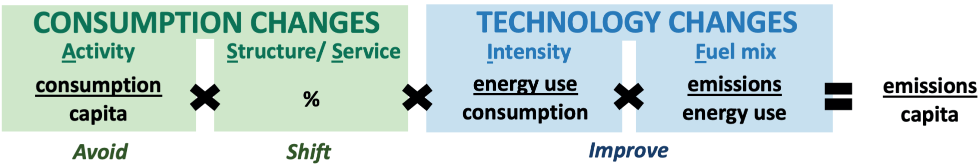


Figure 3-1: ASIF* factors categorised into contributing factors of consumption and technology changes based on the Kaya Identity, with the corresponding ASI behavioural interventions shown in italics.

In the literature, there are various types of decomposition analysis for energy and environmental analyses. Ang et al. (2003) highlight the strengths and weaknesses of several of these methods. We apply the Sun (1998) method using the n-term decomposition. Sun's method is a so-called *perfect* decomposition as it distributes the contribution from interaction terms to their respective factors, leaving zero residual terms. Moreover, contrary to the other conventional methods (like the Laspeyres Index), Sun's method is robust to factor reordering and time-reversal (Ang, 2004; Ang et al., 2003). The following section explains the application of the decomposition analysis (see Figure 3-2 for the calculation overview in terms of the ASIF* framework).

Table 3-1: Details of ASIF* factors contributing to per capita emissions

ASIF* contributing factors	**Details**	
	Transport	**Residential**
Activity	Effects of Changes in transportation demand (i.e. passenger-kilometres (pkm) per capita)	Effects of changes in residential energy demand (e.g. floor space per capita).
Structure/service	Effects of Changes in modes of transportation (i.e. pkm per capita in a particular transport mode)	Effects of changes in service demand in residential energy services (e.g. Heating Degree Days, or HDD).
Intensity	Effects of Changes in energy intensity within transport modes and fuel type (i.e. energy usage per pkm of a particular transport mode and fuel type)	Effects of changes in energy intensity within residential energy services (e.g. energy usage per HDD of floor space).
Fuel mix	Effects of changes in transport fuel types	Effects of changes in residential fuel types

The contributing ASIF* factors to emissions among the sectors transport, residential cooking, residential space heating, space cooling, water heating and appliances is summarised in Figure 3-2. Further details are shown in S3.2 In this ASIF* framework, the CO_2 emissions per capita at time t are calculated using an extended version of the Kaya-identity, for each energy service es and region r:

$$E_{es,r}(t) = \text{CO}_2 \text{ emissions per capita}_{es,r}(t)$$
$$= \text{Activity}_{es,r}(t) \times \text{Structure/service}_{es,r}(t) \times \text{Intensity}_{es,r}(t) \times \text{Fuel mix}_{es,r}(t),$$

where the fuel mix is calculated by summing over each fuel type f:

$$\text{Fuel mix}_{es,r}(t) = \sum_f \left(\text{emission factor}_{es,r,f}(t) \times \text{fuel use share}_{es,r,f}(t)\right).$$

The decomposition method used here splits the difference between the per capita CO_2 emissions in two years (in our case, 2050 and 2015) in differences attributable to each component:

$$E_{es,r}(2050) = E_{es,r}(2015) + \Delta E_{\text{activity},es,r} + \Delta E_{\text{structure/service},es,r} + \Delta E_{\text{intensity.},es,r} + \Delta E_{\text{fuel mix},es,r}.$$

The exact formulations of each factor of the decomposition are described in S3.2.

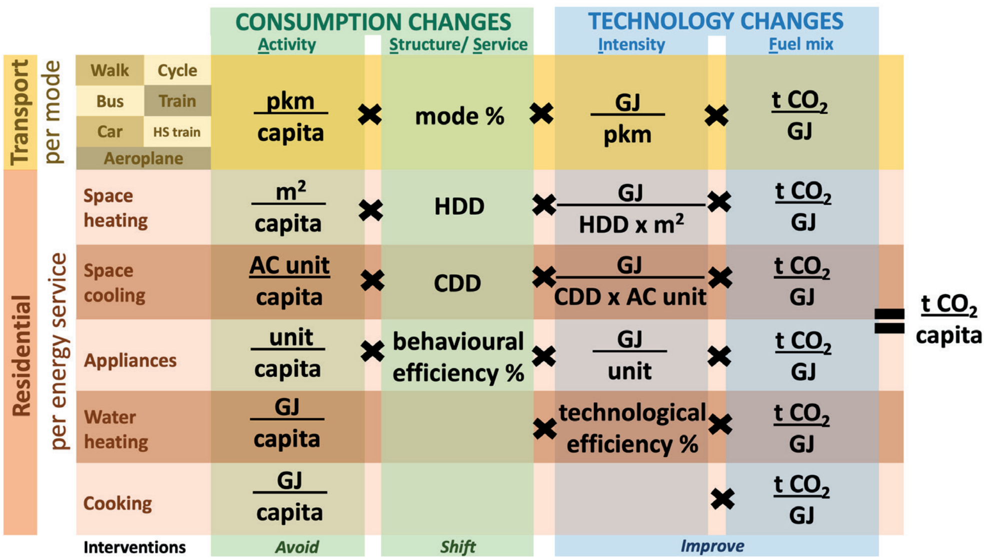


Figure 3-2: Breakdown of variables and units for decomposition analysis in transport modes and residential energy services in terms of the Activity, Structure/Service, Intensity and Fuel Mix (ASIF*) impact factors HDD = Heating Degree Days, pkm = passenger-kilometres, AC unit = airconditioning unit

The tool decomposes all four ASIF* factors as separate contributors for the energy services transport, space heating, space cooling and appliances. Due to missing representation in the IMAGE model for some factors in water heating and cooking, the tool decomposes three and two factors available (see Figure 3-2). Based on the behaviour measures, these factors would not have a significant impact on the results and can therefore be merged with other factors (see Table 3-3 and more details in S3.3). However, if the decomposition tool would use different scenarios, the methodology should be adjusted to consider these factors explicitly, if relevant.

3.3. SCENARIOS ANALYSIS

We apply the framework on three scenarios developed by IMAGE (Integrated Model to Assess the Global Environment) to illustrate how the ASIF* framework can help to identify the implications of behaviour change (or other measures, e.g. carbon pricing) in scenarios. The IMAGE 3.0 framework (Stehfest et al., 2014) is an integrated assessment model (IAM) to illustrate long-term dynamic changes in the land and energy systems.

Table 3-2 describes the various previously-published scenarios analysed in this research. The study applies a baseline scenario illustrating a situation in which current trends, including high increases in consumption, are continued without climate policy. This baseline scenario provides a good business-as-usual (BAU) reference to compare with the other scenarios. This research applies a behaviour change scenario to show the effects of behaviour measures such as reduced travel, car use, reduced floor space heated, thermostat adjustments, more efficient use of appliances and shorter shower time (described in Table 3-3). This scenario shows the extent to which the selected behaviour changes contribute to reducing emissions. Furthermore, this study also applies a behaviour change scenario that adopts the behaviour measures in parallel to climate policy measures that align to the Paris climate agreement (limiting average global warming to less than 2°C Celsius compared to industrial levels). This scenario allows analysis of the added effect of behaviour change under emission reductions forced through carbon pricing.

Table 3-2: Scenario descriptions

Scenarios	Description
Baseline scenario	"Middle-of-the-road" (O'Neill et al., 2017) scenario (assumes current social and economic trends and patterns will continue up until 2100, with consumption patterns following GDP per capita trends), without climate policies other than those already implemented.
Behaviour change scenario	Behaviour change scenario (van Sluisveld et al., 2016) is based on the SSP2 scenario that assumes several behaviour changes within the residential, food and transport sector (e.g. less-meat intensive diet, modal shifts, reduction in heated floorspace and thermostat adjustments; see details in Table 3-3).
Behaviour change + 2°C scenario	The Behaviour change scenario with climate policies included that aim to stabilise GHG emission concentrations at 450 ppm CO_2-eq in 2100, corresponding to a maximum of 2°C temperature increase in global mean temperature. The emission factor of electricity for some regions becomes negative before 2050 due to extensive use of renewables and bioenergy with carbon capture and storage (BECCS). In our analysis, however, we do not attribute negative emissions to electricity, as otherwise, an increase in demand for electricity would lead, *ceteris paribus*, to lower emissions per capita.

This study analyses the outcomes for the global average, for the average of a selected set of least-developed regions, and the average of a selected set of highly-developed regions (see S1.3 for the selection of regions). The IMAGE model implements measures and carbon prices similarly and universally across the different regions.

Table 3-3: Overview of implemented behaviour measures for the behaviour change scenario representing the behavioural actions for various ASIF* factors (adapted from van Sluisveld et al. (2016))

	ASIF* factor	Measure	Implementation	Transition	Source
Transport	Activity/ structure	Reduced vehicle use	Capping the travel money budget (TMB)[4] to not more than 7% of income (compared to the range 6%-10% assumed in the baseline scenario).	Gradual	van Sluisveld et al. (2016)
			Changing income elasticity to – 5% to improve passenger load per mode.	Immediate	Girod et al. (2013)
	Structure	Mode shift to public transport	Change of perceived price and increase of daily traveling time budget (TTB)[5] by 0.5 min/year resulting in 122 min/day in 2100 (compared to 0.25 min/year daily TTB increase in the baseline scenario resulting in 97 min/day in 2100).	Immediate	van Sluisveld et al. (2016); Girod et al. (2013)
Residential	Service	Reduced heating/cooling demand	Change of base temperature by 1 °C, reducing the number of heating degree days (HDD) or cooling degree days (CDD).	Immediate	van Sluisveld et al. (2016); Isaac and Van Vuuren (2009)
	Activity	Reduced appliance ownership	Reduced ownership levels for 'luxury goods' to zero (e.g. no tumble dryers, dishwashers).	Gradual	van Sluisveld et al. (2016)
			Maximum ownership rates for other major domestic appliances are fixed to 2013 values.	Immediate	
	Service	More efficient use of appliances	BAT energy consumption estimates and appliances converge to these new levels gradually over time.	Immediate	Goodall (2010)
	Activity	Reduced water heating	A correction factor in total energy demand for water heating (based on cutting down 2 min of shower time), based on an estimate in literature.	Immediate	Goodall (2010); Daioglou et al. (2012)
	Activity	Capping household dimensions	Maximum floor space (m^2/cap) is fixed to a representative 2010 value, differentiating for rural (50 m^2/cap) and urban households (40 m^2/cap).	Immediate	van Sluisveld et al. (2016); IEA (2004)

[4] Travel money budget (TMB): a travel constraint implemented based on the share of income of the person travelling.

[5] Travel time budget (TTB): a travel constraint implemented based on the time per day spent on transportation.

3.4. RESULTS

In this section, we show the contributions of the ASIF* factors to the change in transport and residential per capita emissions between 2015 and 2050 in the behaviour change scenario and behaviour change 2°C scenario, compared to the baseline scenario (see scenario descriptions in Table 3-2). In this study, we presented the model responses between two points in time (i.e. 2015 and 2050), but also multiple time steps and thus, trends over time (see figures in S3.4.5 and S3.4.6). The fuel mix (F) is further decomposed into fuel use and emission factors and shown in S3.4.7 for more detail. Refer to S3.4.4 for a scenario comparisons with scenarios with exclusively CO_2 prices.

3.4.1. Decomposed transport per capita emissions

In the scenarios analysed, behaviour measures mainly affect global emissions via a mode shift from air and car to trains (S) (see Figure 3-3). There is hardly any change in total pkms (A). This relatively small change can be explained by the underlying assumptions of the behaviour scenario, which consisted of a shift towards Japanese transport patterns via a capped Travel Money Budget (TMB), changed perceived prices and increased Travel Time Budget (TTB) (see Table 3-3). These behaviour measures result in mode-shift but have a small effect on the overall transport distance.

The behaviour change 2°C scenario shows the impact of adding a CO_2 price in addition to behaviour measures on per capita transport emissions (see S3.4.3. for a scenario comparison with a climate policy scenario). The CO_2 price leads to additional reductions in per capita emissions, primarily because of reducing travel demand (A) and changes in the fuel mix (F). The strong impact of changes in the fuel mix on emission reductions is the logical result of the CO_2 price changing the relative costs of fuels. The reduction in travel distance is a result of the increase in travel costs. This is consistent with the strong impact of costs on travel demand in IMAGE via the empirically observed fixed TMB. As a result of a carbon tax, it becomes more expensive to travel, consequently resulting in less distance travelled.

There are notable differences in 2015 transport per capita emissions between developing regions and developed regions. As shown in Figure 3-3, developed countries have a factor of 10 higher emissions per capita than developing countries. Almost all emissions in developed countries are from car travel with the remainder from air travel. In contrast, a large portion of the emissions (and thus demand) in developing regions are from buses and trains. There are also contrasting trends between these regions from 2015 to 2050, shown in the baseline scenario. A rapid increase in mobility (A) is projected in the baseline scenario for developing regions along with further development. Developed regions, on the other hand, show high emission reduction from intensity improvements in the baseline scenario in line with historical trends. Compared to the baseline, the behaviour change scenario shows some impacts from mode shifts (S), especially in developing regions. However, for developing regions, the result of mode changes (S) from aeroplane and car to the cheaper train and bus leads to an increase in activity (A).

The inclusion of a CO_2 price in addition to the behaviour measures (*behaviour + 2-deg*), results in significant additional improvements in the fuel mix (F). There is also an effect of a CO_2 price on the total travel distance (A) in developed regions, but this is relatively small compared to the absolute per capita emission reductions. In contrast, developing regions' emission increase is limited mostly via reduced travel distance (A) and mode shifts (S), and, depending on the scenario, significant improvements in the fuel mix (F). Similar to developed regions, developing regions show high potential for emission reductions by improving the intensity (I) of vehicles/modes and fuel choices (F).

Within the selection of developed regions and developing regions there are notable variations (see the S3.1 for the selection of regions). The characteristics of two developed regions, Japan and the USA, differ substantially. The mix of the transport modes is relatively equally distributed in Japan, while in the USA there is a predominant use of car and aeroplane transport modes. For the USA, the highest potential is the reduction of travel distance (A), improvement of intensity (I) and fuel mix (F) in these predominant modes, stimulated mostly by a CO_2 price. In Japan, unlike the USA, there is a relatively strong shift (S) to less CO_2-intensive transport modes from behaviour measures, with (high-speed) train replacing car and aeroplane travel. The two selected developing regions, India and Western Africa have relatively diverse mixes of transport modes. Thus behaviour measures cause a substantial shift (S) to more sustainable transport modes, especially considering their already low absolute per capita emissions. However, the differences in shift directions are interesting to note. In India, they shift mostly from aeroplanes and cars to trains, while in Western Africa they shift to buses. Increased train travel in India is logical considering the current proportion of train travel and thus preferences and infrastructure availability. These contrasts between countries highlight how context and situational factors affect behaviour changes, and thus their impacts.

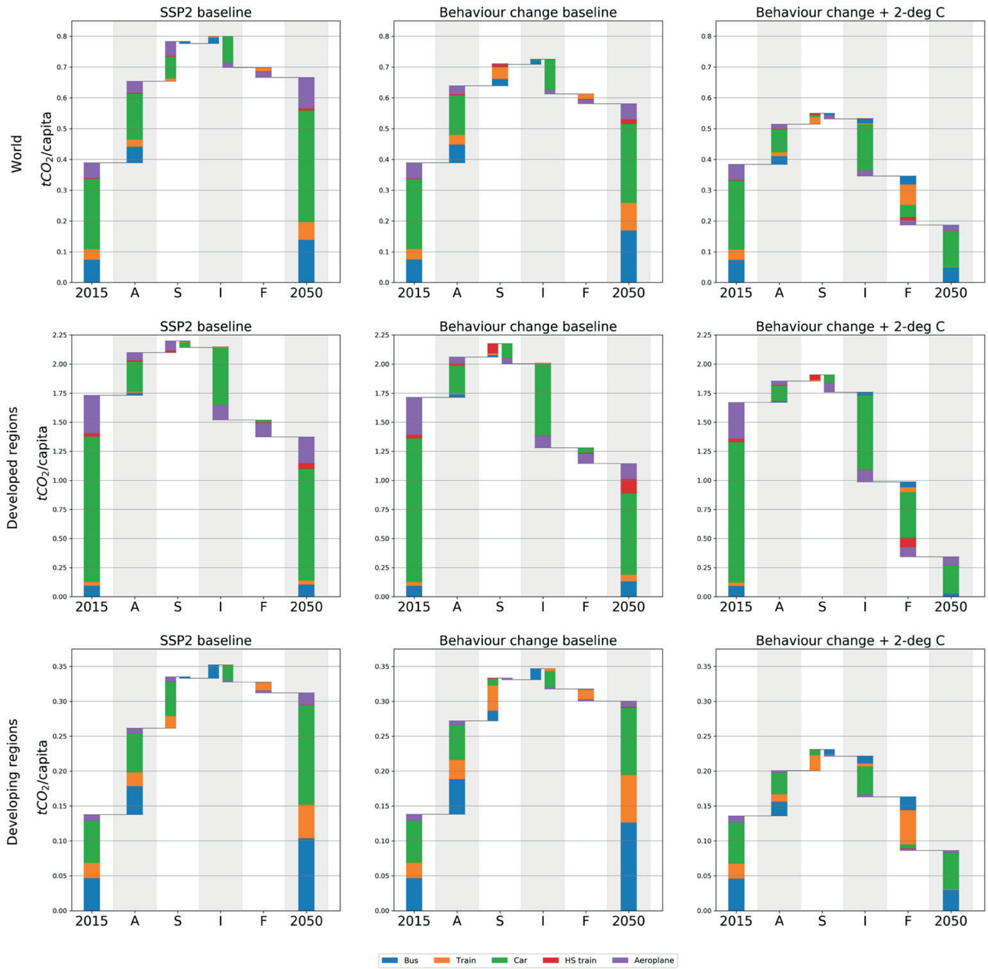


Figure 3-3: Decomposition of per capita transport emissions for the business-as-usual scenario (Baseline) and two behaviour scenarios that exclude (Behaviour change) and include (Behaviour change + 2-deg) climate policy. The factors A (Activity changes), S (Structural changes), I (Intensity changes) and F (Fuel mix changes) contribute to the change in emissions between 2015 and 2050 for various regions (for more specific regional effects the reader is referred to S3.1).

3.4.2. Decomposed residential per capita emissions

Figure 3-4 shows the residential per capita emissions that are decomposed for space heating, space cooling, water heating, cooking, and appliances. The trends are markedly different from those of transport. Globally, the behaviour change scenarios, in contrast to transport, shows the considerable impact of activity changes (A) on emissions. Measures likely affecting activity include the capping of floor space heating and reduction of shower time. Changes in energy service demand (S) (e.g.

changing thermostat temperatures) have a much lower impact on emissions. Part of this can be explained by higher climate warming in the baseline, resulting in less demand for space heating. The opposite phenomenon occurs in space cooling, as a higher cooling energy demand is needed in a warmer climate – although the effect is relatively small.

The behaviour change 2°C scenario shows that with a CO_2 price (compared to the behaviour change scenario without a CO_2 price the most substantial difference is from the fuel mix improvements (F), and the second-largest difference from activity changes (A) (mostly in appliances). Service changes (S) (e.g. HDD, CDD, use efficiency) have a relatively small effect in both the behaviour change scenario and in the behaviour 2°C scenario. However, it is vital to note that some energy services do not consider *service* (S) a separate factor (see Figure 2), and thus the service changes (S) refer specifically to the impacts from space heating, space cooling and appliances.

There are substantial differences in 2015 residential per capita emissions between developing regions and developed regions. A notable contrast is that generally-warmer, developing regions tend to have high space cooling. In comparison, generally-colder, developed regions have high heating demand. In contrast to developed regions, developing regions' emissions increase between 2015 and 2050 in the baseline scenario. These increases are attributed mostly due to increased appliance ownership and air conditioners in space cooling, but also some worsening intensity (I) in appliance and space cooling. This latter result is due to additional lower-income households in developing countries getting access to appliances that have a higher energy consumption (i.e. less-efficient appliances) or have dwellings with poor characteristics for cooling. Furthermore, behaviour measures in the behaviour change scenario have the highest impact via reduced appliance ownership (A). In developed regions, the highest impacts are from reduced floor space heating (A) and from shorter shower times (A) with the corresponding water heating.

We observe some specific differences within the selection of developed regions and developing regions (see S3.1). For example, comparing developed countries USA and Japan (see S3.2), a cap on heated floor space has a more considerable emission reduction from activity (A) in the USA which has a relatively larger floor space per capita than Japan. When comparing the two developing regions, India and Western Africa (see S3.4.2), cooking energy demand (A) is a relatively high proportion in Western Africa (but in absolute numbers comparable to India). However, appliance use (A) is a much higher proportion in India. This result is due to the differences in GDP per capita, as the model assumes that higher income leads to more appliance ownership.

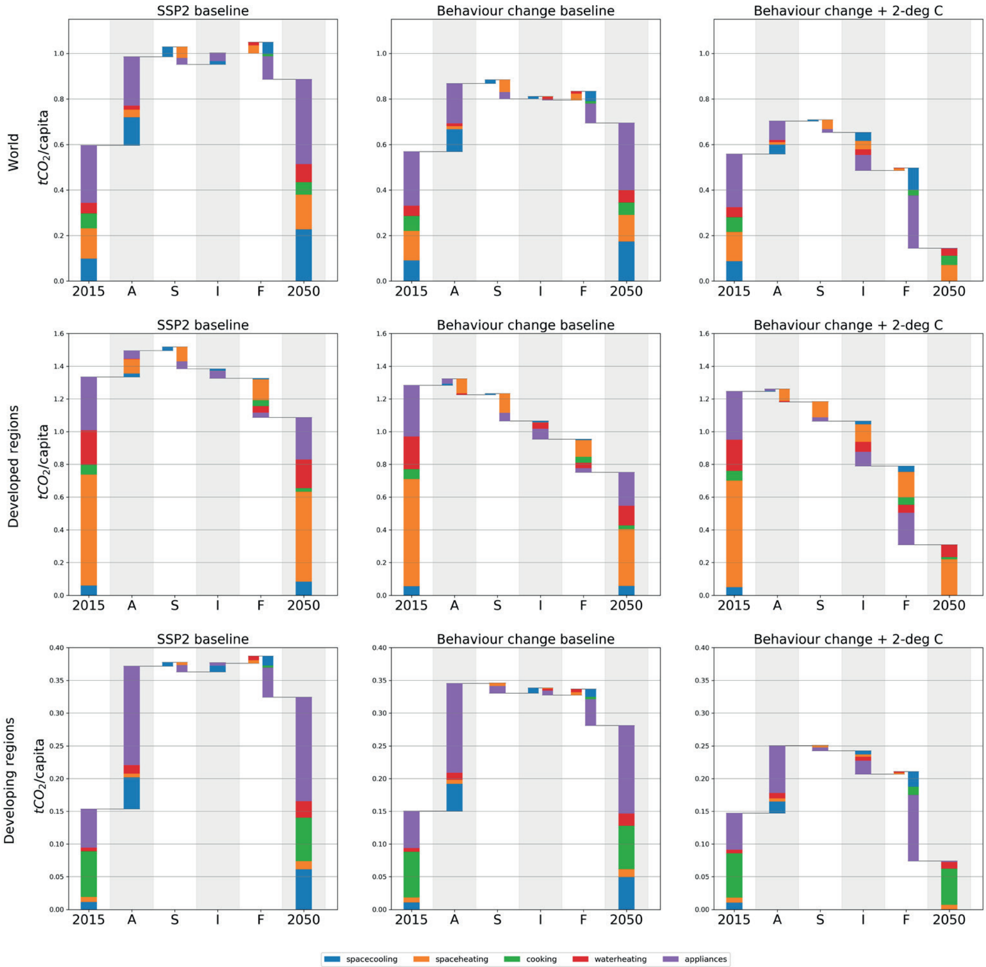


Figure 3-4: Decomposition of per capita residential emissions for the business-as-usual scenario (Baseline) and two behaviour scenarios that exclude (Behaviour) and include (Behaviour + 2-deg) climate policy. The categories A (Activity changes), S (Service changes), I (Intensity changes) and F (Fuel mix changes) represents the contribution of these factors to the change in emissions between 2015 and 2050 for various regions (for regional classification see S3.1)

3.5. DISCUSSION

The current study presents the ASIF* decomposition analysis as a tool for IAMs to highlight the impact of behaviour, consumption and technology changes on emissions in scenarios. We applied this tool to decompose per capita emissions in terms of behaviour changes, consumption changes and technology changes. We analysed the effects of carbon pricing and behaviour measures in existing scenarios. This process illustrated how the tool could be used to visualise trends of the impact of consumption and technology changes on emissions and differences in these trends between regions, sectors, and scenarios.

Expanding the ASIF* decomposition tool

In addition to the model responses between two points in time, we show multiple time steps (as shown in S3.4.5 and S3.4.6). For example, the effect of intensity changes in developed regions is more substantial from 2020 to 2030 compared to the other years. This option of tracking trends is another useful way of interpreting the outcomes of the decomposition tool. It is interesting to explore more ways to present the decomposition outcomes, for example by plotting the decomposition results on an annual basis as pathways instead of a step-wise manner to show more detail on trends over time.

Furthermore, we can expand the tool with additional indicators. For example, the tool could expand water heating, by representing the changes in *activity* (e.g. reduced shower time) with the unit 'litres per capita'. Furthermore, the tool could represent the *service* factor as changes in the temperature of water (e.g. less-hot showers). For cooking, The tool could represent the *activity* as 'kg cooked food per capita' so changes in meal type (e.g. short-cooked meals instead of long-cooked meals) could influence this factor. Within the cooking energy service, a behavioural efficiency (as a percentage) could represent the *service* (affected by behavioural shifts such as community dinners or batch cooking). Like the other energy services, the *intensity* represents the changes in technological efficiency as GJ per kg, independent of fuel switches (e.g. more efficient appliances). See S3.6.1 and S3.6.2 for the proposed structure for decomposition tool of residential and transport emissions. By creating more relevant variables in IAMs, it forms a stronger basis for improved behaviour change, and consequently lifestyle change, modelling for future research.

Broader application of the decomposition tool

There are other behavioural change scenarios available in the literature (e.g. Grubler et al. (2018)), but applying the decomposition tool is complex given the differences in model outputs. For example, the behaviour change scenario by van Sluisveld et al. (2016), analysed in this research, shows significant differences with the LED scenario in a comparable study by Grubler et al. (2018) (see S3.5). The former scenario shows lower emission reductions in all sectors compared to Grubler et al. (2018)'s LED scenario. For better model response interpretations, it would be valuable to harmonise and compare the results of this decomposition analysis with other scenarios on behavioural change such as the LED scenario (Grubler et al., 2018). The ASIF* decomposition tool could function as a basis for harmonisation of various scenarios.

Process-based IAMs with a high spatio-technological resolution (Wilson et al., 2017) are considered most suitable to include in a broader application of the ASIF* decomposition tool given their closest representation of consumer behaviour and decision-making. If IAMs could get their output variables to match the tool's variables, the tool could also find application in a broader set of modelling frameworks. Even if not all variables can be matched, an aggregated variable can be used so that two or more ASIF factors are merged (similar to the cooking and water heating energy services in this study).

Scenario developments

From this analysis, we can critically consider how the scenarios' behavioural measures are implemented and make recommendations on how to improve the representation of behaviour changes in IAMs. Firstly, the behaviour change scenarios analysed illustrates the impacts of only a limited selection of behavioural measures possible, but also likely overestimates the adoption of these behaviour changes since it assumes 100% adoption in all regions. The simplified assumptions highlight the need for less-stylised scenario development of behaviour changes.

Secondly, the tool can highlight where, in particular, it is useful to consider influencing factors in future scenarios. For example, the decomposition results show a lack of diversity in transport modes (and consequently modal shifts) for certain regions over time. By explicitly considering infrastructural or accessibility changes (as separate from preferences) that influence behaviour changes, scenario development can be more nuanced. Therefore, modelling of a more representative selection of behaviour measures, cross-cutting lifestyle changes, and their adoption rates per region, can be improved by, for example, accounting for influencing factors (e.g. infrastructure and cultural factors) and taking an intent-oriented approach focusing on different motivations.

Lastly, the scenarios show substantial changes in developing regions, especially with carbon pricing, in response to more reduction opportunities. However, when does a carbon price incentivise sustainable behaviour and consumption patterns, and when does it limit the development of regions? Policies could be differentiated based on fairness principles (Höhne et al., 2013; van den Berg, van Soest, et al., 2019), which could also be in line with behaviour change assumptions. Therefore, future behaviour scenario development should take these equity considerations into account.

3.6. CONCLUSION

The current study presents the ASIF* decomposition analysis as a tool for IAMs to highlight the impact of behaviour on per capita emissions in scenarios. We draw the following conclusions from decomposing scenarios with behaviour changes that show the impacts of the various measures in reducing emissions.

The ASIF* decomposition tool helps to interpret both technological and non-technological model responses. By highlighting the necessary variables and parameters, IAMs can improve the translation of behaviour-related scenario outputs to model parameters. Through this, future scenarios could better incorporate an intent-oriented approach to represent cross-cutting lifestyle changes and influencing factors.

Moreover**,** the decomposition tool can visualise differences in trends in the ASIF* factor changes between developing and developed regions. For example**,** developing regions' energy demand increases substantially in a baseline, notable in *activity* and *structure*/*service* (i.e. consumption changes) due to their relatively strong expected economic growth. The decomposition results could be presented as a change between two points in time, but also as changes over time with multiple time steps or even pathways.

The ASIF* decomposition tool is flexible for use by other modelling frameworks. The ASIF* decomposition initial application is demonstrated in this paper using the IMAGE integrated assessment model. We needed much information for the decomposition analysis in this research. We argue that process-based IAMs with a high spatio-technological resolution are better equipped to provide this information. However, a less aggregated decomposition could be applied for different purposes. It is also possible to decompose factors even further, for better representation of consumption and technology changes.

ACKNOWLEDGEMENTS

The authors of this paper are immensely grateful for the financial support received by the KR Foundation. The research leading to these results has also received funding from the European Union Horizon 2020 Research and Innovation programme under grant agreement n° 730053 (REINVENT).


JOOP
MCMXL

CURRENT LIFESTYLES IN THE CONTEXT OF FUTURE CLIMATE TARGETS: AN ANALYSIS OF LONG-TERM SCENARIOS AND CONSUMER SEGMENTS FOR RESIDENTIAL AND TRANSPORT

Nicole J. van den Berg, Andries F. Hof, Vanessa J. Timmer, Detlef P. van Vuuren

"Current lifestyles in the context of future climate targets: an analysis of long-term scenarios and consumer segments for residential and transport"
Environ. Res. Commun. 4 095003

ABSTRACT

Carbon emissions of individuals strongly depend on their lifestyle, both between and within regions. This means that, in theory, lifestyle changes 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, as a case study. 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.

4.1. INTRODUCTION

Recent studies have shown that behavioural changes could significantly contribute to climate change mitigation (Akenji et al., 2021; Capstick et al., 2020; Costa et al., 2021; Grubler et al., 2018; IPCC, 2018; Ivanova et al., 2020; van Vuuren et al., 2018; Vita et al., 2019). 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 (Grubler et al., 2018; van Sluisveld et al., 2016) are often stylised (Krumm et al., 2022; van den Berg, Hof, et al., 2019). 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; Edelenbosch et al., 2018; McCollum et al., 2017). In addition, few scenario analyses take a consumer perspective and account for regions' heterogeneity across different consumer segments with different lifestyles and behaviours. In analysing these key differences, it is possible to identify real opportunities and barriers in implementing behavioural change options for climate mitigation.

However, consumption-based carbon footprints (CBCFs) 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). Large regional differences are highlighted in recent reports in which potentials for reducing lifestyle carbon footprints in an equitable consumption space are analysed (Akenji et al., 2021; Lettenmeier et al., 2019). 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 to guide climate strategy and actions that take these contextual elements into account. 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 (Froemelt et al., 2018; Gore, 2020; Nielsen et al., 2021; Seriño, 2017). The 10% highest income group's per capita emissions is less than half of the top 1% in the EU (Ivanova & Wood, 2020). Similarly, residential areas strongly affects per capita emissions (Ala-Mantila et al., 2014; Ala-Mantila et al., 2016; Czepkiewicz et al., 2018; Heinonen et al., 2013a, 2013b; Jones & Kammen, 2014; Jones & Kammen, 2011; Minx et al., 2009; Nissinen & Savolainen, 2020; Ottelin et al., 2019). Other demographic differences and transitions such as age and household composition also affect per capita emissions substantially (Koide et al., 2019; Yu et al., 2018). 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 the context of 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 different 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 CBCFs 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 different 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.

4.2. 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.

4.2.1. 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 S4.2). In IMAGE, we calculate energy use for sectors and the fuel mix and calibrate to the IEA energy statistics for the historic period. CO_2 emissions are directly calculated by the fuel-specific emission factors used in emission inventories such as EDGAR and CEDS (for air pollutants, a wider range of factors is used, also based on these sources). The emissions represented are direct emissions in each sector and the indirect emissions for electricity and hydrogen production. The same calculations are applied to the electricity sector (again calibrated to the IEA data to determine the regional CO_2 intensity).

4.2.2. 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 4-1 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).

Table 4-1: 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. 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 floorspace per capita) (van Sluisveld et al., 2016).

4.2.3. ASIF* Decomposition tool

Decomposition analyses provide detailed information on different factors contributing to emissions (Ang et al., 2003; Chen et al., 2021; Edelenbosch et al., 2017). 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 4-1 and further detail in S4.2). 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).

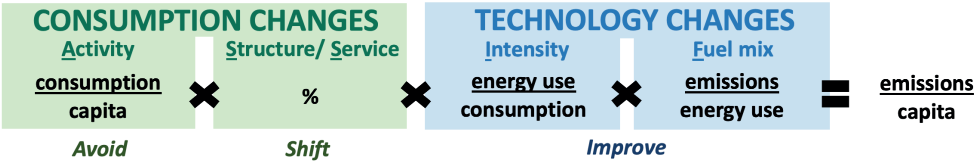


Figure 4-1: ASIF* decomposition tool categorises contributing factors of consumption and technology changes based on the Kaya Identity, with the corresponding ASI behavioural interventions shown in italics (van den Berg et al., 2021)

4.2.4. Japanese household data

This study uses the survey expenditure on Japanese households to assess emissions attributed to specific activities via an environmentally-extended input-output analysis (Koide et al., 2019). These sectoral CO_2 emissions are based on a survey expenditure dataset of anonymous microdata from the 2004 National Survey of Family Income and Expenditure (NSFIE). The dataset contains detailed information of 47,000 households categorised in 15 different consumer segments, distinguished by various sociodemographic characteristics and covering more than three hundred consumption categories. (Heinonen et al., 2020) stated that many differences between different CBSFs reduce their comparability. Examples include varying scopes in types of emissions, unit of analysis, geographical regions, actors of consumption, energy use, imports and durable goods. Therefore, we decided to focus on only one study to compare with IMAGE. We also noted inconsistencies between the household survey data and IMAGE data in the residential sector. This discrepancy can be explained as the survey data was filled with estimates, and the IMAGE model and Japanese survey used different emission factors. Therefore, we adjusted the residential CO_2 emissions to match the IMAGE scenario results for comparability. Note that the IMAGE emission data is consistent with Japan's IEA energy use statistics.

4.3. 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).

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

4.3.1.1. 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 4-2a shows the transport and residential per-capita emissions in 2015 and how these would change by 2050 in mitigation scenarios due to changes in consumer behaviour and technology. 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 keep in mind 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 4-2b 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 4-2a 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 4-2b 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 transport but higher for residential, primarily in appliance use. This 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.

4.3.1.2. 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 4-3). 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 increases. This increase is due to more use of inefficient air conditioners and appliances. At the same time, for Russia, a shift to higher carbon fuels for space heating and water heating causes an emission increase.

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.

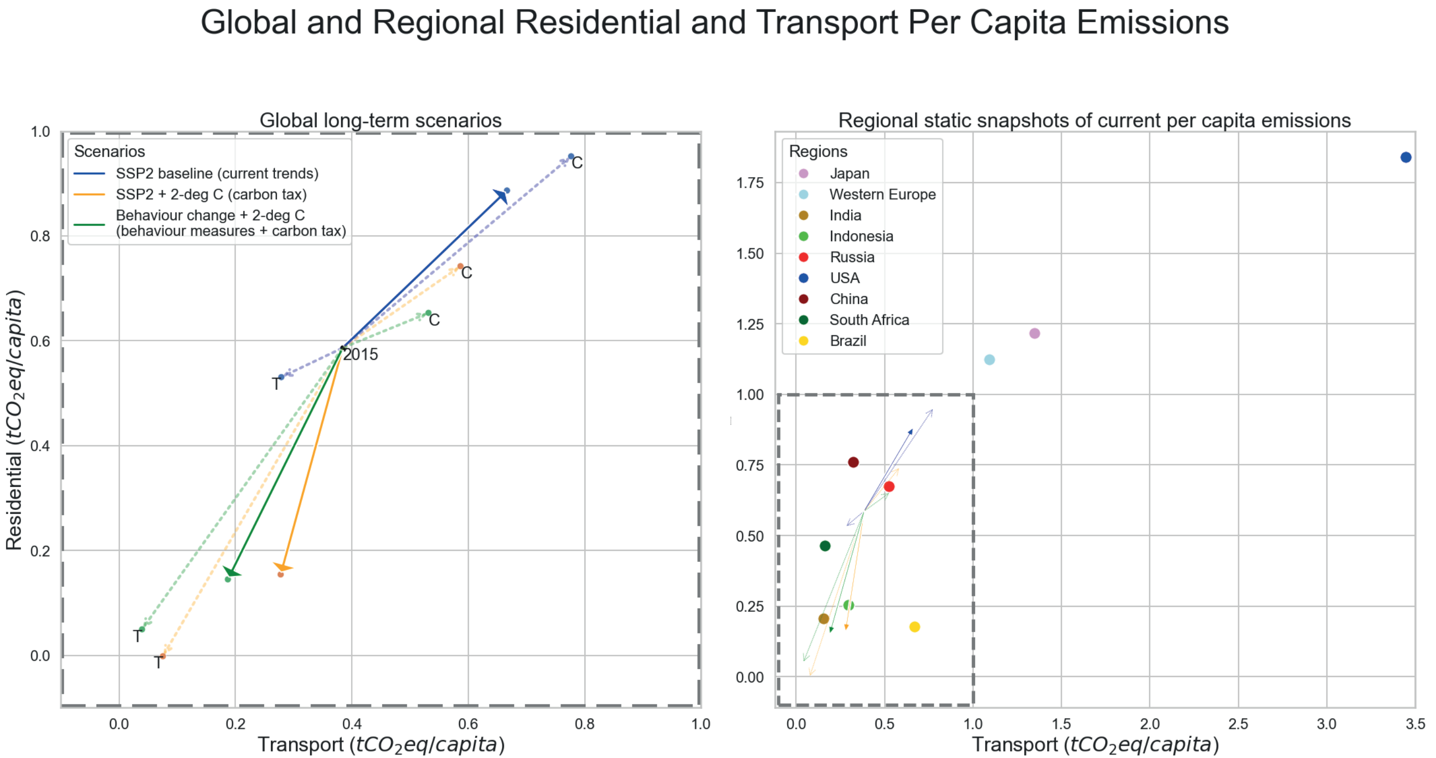


Figure 4-2a) Global long-term scenarios and impacts from different types of changes, C=consumption changes (without technology changes), T=technology changes (without consumption changes); b) Global long-term scenarios (zoomed-out, as shown by the grey, dotted boxes) in context of regional current per-capita emissions.

4

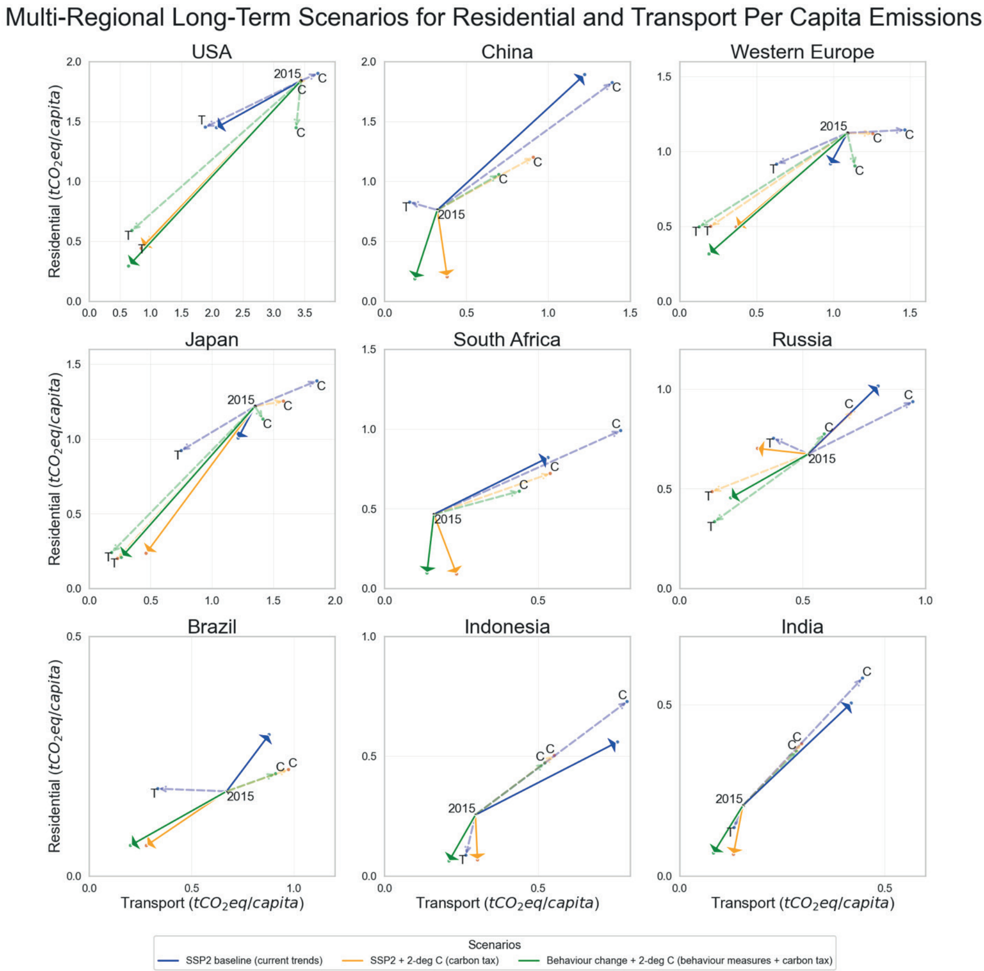


Figure 4-3: Residential and transport per-capita emissions between 2015 and 2050 for a range of regions (i.e. USA, China, Western Europe, Japan, South Africa, Russia, Brazil, Indonesia and India) with various long-term scenarios and impacts from different types of changes, C=consumption changes (without technology changes), T=technology changes (without consumption changes).

4.3.2. 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 4-4a shows the average per-capita emissions in 2015 and 2050 under various scenarios. Figure 4-4b compares these numbers with the variation in per-capita transport and residential emissions of consumers in Japan.

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 4-4b), while others have high emissions in both residential and transport (top-right in Figure 4-4b). 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.

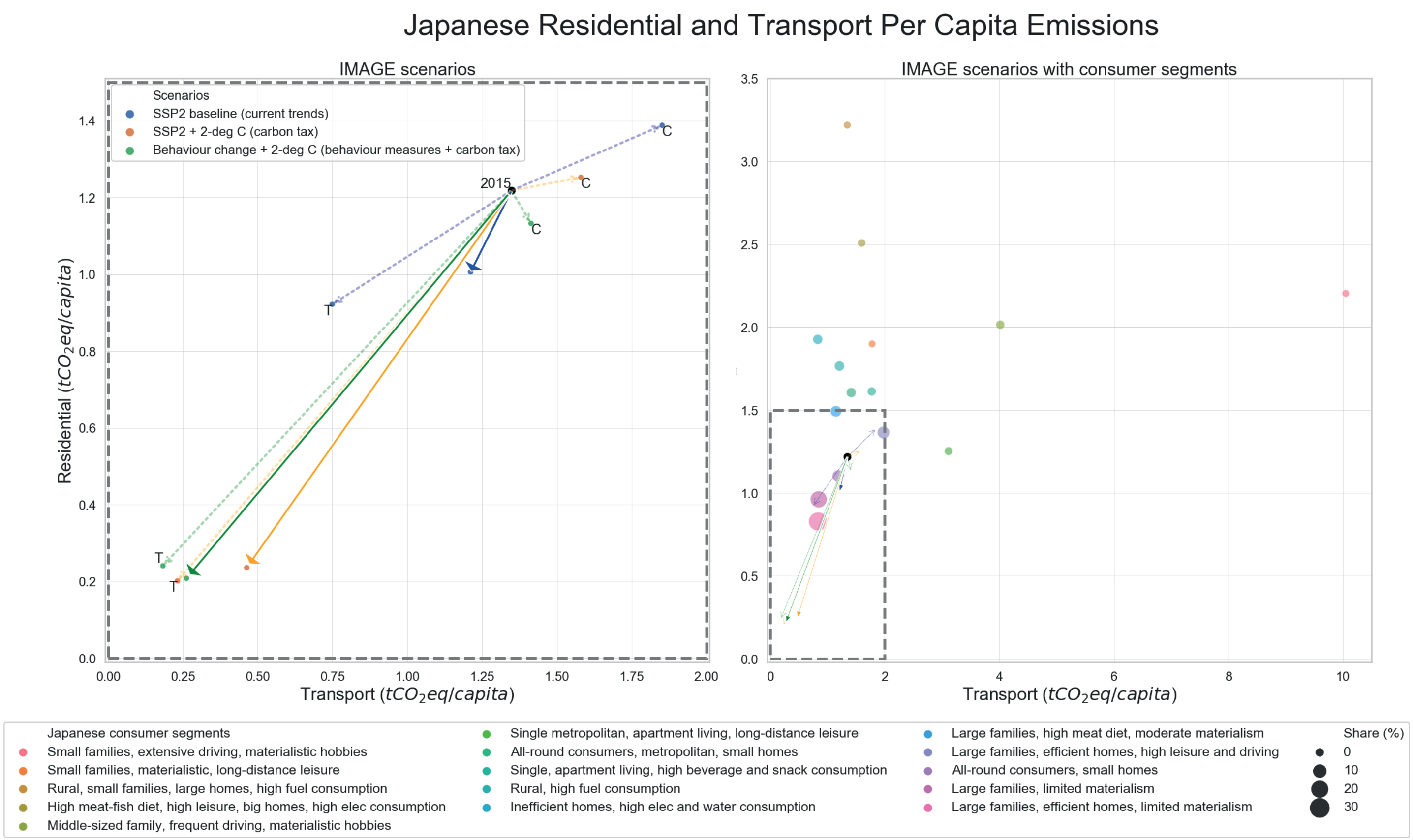


Figure 4-4a) Japanese long-term scenarios and impacts from different types of changes, C=consumption changes (without technology changes), T=technology changes (without consumption changes) for residential and transport; b) Comparison of long-term scenarios (zoomed-out, as shown by the grey, dotted boxes)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

4.4. 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, a comparison of 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 assumption in the Koide et al. (2019) article. Secondly, as the CO_2 emissions were based on household survey data, we had to calibrate the results to the IMAGE scenario emission factors. Thirdly, we focused on transport and residential and did not consider food and consumer goods, which are also highly relevant to lifestyle changes. In IMAGE, the transport and residential sectors are modelled within the IMAGE-TIMER energy model, and food and consumer goods were, therefore, beyond the scope of this research. Applying the decomposition tool to the food sector could allow for a more extensive analysis 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 for 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.

4.5. 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.

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.

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 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.

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.

ACKNOWLEDGEMENTS

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


TILLIE

A DIVERSITY OF SUSTAINABLE LIFESTYLES IN 2050: FUTURE SCENARIO NARRATIVES FOR CLIMATE CHANGE MITIGATION

Nicole J. van den Berg, Lauren Thu, Andries F. Hof, Vanessa J. Timmer, Lewis Akenji, Nicole-Anne Boyer, Detlef P. van Vuuren

ABSTRACT

Sustainable lifestyle changes can play a critical role in climate change mitigation. This paper presents and discusses a set of four comprehensive sustainable scenario narratives, collectively named Sustainable Living in Models, or SLIM, scenario narratives. These narratives describe different alternative pathways in which lifestyle changes may unfold towards 2050 and can support strategic dialogue or form the basis for model-based scenario analysis. The four SLIM scenario narratives emerged from multidisciplinary workshops with lifestyle change experts, scenario analysts and integrated assessment modellers. The narratives diverge along two critical uncertainties: focus on individual versus communal values and the level of access to centralised vs. distributed support for the transition to sustainable lifestyles. These SLIM scenario narratives present a richer understanding of the role that sustainable lifestyles could play in climate change mitigation. The SLIM scenario narratives emphasise the role of society, enablers, lifestyles *and* behaviours in systems change. We also describe the SLIM scenario narratives in terms of contrasting characteristics. The SLIM scenario narratives support a greater understanding of the role of sustainable lifestyles in climate change mitigation while providing less-stylised assumptions for model-based scenarios. The enduring impact of this process is through a longer-term research programme attracting a burgeoning community of practice with modellers and sustainable lifestyle practitioners. Most notably, the narratives can allow for strategic discussion and action for policymakers.

5.1. INTRODUCTION

Achieving the goals of the Paris Climate Agreement requires major changes in demand and supply-side systems (IPCC, 2022). In the past, most scenario studies assessed by IPCC focused on technological changes and energy efficiency improvements to reduce emissions. In the last few years, several studies have shown that lifestyle and behaviour changes may also contribute significantly to climate change mitigation (Akenji et al., 2021; Capstick et al., 2020; Costa et al., 2021; Creutzig et al., 2022; Grubler et al., 2018; Ivanova et al., 2020; van Vuuren et al., 2018; Vita et al., 2019). Based on recent studies, IPCC estimates that with the right policies and infrastructure, demand-side options, including lifestyle and behaviour changes, can result in a 40-70% reduction in greenhouse gas emissions by 2050 (Creutzig et al., 2022). Understanding lifestyle changes within a complex and uncertain future is challenging, and we cannot predict what will happen based on past experiences. However, as a society, we need to make crucial decisions considering urgent societal challenges. Imagined futures or scenarios can support this by stimulating strategic discussions and actions.

Existing studies on lifestyle and behavioural change in the context of climate change can be broadly categorised into qualitative (focusing on the intent of lifestyle change) and quantitative (focusing on the impact of lifestyle changes) studies. Examples of qualitative scenario studies include the SPREAD 2050 scenarios (Mont et al., 2014) and GLAMURS backcasting scenarios (Vita et al., 2019). Quantitative studies typically use some form of modelling to translate narrative assumptions into a description of quantitative changes over time. Socio-technical transitions have been represented in model-based scenarios that include more-nuanced qualitative descriptions of possible societal changes and the dynamics with technological changes (Bauer et al., 2017; O'Neill et al., 2017). A notable example of quantitative studies is the Shared Socio-economic Pathways (SSPs), which describe plausible major global changes leading to various challenges for adaptation and mitigation of climate change (Bauer et al., 2017; O'Neill et al., 2017). These include a brief description of lifestyle changes, but do not focus deeply on the possible contribution to mitigation. Over the past years, many model-based scenario studies have been published, looking specifically into the role of lifestyle change (Grubler et al., 2018; van Sluisveld et al., 2016; van Vuuren et al., 2018). However, these studies typically use rather stylised assumptions and hardly describe the transition pathway and underlying logic for change. Rather, they explore questions like "what if substantial changes in diet are achieved in 2050" without a strong focus on underlying intent or value shifts that enable scenario outcomes (van den Berg, Hof, et al., 2019).

Combining qualitative and quantitative scenario analysis approaches can help to better understand the motivation and drivers of lifestyle changes over time and how these contribute to climate change mitigation (Samadi et al., 2017). However, current qualitative scenario studies are not developed to be modelled in global models as such scenarios do not aim to analyse the *impact* of lifestyle changes but focus on *intent*. Therefore, the translation of these narratives into quantitative scenarios is a challenge.

As such, there is a gap in the literature on comprehensive and engaging narratives that showcase possible pathways towards sustainable lifestyles in combination with estimates of their contributions to climate mitigation. The approach of scaffolding narratives *with* modelled scenarios can inform policymakers, lifestyle change actors, and foresight specialists of possible improvements to climate planning through the synergism of lifestyle motivations and systems change. They can promote the importance and inclusion of lifestyle change and demand drivers in policymaking through memorable, complex, and well-represented narratives.

Based on these considerations, this paper focuses on developing four lifestyle-focused scenario narratives, named the Sustainable Living in Models, or SLIM, scenarios, which provide a story about the intent, motivation, speed and extent of lifestyle change adoption. We define sustainable lifestyles as habits or patterns of behaviour that minimize the use of natural resources and waste generation while maintaining a fair and decent living. These actions are embedded in and facilitated by societal institutions, norms and infrastructures that frame individual choices and practices (Akenji & Chen, 2016). This definition includes aspects of global disparity and environmental integrity. The qualitative sustainable lifestyle scenarios we develop can be used to strategically discuss the possible impact of lifestyle change and explore possible pathways and policies to stimulate such changes. They can also be used as input to subsequent quantitative scenario work and modelling. This research aims to create a comprehensive set of SLIM scenario narratives around lifestyle changes that can be used directly to support strategic dialogue and action and form the basis for model-based scenario analysis.

The SLIM scenario narratives were built through multiple stakeholder engagement sessions involving experts in modelling, scenario planning, transition studies and sustainable lifestyles. The outcomes of these engagements - four SLIM scenario narratives - aim to illustrate various possibilities of sustainable lifestyle changes and systems change working in tandem to mitigate climate change. This aim is based on the larger focal question "How can lifestyle changes accelerate deep climate change mitigation by 2050?". As such, we present a set of detailed and nuanced SLIM scenario narratives for enriching qualitative and quantitative scenario analysis. An example of how these scenarios can be modelled is found in the accompanying paper of van den Berg (in review).

We first describe the method of scenario narrative development. Second, we illustrate the SLIM scenario narratives through summarised figures, tables, and detailed descriptions. Third, we discuss the SLIM scenario narratives and explore overlaps and divergences. Last, we conclude with the main aspects that should be taken from this research.

5.2. METHODOLOGY

We explain the methodology of this research by first describing the scenario narrative development, including the details of the engagement with advisors and policymakers. We then define the criteria set for the narratives that were presented when developing the narratives. Finally, we describe the reference scenario Tech-Innovation from which the SLIM scenario narratives diverge.

5.2.1. Scenario narrative development in the broader research project

There are critical steps in a scenario development process. We start with the focal question, "How can lifestyle changes accelerate deep climate change mitigation by 2050?". Secondly, we identify driving forces (i.e. building blocks). Thirdly, we identify critical uncertainties. Fourthly, we develop plausible scenarios and discuss strategic implications and paths. From these critical steps, we followed the process shown in Figure 5-1. The SLIM scenario narratives were created as part of a transdisciplinary process involving a range of advisors with expertise in qualitative scenario development, sustainable lifestyles and modelling, and policymakers, our key stakeholders. We included people from different disciplines and diverse regions of the world. The advisor and policymaker engagements include expert-attended workshops, document reviews and meetings.

In each stage of the scenario narrative development, we categorise the sub-stages based on intent (i.e. scenario narration) or impact-orientation (i.e. scenario quantification). We focus on the intent-orientation as shown by the substages within the scope of this research article (see solid boxes in Figure 5-1). We show these substages in the context of the larger research project (i.e. including impact-orientation) since they are heavily intertwined. The purple substages represent the engagements, workshops, and smaller group meetings and sent out documents for review from experts ranging from social scientists to quantitative modellers (see more detail of the stakeholder engagements in Table 5-1). We also organised a meeting with policymakers in an early stage of scenario narrative development to incorporate their input and feedback. It should be noted that there are stages beyond these four stages as this scenario narrative development continues (see Discussion in Section 5.5 for further elaboration).

Stage 1: Scenario narrative building blocks based on criteria & gaps in modelling. In this stage, based on identified gaps in scenario development, we defined scenario criteria: relevant, plausible, divergent, clear and challenging (see Section 5.2.2). In the first set of workshops, the criteria were presented and used to create scenario building blocks – elements that could be imagined to be part of different future sustainable lifestyles scenarios – in smaller break-out groups and the large group discussions.

Stage 2: Draft scenario narratives & required inputs for quantification. The building blocks were used to create a framework with diverging uncertainties to build the SLIM scenario narratives. We presented this framework in a second workshop to test it among participants. After receiving buy-in, the divergence framework was used to explore plausible end-state sustainable lifestyle futures and storylines of SLIM scenario narratives. Subsequently, we discussed the framework based on the workshop with policymakers in a 2-hour meeting. In parallel, we defined the inputs required for scenario quantification.

Stage 3: Refine SLIM scenario narratives & finalise quantitative assumptions. We refined the SLIM scenario narratives with various advisors and in a meeting with policymakers. In this refinement, we described various characteristics of each scenario narrative to contrast and compare them with each other. These characteristics crosscut and extracted complex issues from dominant domain drivers. We finalised the quantitative assumptions in food, transport and residential for the four developed lifestyle scenarios. These assumptions include lifestyle changes and behavioural actions for each scenario narrative, the motivations behind them, enabling factors, the extent and speed of transition. The advisors were able to comment, change, add any of the contents of the document, including references to substantiate assumptions. Beyond the scope of this research article, we translated these finalised quantitative assumptions to model inputs for scenarios modelling.

Stage 4: Finalise SLIM scenario narratives & model long-term emission scenarios. Based on the workshop in stage 3, where we refined the narratives, and the stakeholder engagement on quantitative assumptions, we finalised the SLIM scenario narratives. The modelling of long-term emission scenarios is outside the scope of this article; this is done in an accompanying article (van den Berg, in review).

Research outputs: SLIM scenario narratives and emission scenarios. Two research outputs result from this project: 1) divergent qualitative SLIM scenario narratives on possible future lifestyle changes and 2) quantitative long-term emission scenarios of various lifestyle changes (outside the scope of this article; see the complementary article (van den Berg, in review). The SLIM scenario narratives are the main focus of this research article.

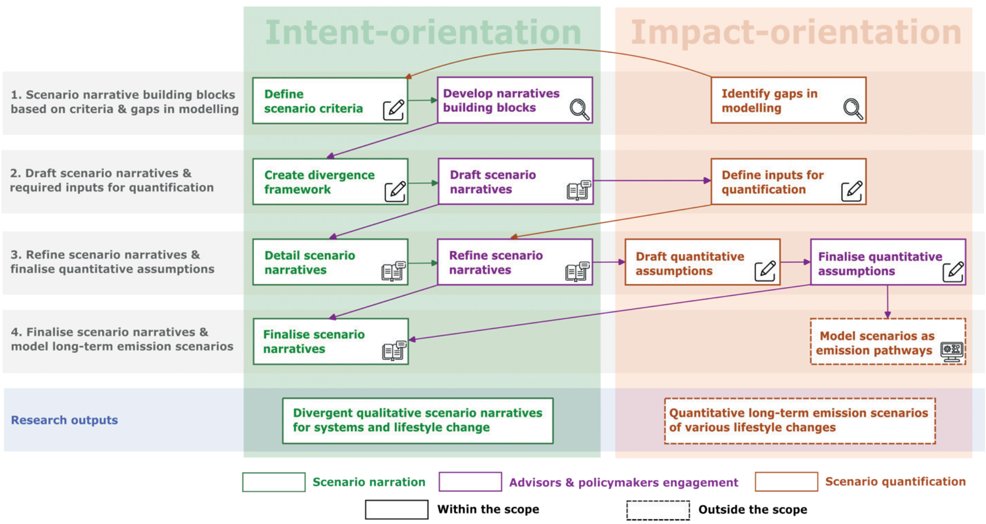


Figure 5-1: Scenario development process (the solid boxes relevant to this article)

Table 5-1: Details of advisors and policymaker engagements

Engagements	Aim	Process	Product	Dates (Duration)	Number of participants
Advisors Workshop series #1	To create building blocks for scenario narrative development from criteria	*plenary*: presentation of scenario planning and criteria *breakout groups*: discussions of how lifestyles could change *plenary*: report back and discussion	Framework of four key uncertainties to build the scenario narratives on	20/01/2021 (3 hours) 04/02/2021 (2 hours)	36 11
Advisors Workshop series #2	To get feedback and detailed input on draft scenario narratives framework	*plenary*: presentation of scenario narratives framework *breakout groups*: brainstorm on details of one of the four scenario narratives using the MIRO interactive platform *plenary*: reporting back and sharing ideas of the different scenario narratives	Detailed scenario narratives with timing and events	30/03/2021 (3 hours) 08/04/2021 (3 hours)	39 13
Meeting with Policymakers	Test detailed scenario narratives in a policy context	*exercise*: on anticipated changes presentation of project and scenario narratives *exercise*: potential policy interventions *exercise*: wild cards, unexpected, but likely events *discussion*: what outcomes are useful for policymakers in connecting lifestyles to climate change?	Refined scenario narratives with policymakers' feedback	01/07/2021 (2 hours)	7
Advisors Workshop #3	Finalise scenario narratives	presentation of scenario narratives and scenario inputs based on: behavioural actions, motivations, contextual factors, adoption rates and speed of transition	Finalised scenario narratives	15/12/2021 (1.5 hours)	20
Advisors feedback Review	Get detailed feedback on scenario inputs assumptions	*adjust, add, remove* details of scenario inputs (as mentioned above).	Finalised scenario input assumptions	12/2021	17

5.2.2. Criteria definition

The criteria we developed for the scenario development is defined below. These were presented and used as a basis throughout the stakeholder engagement and scenario development process.

Each scenario narrative needed to meet the following criteria:

- Relevant: addresses our focal question "How can lifestyles changes accelerate deep climate change mitigation by 2050?" and framed towards key target audiences (notably policymakers).
- Plausible – the changes could happen within the time frame.
- Divergent - the scenario narrative diverges from the others and the reference scenario narrative "Tech-Innovation".
- Clear - memorable and compelling narratives, that can be easily shared and circulated among key target audiences.
- Challenging - challenge conventional thinking about the future, surface assumptions and taboos.

5.2.3. Scenario planning and interpretation

Scenario planning is a method to represent and deal with deep uncertainties for decisionmakers (Volkery & Ribeiro, 2009). This approach can help us imagine a future that we cannot predict and understand the potential implications of our decisions. Scenarios narratives, resulting from scenario planning, are alternative images of our future – the plausible stories of future landscapes. They combine the possible, probable and preferable while keeping us honest about what is uncertain (Schwartz, 2012; Wade, 2012). Scenario planning focuses on what could be possible, not probable or preferable, as it would provide blind spots and cloud our judgements and observations. In scenario planning, we explore not one future but multiple futures that differ across critical uncertainties about how the future could unfold. Therefore, scenario planning is a method for making flexible long-term plans and decisions and identifying innovative responses under conditions of uncertainty and complexity (Amer et al., 2013). There are different approaches for building scenarios: 1) matrix or deductive, 2) inductive or emergent, and 3) default or incremental (Cairns & Wright, 2017; Chermack, 2011; Konno et al., 2014).

At the beginning of this scenario development process, we used the matrix approach to identify the key directions in which these scenarios may evolve. Determining the uncertainties and their descriptions took numerous iterations in the advisor engagements due to associations with both proposed specific uncertainties and the matrix itself (positive or negative) leading to inaccurate perceptions of the SLIM scenario narratives. While the matrix was a valuable tool in developing the scaffolding for the SLIM scenario narratives, it was decided by experts in workshop #3 that the matrix withheld the ability for the SLIM scenario narratives to be seen as a continuum and more fluid in the outcome. Therefore, we shifted the narratives to a continuum with the matrix as a reference. We identified the dominant drivers of lifestyle change and two critical divergences to structure our four separate SLIM scenario narratives.

The SLIM scenario narratives should be interpreted as unique alternatives, as distinct 'worlds' even though elements in these scenarios may be mixed in the real world. Furthermore, we include assumptions of tipping points and discontinuities. These narratives are meant to be provocative and stimulate reflection and dialogue. They challenge our assumptions, stretch our boundaries and shake up our mental models. However, they are not utopian or dystopian, as each has opportunities and challenges. Our SLIM scenario narratives provide an opportunity to reframe stuck debates, build a shared understanding of emerging realities, identify common interest and re-perceive our present. They integrate both facts and imagination: "scenarios deal with two worlds – the world of facts and data, and the world of ideas and perceptions" (Wack, 1985).

These four scenarios follow a research criterion of staying relevant to climate mitigation and policy change; maintaining plausibility concerning timelines, givens, and possibilities; divergence from one another for comparative analysis; clearly described storying for audience retention; challenge both conventional notions of future visions and conventional supply-driver prominence in sustainable climate futuring. The bolstering of qualitative scenarios with quantitative inputs allows for a richer, demonstrable example of lifestyle change impacts and avoids oversimplification common in polarised utopian or dystopian scenarios, or through omission of interconnected, previously unsupported factors of change.

5.2.4. Reference scenario narratives "Tech-Innovation"

We define a reference scenario narrative from which the lifestyle scenarios diverge, based on the commonly-used SSP2 "Middle of the Road" mitigation scenario with climate policies (Bauer et al., 2017). We name our reference scenario "Tech-Innovation" and describe it as "technological innovation is the dominant climate mitigation strategy, and lifestyle changes play a minor role" (see Table 5-2).

Table 5-2: Tech-Innovation reference scenario description

Tech-Innovation	*Tagline:* **net-zero by tech change** Technological innovation is the dominant climate mitigation strategy, and lifestyle changes play a minor role.
Individual agency	Low
Technology support for lifestyle change	Digitally enhanced
Pace of life	Fast pace
Inclusive access / Social equity	Low
Security and safety	Low
Public / Private / Community	Private
Speed of lifestyle transition	Low
Extent of lifestyle change adoption	Low

The tagline "net-zero by tech change" highlights the pathway to emission reductions through technology change for reaching net-zero carbon targets. Some key characteristics are listed in Table 5-2. There is a low individual agency to change lifestyles and behaviours. Furthermore, technology that is digitally enhanced mainly facilitates efficiency. There is a fast pace of life, favouring fast and efficient ways of travelling, eating, living, etc. Overall, there is low inclusivity and social equity regarding lifestyles. Security and safety would be at risk with increasing technology reliance and artificial intelligence. The market would be primarily private. The extent and speed of adopting lifestyle changes, would be largely dependent on motivations and contextual factors, such as infrastructural changes and social changes. In this reference scenario, the transition speed and extent of lifestyle change would be relatively low, and more reliant on technological changes.

5.3. RESULTS: LIFESTYLE SCENARIO NARRATIVES

In this section, we first discuss the framing of the SLIM narratives. Second, we introduce the SLIM scenario narratives and compare them to their placements on uncertainties spectrums. Third, we dive deeper into the scenario narrative details across societal, enabling, lifestyle, and behavioural factors and provide examples of how they could happen. Lastly, we analyse the SLIM scenario narratives from different characteristics.

5.3.1. Scenario Narratives Framing

The SLIM scenario narratives represent alternatives along a continuum. These two continuums of uncertainties formed the basis on which the SLIM scenario narratives were built (see Figure 5-2 and Section 5.3.3):

Individualistic vs collective values. In the literature, the concept of lifestyle change is used in the context of individual behavioural change and a broader societal transition. In the first case, individual decisions and individualistic values lead to changes in climate-relevant behaviour. In the second case, the change is part of a broader societal shift towards a more inclusive society and communal values. As climate mitigation affects both the individual and the community, both values can lead to sustainable outcomes, but in different ways.

Centralised vs distributed access to structural support. We identified this second uncertainty regarding access to structural support, namely centralised or distributed. Societal support is critical to sustainable lifestyles (Mont et al., 2014). The types of lifestyles differ by whether people have centralised access to structural support, such as infrastructure, legislation and government programs, or whether opportunities and access are devolved to local or household levels, such as community-supported education, local food distribution, or private car ownership. The importance of structural support in realising sustainable futures reflects that our ability to live sustainable daily lives is supported or constrained by our context.

5.3.2. Scenario narrative descriptions

By the end of our third workshop, we represented our SLIM scenario narratives as follows: Designed World (sustainable lifestyles by default); Global Commons (an inclusive global governance system); Big Village (community-based sustainable living); and Pocket Lifestyles (peer-to-peer lifestyle platforms). In Table 5-3, we describe the four SLIM scenario narratives compared to the reference Tech-Innovation scenario narrative with their distinct divergences (see 5.3.1) and descriptions. In S5.1, we describe the SLIM scenario narratives in more detail with some examples of specific changes that lead to the end-states. These can give some insights into how these changes could happen. Furthermore, these scenario narratives describe how they can be found in different parts of the world today and in the future.

Table 5-3: Overview of value positions and summary statements regarding each scenario narrative

Reference Scenario **Tech-Innovation**	*Tagline:* **net-zero by tech change** Technological innovation is the dominant climate mitigation strategy, and lifestyle changes play a minor role.
Lifestyle Scenario **Designed World**	*Tagline:* **sustainable lifestyles by default** *Individualistic values / Centralised access to structural support* Governments, corporations and cities leverage existing values and market systems to shape citizen and consumer preferences and practices
Lifestyle Scenario **Global Commons**	*Tagline:* **inclusive global governance system** *Group / Collectivist values / Centralised access to structural support* Universal values shape ways of living, new institutions, and a global governance structure with less emphasis on sovereignty, with a more active Global South participation.
Lifestyle Scenario **Big Village**	*Tagline:* **community-based sustainable living** *Group / Collectivist values / Distributed access to structural support* People band together in communities regionally while remaining networked globally to support bottom-up innovation, shared infrastructures, and belonging.
Lifestyle Scenario **Pocket Lifestyles**	*Tagline:* **peer-to-peer lifestyle platforms** *Individualistic values / Distributed access to structural support* People take it upon themselves to adopt and rapidly spread ambitious sustainable lifestyles, behaviours and practices through digital technology.

As shown in Table 5-3, Designed World and Global Commons would be mostly driven by centralised access to structural support, such as government interventions and global governance structures. In contrast, Big Village and Pocket Lifestyles have distributed access to structural support, relying on bottom-up initiatives and innovations, taking it upon themselves to spread sustainable practices. Designed World and Pocket Lifestyles would be more individualistic in their actions, while Global Commons and Big Village would be more collectivistic. These characteristics of the SLIM scenario narratives are visualised in Figure 5-2. We emphasise that these scenario narratives are possible "what-if" futures to imagine how lifestyles and systems could change under different contexts and should be interpreted as such (see Section 5.2.3 on scenario planning for more details).

Figure 5-2: Visualisation of the lifestyle scenario narratives

5.3.3. Levels of change in lifestyle narrative scenarios

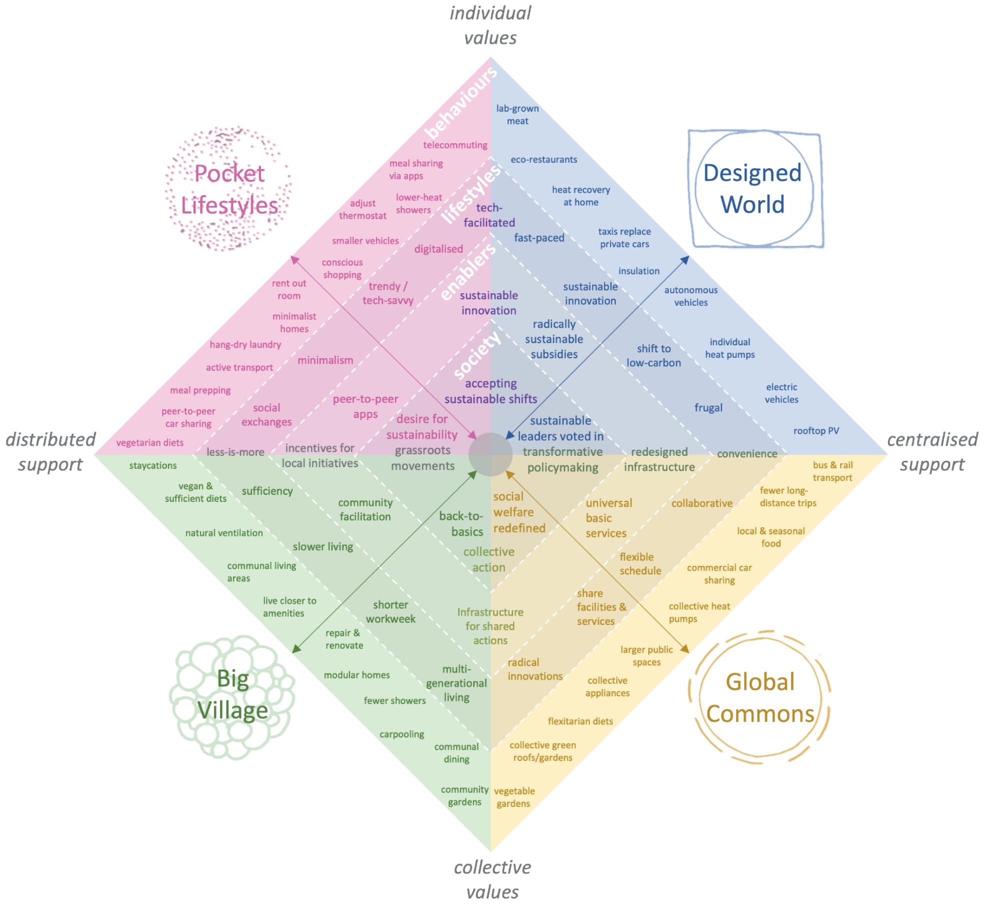


Figure 5-3: Overview of the lifestyle scenario narratives (i.e. Designed World, Global Commons, Big Village and Pocket Lifestyles) varying in type of support (distributed vs. centralised) and values (individualist vs collective) across different characteristics, namely changes in society, enablers, lifestyles and behaviours, diverging from the reference scenario narrative (i.e. Tech-Innovation represented by the circle in the middle). There is no fixed direction or starting point of change.

In Figure 5-3, we illustrate the four SLIM scenario narratives across different levels of change: societal, enabling, lifestyle and behavioural changes. We highlight key lifestyle changes and related behaviours and how societal values and specific enablers for each scenario narrative support these changes. The behaviours and lifestyle descriptions are positioned in relation to the other scenarios. For example, the closer a behaviour and lifestyle description is to another scenario triangle, the closer it resembles that scenario. If a behaviour and lifestyle description share a dividing line with another scenario narrative, this behaviour or lifestyle is consistent with both SLIM scenario narratives. This figure is not exhaustive, as there are many behaviour and lifestyle descriptions that may emerge in and across the SLIM scenario narratives. Through the function of this figure, we attempt to address the limitations of the matrix cited by workshop attendees. It is also important to note that changes in behaviours do not necessarily happen linearly. There is no fixed direction or starting point of change (shown by the multidirectional arrow), but it should rather be interpreted as complex and dynamic. For example, change does not always start at society and influence the other levels but could begin with enablers that influence behaviours that affect society. We describe the SLIM scenario narratives across the different levels of change below.

5.3.3.1. Societal changes

We show how societal changes in the SLIM scenario narratives diverge from Tech-Innovation in the central layer of Figure 5-3. In Designed World, we elect sustainable leaders to make sustainable decisions on our behalf. Where Designed World and Global Commons overlap is in transformative policy-making that supports sustainable lifestyles. Furthermore, we redefine social welfare in Global Commons to accommodate and empower different groups of society. A central element in both Big Village and Global Commons is that collective action becomes a social norm. In Big Village, a shift to back-to-basics is an important societal change, embracing the simplicities in life. A commonality in Big Village and Pocket Lifestyles is the rise of grassroots movements, society taking it upon itself to ask for and adopt changes. Societal changes in Pocket Lifestyles would be based on the desirability of sustainable actions to the masses. An overlapping societal change in Pocket Lifestyles and Designed World is the acceptance of sustainable shifts, respectively facilitated by bottom-up initiatives and enacted by sustainable.

5.3.3.2. Enabling changes

The difference in enablers highlights how lifestyle changes are facilitated across the SLIM scenario narratives (see the 'enablers' layer in Figure 5-3). In Global Commons, universal basic services (e.g. free access to public basic income and public transport) would be provided through a societal redefinition of social welfare. A common enabling factor in Global Commons and Big Village is the development of infrastructure for shared actions, where collective action can be amplified. A vital characteristic of Big Village is community facilitation, engaging the back-to-basics in a strong community setting. For Big Village and Pocket Lifestyles, private incentives for local initiatives would be essential to facilitate grassroots movements. A key enabler in Pocket Lifestyles is the availability of peer-to-peer apps and open-source assets (e.g. tool share sheds, community learning) that makes certain lifestyle changes convenient and accessible. For Pocket Lifestyles and Designed World, the provision of sustainable innovations enables sustainable shifts. In Designed World, because of the strong sustainable leadership, radically sustainable subsidies incentivise sustainable lifestyles. In Designed World and Global Commons, enabling factors overlapping include the redesigning of infrastructure to facilitate lifestyle changes.

5.3.3.3. Lifestyle changes

The types of lifestyle changes (see 'lifestyles' layer in Figure 5-3) differ significantly between the SLIM scenario narratives. Big Village would have a shift to sufficiency, slower living, shorter workweeks and living in multi-generational homes. A lifestyle focused on less-is-more is common in both Big Village and Pocket Lifestyles. For Pocket Lifestyles, social exchanges, minimalism, trendy/tech-savvy changes, and digitalised lifestyles would be amplified by peer-to-peer sharing and a desire to be more sustainable. Technology-related lifestyle changes would be key in both Pocket Lifestyles and Designed World. In Designed World specifically, lifestyles would be fast-paced, focused on sustainable innovations, shifts to low-carbon, and frugality would be central to the motivation behind the changes. Both in Global Commons and Designed World, lifestyle changes would be based on convenience and diverse accessibility to adequate options. The lifestyles central to Global Commons would be collaborative, flexible, related to shared facilities and services, and focused on more-radical innovations. For both Global Commons and Big Village, social cohesion would be key in lifestyle changes.

5.3.3.4. Behavioural changes

The behavioural changes (see the 'behaviours' layer in Figure 5-3 and specific assumptions on motivations, contextual changes, adoption speed and capacity in S5.3) within the dominant domains of transport, residential, and food are influenced by the lifestyle changes cross-cutting the domains and taking into account the complexity of various lifestyles (discussed above).

In Pocket Lifestyles, the food-related behavioural actions vary from shifts to vegetarian diets (based on trends) to meal sharing and prepping (facilitated by apps and digital lifestyles). Residential-related actions include adjusting thermostats, renting out rooms, living in minimalist homes and hang-drying laundry (amplified by trends and social exchanges). In transport, behavioural actions consist of peer-to-peer car sharing (facilitated by apps and digital lifestyles), smaller vehicles (based on minimalism), active transport (e.g. cycling and walking become trendy) and telecommuting (expanded by tech-savvy digital lifestyles).

For Designed World, the behavioural actions in transport include replacing personal cars with taxi use (matching fast-paced lifestyles) and autonomous electric vehicles (shifting to low-carbon and adopting sustainable innovations). Residential behavioural actions include heat recovery (e.g. shower heat recovery), heat pumps, insulation and rooftop PV motivated by frugal lifestyles to save money n energy use. Food-related behavioural actions include lab-grown meat and eco-restaurants, facilitated by subsidies and sustainable innovation provisions.

In Global Commons, behavioural actions related to food include vegetable gardening, flexitarian diets, and local and seasonal produce supported by flexible lifestyles. In passenger transport, commercial car sharing (influenced by the shared facilities), fewer long-distance trips and more bus & rail transport (matching the flexible lifestyles). For residential behavioural actions, shared gardens, appliances, and heat pumps would be collectively adopted through lifestyles focused on collaboration, shared facilities and services, and radical innovation.

In Big Village, transport-related behavioural actions include staycations, living closer to amenities and carpooling. For the residential sector, communal living areas, modular homes, repair & renovation, community gardens and natural ventilation would be vital. For behaviours related to food, the adoption of vegan & sufficient diets and communal dining is prominent. These behaviours would all be heavily motivated by slower living, a shorter workweek, social cohesion, multi-generational homes and sufficient lifestyles.

5.3.4. Comparison of Scenario Narrative Characteristics

Table 5-4: Comparison of scenario narrative characteristics

Scenario narratives Characteristics	**Tech-Innovation**	**Designed World**	**Global Commons**	**Big Village**	**Pocket Lifestyles**
Individual agency	Low	Low	Medium	High	High
Technology support for lifestyle change	Digitally enhanced	Digitally enhanced	Digital, low-tech	Low-tech	Digitally enhanced
Pace of life	Fast pace	Fast pace	Medium pace	Slower pace	Fast pace
Inclusive access / Social equity	Low	Medium	High	Medium	Low
Security and safety	Low	High	High	Medium	Medium
Public / Private / Community	Private	Public-private with city	More public	Community public	Market / Private

The complexity of the developed SLIM scenario narratives can be unravelled by comparing their main characteristics regarding individual agency, technological support, the pace of life, social equity, security, and the relationships between public, private, and community enterprises (see Table 5-4).

We have included the Tech-Innovation scenario narrative in Table 5-4 as a reference point (see description in Section 5.2.3 of the Methodology). Outcomes from our SLIM scenario narratives are based on expected trends from now until 2050, such as population increase and generational shifts. The resulting lifestyle changes discussed below may overlap or have similarities, differ slightly, or stand-alone and far from other scenario narrative outcomes. The comparisons of our SLIM scenario narratives in this fashion allow a deeper engagement with the possibilities of these stories, explore strategic implications, and explore which directions may be most favourable in climate change mitigation. For a further overview of scenario narrative descriptions, refer to S5.1.

5.3.4.1. Individual Agency

Individual agency addresses the level of self-fulfilment or self-direction that one may have access to in each of our SLIM scenario narratives. Whether a scenario narrative has a lower or higher level of individual agency does not necessarily align with utopic or dystopic trajectories, as lower levels of agency may mean more government subsidies and support. In contrast, higher levels of agency may leave individuals without common care assistance and infrastructural support for sustainable living.

Both Big Village and Pocket Lifestyles operate with high levels of individual agency as both SLIM scenario narratives rely heavily on community support structures (High, see Table 5-4). With growing advancements in open-source software and technological ubiquity, community in Pocket Lifestyles is built through digital platforms and exists outside of governance. Big Village emerges from a contraction into or revival of simple living and is focused on face-to-face interactions and hyperlocal government formation. Food sufficiency becomes a cultural value, and both Big Village and Pocket Lifestyles address sustainable farming. Big Village takes the approach of community gardens, with knowledge being passed on across generations within a community of how to grow vegetables and maintain food sources. In contrast, Pocket Lifestyles passes on knowledge of sustainably grown, packaged, and shipped food through peer-to-peer apps, giving one another the agency to make informed decisions (see Figure 5-3). Big Village's focus on ground-level community building allows individuals to bring suggestions forward and have them acted upon quickly. Peer-led education in repairs, renovations, and sustainable innovations leads to high feelings of agency. Pocket Lifestyles educates globally through peer-to-peer applications, allowing a larger group of people in different parts of the world to share knowledge and giving the app users the agency to act or purchase sustainably.

As Pocket Lifestyles gives options for navigating sustainable consumer and lifestyle choices through peer-to-peer learning, Designed World restricts unsustainable options and increases sustainable options through government legislation, choice editing and carbon quotas, and thus has less individual agency (Low, see Table 5-4). The ubiquity of restrictions in Designed World gives individuals less agency

in food and transport yet eases the transition to sustainable lifestyles, resulting in higher and faster adoption rates across populations. While individuals in Pocket Lifestyles and Big Village create groups and assemblies to enable sustainable food practices, people in Designed World only have access to sustainably produced food due to massive shifts in carbon legislation. Significant infrastructure changes, including EV taxi hubs and net-zero buildings, mean individuals act sustainably by default.
In Global Commons, a scenario narrative with a medium level of individual agency (Medium, see Table 5-4), infrastructure change is similar in scale to Designed World but allows options for individual choice. Citizens would be inclined to rent and share further through electric shuttle buses, carpooling, and appliance rentals. Governments provide subsidies and opportunities for sustainable lifestyles, and values shift towards human-centred daily actions. Regarding food, Global Commons is close to Big Village but on a larger scale. Because of the shift towards planetary care, Global Commons citizens use their agency to move further towards flexitarian diets, eating meat infrequently or on special occasions. This change in values moves the meat industry towards sufficient, vernacular farming over excessive industrial production. Governments do not need to intervene with legislation in Global Commons. In Designed World, a meat tax is introduced before the cultural adoption of flexitarian or vegetarian diets (see 'behaviours' in Figure 5-3). In Big Village, meat production and meat-heavy diets would vary by community groups. Yet, in Pocket Lifestyles, the meat industry would continue to operate in response to market trends while individuals make their own dietary choices.

5.3.4.2. Technological support

Technological support refers to the level of digital and innovation involvement a scenario narrative requires for its means of sustainability. Designed World and Pocket Lifestyles would both be highly supported by technology (digitally-enhanced, see Table 5-4). In Designed World, apps evolve to maintain many day-to-day services including gig-based employment, food transportation, communication, and EV car sharing or taxis. Technology is built into infrastructure; all new buildings would be built to net-zero efficiency standards and retrofitting older buildings to meet the same standards becomes required. Heavy subsidies exist for net-zero retrofitting and sustainable innovative practices. Massive clean energy infrastructure projects would be built, and energy would move to solar, wind, geothermal, or hydropower. Energy and carbon usage is measured and controlled digitally by government offices, and everyone is responsible for reporting their yearly carbon quotas. This process would become synonymous with doing annual taxes. The digital technology industry would become the biggest workforce.

In Pocket Lifestyles, governments would be reactive and address sustainable legislation primarily in response to citizen protests. Technological infrastructure would continue to grow without sustainability as a forethought, but individuals harness innovations and use technology to promote sustainable lifestyles. Social media apps would reach further and allow bigger audiences to take part. Peer-to-peer online influence would seep into daily life. Individuals use open-source plans to build carbon-friendly tiny homes, DIY solar panels, and family-sufficient food gardens (see behaviours in Figure 5-3). Crowdfunding and start-ups would contribute to a large sustainable technology movement. The growing rate of technological access in the Global South would give rise to further technological advancements and innovations. Bridges would be formed online between Global North and Global South communities, and cultural 'eco-hacks' would be shared and implemented globally.

Global Commons falls somewhere between Pocket Lifestyles and Designed World regarding technological support, as both digital and non-digital lifestyles would be supported (digital, low-tech, see Table 5-4). The value shift in Global Commons would allow for digitalisation to support sustainable development and lifestyles while addressing that many communities and cultures do not require technology to live sustainably. This flexibility means that while governments support sustainable infrastructure, like Designed World, communities would have more direct input towards what, where, and how infrastructure is built. The strength of community is like Pocket Lifestyles, and sharing through open-source platforms would be common. In smaller communities where sufficiency would be met through traditional means, communities could benefit from supportive technologies instead of infrastructural technologies, much like Big Village.

In Big Village, large technology companies would cease to exist, and digital innovation would slow (low-tech, see Table 5-4). There is less budget for significant technological investments as governments and companies dissolve. This is a notable difference between Big Village and Global Commons, Pocket Lifestyles, and Designed World, as sustainability would no longer be funded by larger organisations in Big Village. Sustainability instead would be maintained through shared generational knowledge. Supportive technologies would operate in analogue systems, such as Arduino-powered Garden monitors, solar-powered generators, and self-made batteries. Energy systems are also built through hands-on community involvement, depending on location. Communities based near waterways would build small-scale hydroelectric generators, while those who live near high wind zones build windmills.

5.3.4.3. Pace of life

The pace of life illustrates the type of lifestyles and motivations behind them in each scenario narrative. The balance of work and life in Global Commons (medium pace, see Table 5-4) is partly achieved by a move to a four-day workweek. The importance of well-being and cultural community values from the Global South pushes governments to consider family and community time an essential need. Subsidies support lower-income families, and 'hustle culture' diminishes. These changes would lead to slower lifestyles, a switch to more seasonal foods, and a further acceptance of bus and rail transportation. Like in Big Village, family and community would be highly regarded.

In Big Village, work and life would have crossovers, as many people would live in communities where daily tasks become part of their work (slower pace, see Table 5-4). Self-sufficient practices and less automation would mean hobbies such as gardening and cycling contribute to local production. Personal and leisure time would be valued in Big Village and Global Commons. Vacations are typical in both, but in Big Village, within a short distance of their homes to reduce carbon consumption. Air travel would still be common in Global Commons, although less frequent, usually reduced to at most once per year and long-term (i.e. more than three weeks).

In Designed World and Pocket Lifestyles, faster lifestyles would be typical (fast pace, see Table 5-4), and work would be a priority to individuals. Governments and companies in Designed World would make sustainable choices easy for individuals. Many activities that once took up daily time, such as cooking, housework, and driving, would be automated or outsourced sustainably, meaning more time for work. People would be highly taxed for this level of automated sustainability, and many people supplement their income with gig work. When people would take time off, this level of automation integration would allow for stress-free days off. People would take fewer vacations far away, as flights weigh heavily on carbon quotas. Individuals could 'save' and 'roll over' their carbon quotas if a flight vacation is desired. However, most people would be happy to stay close to home, rent an electric vehicle instead of flying, and use their carbon quotas more frequently on less-carbon-heavy activities.

The work level in Pocket Lifestyles would be similar to Designed World, and many people would work multiple jobs. Paid sponsorship on social media would have become more common among influencers and non-influencers. New sustainable product lines would be lucrative, and crowdsourcing expected, much like the way of Global Commons' technological advancements. Unlike Designed World, there would be no flight restrictions, but some individuals would not want to take part in carbon-heavy vacationing, so they would also choose to stay closer to home.

5.3.4.4. Social equity

Social equity varies in these SLIM scenario narratives, but several equity levels are interwoven with other aspects of social life. While universal social equity is desired across all SLIM scenario narratives, how it is defined and distributed differs significantly.

In Pocket Lifestyles, inclusion in sustainable communities is limited to those with access to social sharing platforms. Technology may be ubiquitous, but different governments and countries limit specific platforms. Thus, Pocket Lifestyles could be less socially equitable at a global level (low, see Table 5-4). There are few subsidies from the government for online sustainability communities, and entrepreneurs self-finance their businesses and ideas. Some apps are directed towards social inequities, such as food waste distribution apps, but lack of access restricts many groups. Those who have access to these online sustainability social groups feel empowered. Many take their knowledge into their social groups by contributing to initiatives, such as tiny house building for lower-income individuals. This work often trickles into social groups secondary to online social groups, and enterprises of mutual aid and empowerment rise. The economic benefit of online entrepreneurship allows higher-income individuals to contribute monetarily to causes. Those explicitly funded by sustainable endeavours may re-invest their money into furthering other sustainable, community-focused projects.

The equities in Pocket Lifestyles, when accessible, are like those in Big Village. Working towards sustainable self-sufficiency drives Big Village to knowledge sharing. Still, it is aided in achieving further equity than Pocket Lifestyles by having close contact with those in their communities (medium, see Table 5-4). Individual considerations are often considered and allow communities to find appropriate work for people. Trading would become usual, contributing to sustainable practices and sharing wealth locally. Also, trading would allow individuals to function in communities without monetary expectations. This may also be a hindrance in Big Village, as prejudice may prevent some people from their preferred jobs. These close communities may also have population caps due to housing and food sufficiency, and lack of government involvement may lead to communities accepting newcomers through non-equitable criteria.

Government support aids for social equity in Designed World (medium, see Table 5-4), focused on taxes and subsidies to support a vast portion of the population. Monetary relief creates more equity for citizens to participate in sustainable living. Traditional subsidies, such as for co-living and EV vehicles, encourage individuals to strive for similar goals, such as living closer to work while operating sustainably by default. The value for efficiency may increase mental health crises and push divides between classes, regardless of subsidies. Those regions outside Global North urban centres struggle to adapt to technology-rich sustainable developments.

Global Commons is more equitable globally, as the inclusion and amplification of the Global South allow a different cast of stakeholders to represent historically underrepresented groups (high, see Table 5-4). Values centred around holistic well-being mean that some subsidies and programs are implemented beyond basic income, with universal basic services, and people feel bonded over protecting the planet and the environment. National interdependence has a positive impact on cultural interactions. More women and gender non-conforming people take leadership roles, and indigenous leadership and land stewardship are respected. Implementation of taxes and levies may increase exponentially in this scenario narrative. For example, governments would implement frequent flyer levies for those who travel and expend fossil fuels. These levies may feel restrictive to some, as the increased global diaspora of Global Commons means people visiting dispersed family members may be financially penalised for travelling by plane more than annually.

5.3.4.5. Security and Safety

Global Commons and Designed World have good security and safety (High, Table 5-4) as governments continue to create and uphold security legislation. In Designed World, technology and cyber laws become vital in maintaining order. As technological adoption and location software increase, crime decreases. Security would become a shared cause in Global Commons due to national interdependence. Measures are enacted to protect people and the environment online and offline. Big Village and Pocket Lifestyles would have less security than Global Commons and Designed World (Medium, see Table 5-4) due to how governments relate to each scenario narrative. In Big Village, governments are smaller and hyperlocal. While community members may have technological knowledge, smaller teams mean internet security is often easier to hack and assumed to be insecure. Offline security issues would stem from guerrilla defence groups. While not commonly required, protection for groups in Big Village, if not self-provided, would be bought through these mercenary groups. In Pocket Lifestyles, governments would have baseline involvement in security legislation, but the rise in technological literacy means hacking would become common. There are difficulties in discerning legitimate companies online, and sustainable accounts and products are often subject to cyber-attacks due to their popularity. It is difficult for governments to intervene, as open-source online communities resist government involvement.

5.3.4.6. Public/Private/Community

Our SLIM scenario narratives differ in their relationship to public/private/community relations. In Designed World, municipalities have relationships with companies that provide sustainable services (Public/Private with City, see Table 5-4). These relationships are public, while the internal dealings of the companies remain private. National interdependence in Global Commons means there would be openness between governments, and between people and their governments (More Public, see Table 5-4). People are more actively involved in politics, and spending is always made public. Big Village is also public by default. Local governments mean public decision-making is key (Community Public, see Table 5-4). Democracy is strong, and there is an open contribution to all decisions. Democratic groups beyond government are normal, extending to community gardens and repair shops. Openness is part of a culture of sharing. In Pocket Lifestyles, trends push the market, and sustainable capital remains market private (Market/Private, see Table 5-4). Government acts separately from sustainable companies.

5.3.5. Adoption extent and transition speed for translation to quantitative assumptions

We hypothesise how fast and how many would change their behaviours and lifestyles in each scenario so we can translate the SLIM scenario narratives to quantitative assumptions for modelling. Note that the extent does not refer to the impact on emissions but rather the number of people who would adopt particular changes. The extent and speed to adopt changes vary among the scenarios (see specific examples for quantitative assumptions in dominant domains of passenger transport, residential and food in S5.3). For example, Pocket Lifestyles' infrastructure shift is mainly unchanged from the Tech-Innovation scenario narrative. Instead, individuals band together to create change within their communities via technology and community platforms and support that already exist. These support structures allow for low-barrier uptake resulting in quick adoption rates. However, this uptake of sustainable behaviours plateaus early without the enabling conditions of greater infrastructural support (Low-medium, see Table 5-5). The types of behavioural changes include but are not limited to, telecommuting, cycling and walking, adjusting thermostats, taking lower-heat showers, and meal prepping (see S5.3 for details on the extent and speed of transition of the quantitative assumptions). As governments and businesses in this scenario are reactionary to demand drivers instead of initiating demand drivers, change is slow and unable to reach high levels of transformation by 2050.

Table 5-5: Quantitative characteristics for scenario modelling

Scenario narratives Characteristics	**Tech-Innovation**	**Designed World**	**Global Commons**	**Big Village**	**Pocket Lifestyles**
Speed of lifestyle transition	Low	Low-medium	Medium	Medium-fast	Fast
Extent of lifestyle change adoption	Low	High	Medium-high	Low-medium	Low-medium

In Designed World, market and governance systems remain the same as the reference scenario Tech-Innovation, but these systems focus on driving demand changes and sustainable systems. Restrictions via laws and levies may elicit disapproval and pushback initially from some members of the public, and construction of infrastructure takes time. However, adoption rates would be high when solutions become accessible and convenient via improved subsidies, more options, and better designs (High, see Table 5-5). The types of behavioural changes include, among others, electric vehicles, insulation, heat pumps and lab-grown meats. Eventually, as new sustainable lifestyles become normalised, the public adjusts, and the space for transformative depth increases. Paradoxically, as change is led from within existing social infrastructures, massive transformational shifts would be bound to the governing systems' limits.

With a lack of centralised support structures in Big Village, communities would be required to find ways to support themselves quickly, resulting in a quicker transition to community-centred and self-sufficient sustainable lifestyles. The capacity of transformational action is restrained to smaller, localised groups with vernacular expertise (low-medium, see Table 5-5). In addition, the societal shift to 'less-is-more' social norms leads to less technologically complex sustainable solutions and vice versa. These adopted lifestyles result in behavioural changes such as choosing staycations, shorter workweeks, natural ventilation, multi-generational homes and vegan diets (see S5.3 for details on the extent and speed of transition).

Global Commons can maintain a steady pace towards faster transition with relatively high capacity (Medium-high, see Table 5-5). The cooperation between both individuals and governments and the interdependence of nations leads to an advancement in lifestyle actions at a medium-high pace. The infrastructural shift towards interdependent states takes time initially. It leads to a slow transition start but quickly moves to a rapid rate of transition once interdependent global governance is established. These lifestyles lead to changes in behaviour, for example, taking public transit, fewer long-distance trips, collective heat pumps and flexitarian diets (see S5.3 for details on the extent and speed of transition). Universal basic services support individuals and communities, and the depth of sustainable actions increases as interwoven social complexities are cared for.

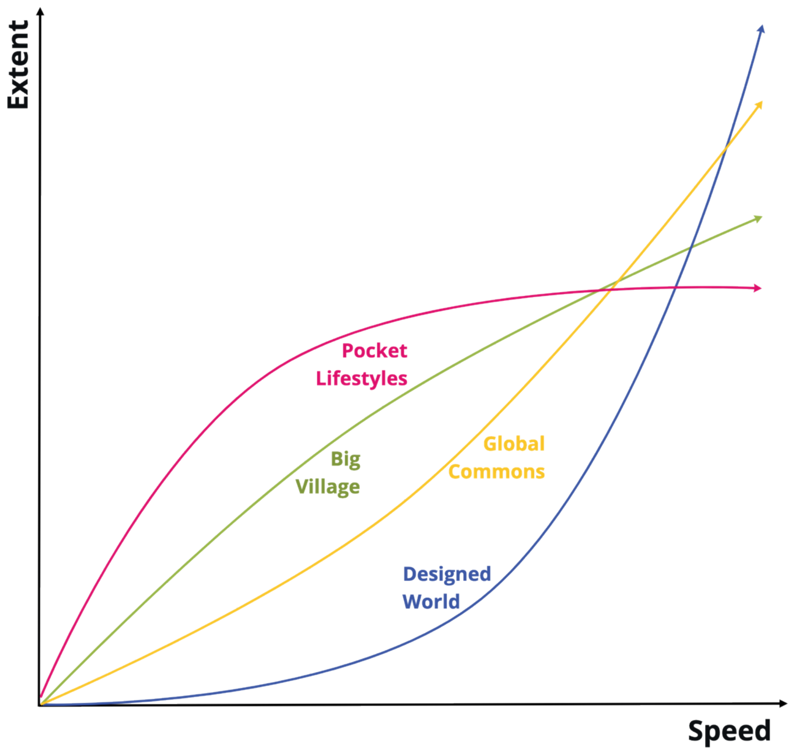


Figure 5-4: Conceptual visualisation of speed vs extent of the lifestyle scenario narratives

5.4. DISCUSSION

Some limitations of this work lie in qualitative work being subjective. These SLIM scenario narratives were constructed through expert workshops and deeply considered and careful scenario planning methods. Yet, they might not fully align with the expectations of other professionals or policymakers. There are many opportunities for future work building on these SLIM scenario narratives and the scenario development process.

Participatory scenario development. We included a range of advisors from different disciplines and regions to help co-create these SLIM scenario narratives. This stimulated great discussions and challenged biases about lifestyle changes for more representative futures. Even though we included several Global South representatives as advisors or policymakers, a specific Global South focus could improve our SLIM scenario narratives in future work. Due to their continued development, Global South leaders are important to climate change mitigation. Furthermore, we do not include business representatives in the scenario development process, as it was out of the scope of this research. However, the business perspective is valuable, especially as they play a vital role as enablers for lifestyle changes. Therefore, the SLIM scenario narratives could be further refined for future work with a range of business representatives.

The next stages of the scenario development process. As we show in this paper, our methods thus far have yielded valuable insights and early implications that validate much of what we know from sustainable lifestyle research. However, we continue to look forward to furthering insights as we complete the last stage in the scenario methodology—the strategic implications and options step—where we evaluate the best portfolio of strategic implications, actions and policies for each scenario and synthesis the most robust options that work across all scenarios. While we do this in part in this paper, this is also the step where we “wind-tunnel” or test existing options and politics to see their efficacy and resilience over time and under different contexts. Further work into why and how these scenarios unfold, the “scenario logics”, could also reveal critical systems dynamics and high-impact places to intervene while providing an important feedback loop into the climate model assumptions themselves. As best practices in the scenario literature show, good scenario thinking is not just a one-off effort but an iterative one that improves as we further understand, interrogate and evolve our assumptions and insights. Indeed, the enduring impact of this process is that it aspires to be a longer-term research program that attracts a burgeoning community of practice (COP) of modellers, sustainable lifestyle practitioners, and policymakers.

Process of describing SLIM scenario narratives and quantifying scenarios. The SLIM scenario narratives built on quantitative modelling and qualitative research could be applied to specific regions to diversify individual and community motivations. They may lead to new, vernacular, cross-disciplinary, and sustainable actions. Although this work draws on multiple disciplines, many disciplines have yet to be included in the scenario development, for example, health sciences that could inform us about lifestyle changes for health-related changes. This expansion of disciplinary input could be further explored in future work. Exploration of differentiating value evolution may result in new variations of adoption rates and climate mitigation solutions. Those interested in using models to support sustainable scenario building or viewing these SLIM scenario narratives' quantitative outputs can look to this paper's quantitative counterpart (van den Berg, in review). When scenario planning is supported by integrated assessment modelling, SLIM scenario narratives give compelling outlooks to policies that allow for broader engagement from various climate community stakeholders.

How users should interpret the scenarios. We will likely find not one but more of these scenarios unfolding in combination and different parts of the world. However, to better understand these SLIM scenario narratives, scenario planning guides us to identify alternative structurally distinct scenarios and contrast them with each other to identify drivers of change. After quantifying the scenarios (van den Berg, in review), we identify their impacts on climate change mitigation. By exploring these distinct scenarios, stakeholders and decision-makers (e.g., modelling community, policymakers, business and community leaders) challenge their assumptions about future lifestyles, analyse what is possible, remain honest about what is uncertain, and identify robust strategies that are adaptive to different plausible pathways. Further research opportunities in this realm include a more extensive inclusion of Global South stakeholders and initiatives.

Equity considerations. Even though the Global South representation is limited, equity was central in developing the SLIM scenario narratives. Firstly, we explicitly cover a section on social equity in comparing characteristics (see Section 5.3.4.4), comparing the social equity between the different scenarios. Secondly, in determining the speed and capacity, we consider differences between Global North and Global South, considering the responsibility, equality, and capability equity principles. However, these assumptions are still very aggregated and limited to only regional differences. In the modelling of lifestyle scenarios (van den Berg, in review), we also accounted for income differences within regions, but this was limited in these scenario narratives.

The combination of systems change and lifestyle change. Systems change and lifestyle change can be considered two sides of the same coin (Capstick et al., 2020). However, often these are considered separately, leading to 'consumer scapegoatism' (Akenji, 2014), in which the responsibility and burden are placed on consumers to change their lifestyles, while many conditions influencing their behaviours are locked in by their context or out of their control. The multidisciplinary nature of this research allows for an integrated systems approach and furthers the insight that our lifestyles are both influenced by our actions and shaped by our context. It allows us to analyse technology and consumption changes alongside each other and account for the various enabling factors that influence which and how impactful lifestyle changes can be.

Implications for society. Creating nuanced and supported SLIM scenario narratives to imagine sustainable futures is important to fully understand how policies affect both society and the individuals within them. SLIM scenario narratives that position demand drivers as a catalyst for change highlight the importance of individual and community actors and the multitude of sustainable directions that demand drivers can shift towards. Policymakers, modellers, sustainable lifestyles experts, and foresight specialists can find the implications of this work helpful in guiding strategic dialogue and decisions towards global climate change mitigation.

5.5. CONCLUSION

Our research aims to illustrate, via novel SLIM scenario narratives, various possibilities of sustainable lifestyle changes and systems change working in tandem to mitigate climate change. This brings to light details and complexities about different routes to sustainable lifestyles diverging in dominant values and the degree of structured support.

Structural support and value systems shape lifestyle changes in different ways. The SLIM scenario narratives diverge on centralised or distributed access to structural support and individual or collective value systems, highlighting the variation in how lifestyles could change. Some pathways with centralised access to structural support might be less-transformative regarding behavioural changes but made convenient for many people (i.e. Designed World). In contrast, others might include substantial system changes (i.e. Global Commons). Some pathways might have distributed access to structural support that could be driven by bottom-up initiatives through social interactions via peer-to-peer technology and sharing of ideas (i.e. Pocket Lifestyles). In contrast, other pathways are characterised by simpler living in communities and shared activities (i.e. Big Village). Therefore, these narratives highlight that there is not only one single lifestyle change scenario, but different contexts could shape different lifestyle changes.

Behaviours and lifestyles change dynamically in response to enablers and shifts in society. The SLIM scenario narratives showcase that changes at various levels are vital, emphasising the dynamics between behaviours, lifestyles, enablers and society. In the future, lifestyles could change in numerous ways, depending on many factors. Designed World and Pocket Lifestyles shift to sustainable lifestyles through individual actions. In Designed World, these sustainable lifestyles are enabled by, for example, decisions by government, policymakers and city planners. In Pocket Lifestyles, bottom-up initiatives drive the change through peer-to-peer interactions enabled by technology. In Global Commons and Big Village, collective action is central to living sustainably. In Global Commons, sustainable governance facilitates and encourages collective changes. In Big Village, social movements and community support and amplify sustainable living. These contrasting characteristics allow for a holistic discussion of the types of futures that could await us, especially in combination with the emission pathways quantified.

The SLIM scenario narratives highlight various characteristics of *how* and *why* lifestyles can change. The qualitative nature of these narratives highlights, that although lifestyle changes are central to these SLIM scenario narratives, the many factors, such as individual agency, the pace of life, equity, security and safety, technology support, public, private or community surrounding those changes are what make them interesting and dynamic.

Details on the extent and speed of lifestyle changes is vital for scenario modelling. By expanding the food, residential and transport domains into smaller, recognisable characteristics, a scenario narrative can paint a fuller picture of what life may be like in 2050 and beyond. This translates effectively into scenario inputs for quantitative modelling in integrated assessment models.

Through transdisciplinary co-creation, the SLIM scenario narratives are useful to a variety of users. Transdisciplinary scenario planning allowed for the co-creation of useful scenarios narratives for social sciences, modelling and informing policymakers. With these diverse SLIM scenario narratives, we can inform about fuller, more dynamic visions of 1.5°C lifestyles in 2050. Understanding these distinctions enables a fuller dialogue about what futures are possible and that there is no single pathway but many possibilities. These SLIM scenario narratives provide valuable insights that can position lifestyle changes, in the context of systems change, as solutions in climate mitigation.

The SLIM scenario narratives can enable strategic discussion and action for sustainable living. The inclusion of lifestyle changes in scenarios can inform climate negotiations. By approaching this process via scenario planning allows us to explore possible pathways, make our assumptions about futures explicit, and explore to have a more strategic dialogue about what could emerge.

ACKNOWLEDGEMENTS

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


JOOP
MCMXL

(PATH)WAYS TO SUSTAINABLE LIVING: THE IMPACT OF THE SLIM SCENARIOS ON LONG-TERM EMISSIONS

Nicole J. van den Berg, Andries F. Hof, Vanessa J. Timmer, Lewis Akenji, Detlef P. van Vuuren

ABSTRACT

Sustainable lifestyles and behaviour changes can be vital in climate change mitigation. Various disciplines analyse the potential for such changes – but without much interaction. Qualitative studies look into the change process (e.g. social practice theory), while quantitative studies often focus on their impact in stylised cases (e.g. energy modelling). A more holistic approach can provide insightful scenarios with diverse lifestyle changes based on informed narratives for quantifying long-term impacts. This research explores how comprehensive sustainable lifestyle scenarios could contribute to transport and residential emission reductions. By translating and quantifying lifestyle scenario narratives through engagements with advisors and policymakers, we modelled two distinct lifestyle scenarios which differ in their degree of access to structural support. In one scenario, governments, corporations and cities leverage existing values and market systems to shape citizen and consumer preferences and everyday practices. In the other scenario, people adopt ambitious sustainable lifestyle behaviours and practices through peer-to-peer interaction and digital technology. We quantified the scenarios based on motivations, contextual factors, extent, and speed of lifestyle adoptions with regional differentiation. Furthermore, we applied heterogenous adopter groups to determine the model inputs. We present the resulting pathways in per capita emissions and more detailed changes in total emissions via decomposition analyses. We conclude that regional differentiation of the scenario narratives and modelling of intra-regional differences allows accounting for equity in lifestyle changes to a certain extent. Furthermore, new technologies play a more critical role in enabling lifestyle change in a scenario with strong structural support. This reduces transport and residential emissions to a larger degree (about 39% for Global North and 27% for Global South overall in 2050 relative to a baseline following current trends). Thus, lifestyle changes in larger systems change are essential for effective climate change mitigation.

6.1. INTRODUCTION

Sustainable lifestyles and behaviour change have increasingly received attention as important means to mitigate climate change. For example, the IPCC WGIII and UNEP Emissions Gap Report added a specific chapter designated for demand-side mitigation (Capstick et al., 2020; Creutzig et al., 2022). Scenarios significantly contribute to these reports by improving our understanding of how lifestyles could change and the impact of the changes. Scenarios can help decision-makers by contributing to the quantification of lifestyle changes for climate change mitigation or preparing them for heterogeneous future lifestyles. They can also support citizen and stakeholder engagement via participatory approaches. Furthermore, they can communicate and disseminate scenario results for dialogue and collaboration between different communities and disciplines. They provide a holistic framing of the possible transitions for policymaking, allow framing of worldviews associated with sustainable transitions and equip policymakers with variables, objects and relations necessary for exerting influence (Beck & Mahony, 2018; Saujot et al., 2020).

Lifestyle scenarios can be distinguished by their focus on either intent or impact (Gifford et al., 2011). Intent-oriented scenarios focus on the motivations of behaviour and lifestyle change, while impact-orientated scenarios focus on the outcomes of these changes. Qualitative scenario narratives are usually intent-oriented, as they focus on motivations behind behaviour and lifestyle changes in alternative visions about the future (Echegaray, 2021; Green & Vergragt, 2002; Manzini & Jégou, 2003; Mont et al., 2014; Quist et al., 2001; Quist & Leising, 2016; Schmidt-Scheele et al., 2022). For example, they can capture the motivations and influencing factors for lifestyle changes in sustainable lifestyles research (Akenji & Chen, 2016; Mont et al., 2014; Vita et al., 2019).

Quantitative approaches are typically impact-oriented, focusing on the impact of different stylised lifestyles or behaviours on emissions (Costa et al., 2021; Grubler et al., 2018; Ivanova et al., 2020; van Sluisveld et al., 2016; van Vuuren et al., 2018; Vita et al., 2019). van Sluisveld et al. (2016) and van Vuuren et al. (2018) looked at the impact of healthy diets, reduced floor space per capita, and a switch to public transit. Grubler et al. (2018) modelled a Low Energy Demand (LED) scenario based on five drivers (i.e. granularity, decentralised service provision, use value from services, digitalisation of daily life and rapid transformation). In another recent study, Hanmer et al. (2022) developed lifestyle change scenarios by downscaling from the country level and differentiating based on various household archetypes. Other models have also been used to quantify behaviour changes in scenarios. For example, Vita et al. (2019) quantified backcasting scenarios using an Environmentally-Extended Multi-Regional Input-Output (EE-MRIO) model. All these quantitative studies showed the potential of behaviour changes for reducing emissions.

To date, there has been little effort to combine the intent- and oriented perspectives. Intent-oriented scenario studies generally do not provide any information on the effectiveness of lifestyle changes in reducing emissions. In contrast, impact-oriented scenarios mainly adopt stylised assumptions and hardly describe the transition pathway or underlying logic for change. This gap can be addressed by combining specific scenario narratives (e.g. representing motivations of the lifestyle changes) *and* model-based scenarios (the emission reductions of the lifestyle changes).

The quantified effects of more elaborated (arguably more realistic) lifestyle change scenarios could be helpful for policymakers, modellers, and experts on sustainable lifestyles in general. For policymakers, these quantified scenarios can highlight the impact of interventions enabling sustainable lifestyle changes. For modellers, it allows them to bring in lifestyle change options more on par with other options – for which also barriers and enables are considered. For experts on sustainable lifestyles, it could highlight which lifestyle changes are significant and could be explored in more detail.

The main research aim of this article is to explore how changes in lifestyles could contribute to emission reduction in passenger transport and residential emissions. This is done by translating and quantifying sustainable lifestyle narratives into model-based scenarios. In these workshops, originally, four sustainable lifestyle narratives were developed (van den Berg et al., in review). For quantification, we selected two of these, namely Designed World and Pocket Lifestyles, as these can be more effectively represented in the Integrated Assessment Model IMAGE (Integrated Model to Assess the Global Environment), which was used in this research. The qualitative narratives were translated into explicit time-dependent behaviour changes in adoption rates and transition speeds. The narratives were subsequently used to develop quantitative lifestyle scenarios using the IMAGE integrated assessment model. These scenarios include varying contexts and underlying value systems for lifestyle changes. They present a unique set of lifestyle change scenarios based on experts on sustainable behaviour and integrated assessment modellers.

In the research, we first describe the qualitative and quantitative scenario development methodology (including vital details on the IMAGE integrated assessment model). Second, we present the lifestyle scenario details and translation to scenario inputs for IMAGE. Third, we illustrate the scenario outcomes in the reference and SLIM scenarios and decomposition analysis on emissions as consumption and technology changes. Fourth, we discuss the limitations, opportunities and implications of these results and the development process of these lifestyle scenarios. Finally, we present the most important conclusions.

6.2. METHODOLOGY

There is a considerable body of scenario research on the possible impacts of behavioural change. However, previous studies have yet to be very explicit on the underlying reasons for change and, therefore, mostly assume somewhat arbitrary changes in types, speed, and depth of changes. For better-grounded scenarios, information on behavioural change options must be combined with an explicit description of the transition processes and their underlying dynamics. The SLIM scenarios we have developed are based on a process bringing in expertise from integrated assessment modelling and sustainable behavioural and transition studies.

We first describe the general methodology of the qualitative and quantitative scenario development process, followed by a description of the scenario narratives and a more detailed description of the methodology used to quantify lifestyle scenarios.

6.2.1. The qualitative and quantitative scenario development process

Scenario narratives provide an excellent way to deal with the more complex aspects of 'intent' - which can often be better described in words than in quantitative equations. In an accompanying paper (van den Berg et al., in review), we describe four narratives of four alternative scenarios in detail. In this paper, the focus is more on the impact of these scenarios (see solid boxes in Figure 6-1). However, we will discuss the intent and impact stages since they are heavily intertwined.

The scenario narratives have been developed based on engagements with advisors and policymakers, including expert-attended workshops providing advice and input for the elaboration of the scenarios by the research team. For the stakeholder engagements, we convened workshops and smaller group meetings and sent out documents for review by experts ranging from social scientists to modellers (see more detail in Table 6-1). We also engaged several policymakers in the early stages of scenario narrative development to incorporate their feedback and input. In the scenario quantification, we utilised the output of the scenario narratives and the engagement of advisors and policymakers to model the scenario narratives. The stages are shortly described below; see (van den Berg et al., in review) for more detail.

Stage 1: Scenario narrative building blocks based on criteria & gaps in modelling. Based on identified gaps in lifestyle change modelling, we developed criteria for creating scenario building blocks Field (van den Berg et al., in review): relevant, plausible, divergent, clear and challenging. In our first workshop, we presented our criteria and created these scenario building blocks in smaller break-out and larger group discussions.

Stage 2: Draft scenario narratives & required inputs for quantification. From these building blocks, we created a framework with diverging possibilities on which to build the scenario narratives. We presented this framework in a second workshop and to a select number of policymakers to explore the plausibility of the scenario narratives.

Stage 3: Finalised scenario narratives and model inputs. We defined and refined the scenario narratives with input from various stakeholders. From the scenario narratives, we also drafted quantitative assumptions about the speed and uptake of lifestyle changes for all four scenarios in the transport, residential and food sectors. We engaged with experts in a workshop and via written reviews to receive their advice to finalise the quantitative assumptions. These assumptions include lifestyle changes and behavioural actions for each scenario narrative, the motivations behind them, enabling factors, the adoption rates (i.e. the extent of the changes) and speed in behavioural changes (see Section 6.2.3.1). The advisors could comment, change, and add any of the document's contents, including references to substantiate assumptions.

Stage 4: Finalise scenario narratives & model long-term emission scenarios. We translated the quantitative assumptions to model inputs for scenario modelling. We modelled two of the four long-term scenarios with the IMAGE integrated assessment model to project the impacts of the lifestyle change scenarios on emissions. This final stage in modelling the long-term emission scenarios was the main focus of this article. Still, the previous stages were highly relevant in creating the emission scenarios.

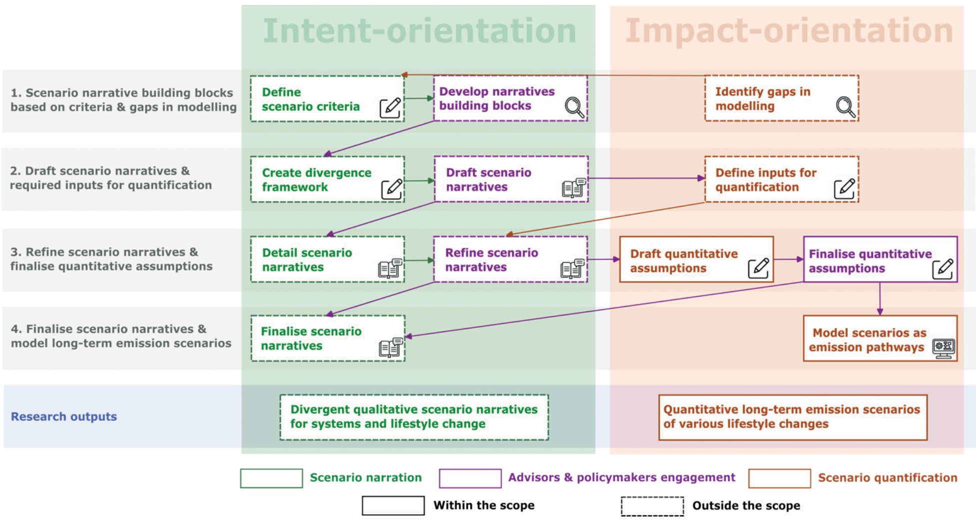


Figure 6-1: Scenario development process (adapted from (van den Berg et al., in review))

Table 6-1: Details of stakeholder engagements (van den Berg et al., in review)

Stakeholder engagements	Aim	Process	Product	Dates (Duration)	Number of participants
Expert Workshop series #1	To create building blocks for scenario narrative development from criteria	plenary: presentation of scenario planning and criteria breakout groups: discussions of how lifestyles could change plenary: report back and discussion	Framework of four key uncertainties to build the scenario narratives on	20/01/2021 (3 hours) 04/02/2021 (2 hours)	36 11
Expert Workshop series #2	To get feedback and detailed input on draft scenario narratives framework	plenary: presentation of scenario narratives framework breakout groups: brainstorm on details of one of the four scenario narratives using Miro Board interactive platform plenary: reporting back and sharing ideas about the different scenario narratives	Detailed scenario narratives with timing and events	30/03/2021 (3 hours) 08/04/2021 (3 hours)	39 13
Meeting with Policymakers	Test detailed scenario narratives in a policy context	exercise: on anticipated changes presentation of project and scenario narratives exercise: potential policy interventions exercise: wild cards, unexpected, but likely events discussion: what outcomes are useful for policymakers in connecting lifestyles to climate change?	Refined scenario narratives with policymakers' feedback	01/07/2021 (2 hours)	7
Expert Workshop #3	Finalise scenario narratives	presentation of scenario narratives and scenario inputs based on: behavioural actions, motivations, contextual factors, adoption rates and speed of transition	Finalised scenario narratives	15/12/2021 (1.5 hours)	20
Feedback Review	Get detailed feedback on scenario inputs assumptions	adjust, add, remove details of scenario inputs (as mentioned above).	Finalised scenario input assumptions	12/2021	17

6.2.2. Lifestyle scenario narratives

In this paper, we model two of the SLIM scenarios, i.e. 'Designed World' and 'Pocket Lifestyles' (see for Table 6-2 and Table 6-3 for details) (van den Berg et al., in review). In the other SLIM scenarios, Global Commons and Big Village, the substantial changes in governance to more collectivist values, social cohesion, alternative work patterns, local governance and community activities are more difficult to capture by IAMs focusing on global regions. In the discussion (see Section 6.5), we elaborate on opportunities to model these other scenarios.

Designed World and Pocket Lifestyles contrast in terms of types of support (distributed vs. centralised) but share the characteristic of individualistic values. This highlights the importance of decision-making by governments, external actors, and industries (through centralised support) that affect lifestyle changes by individuals *and* the peer-to-peer technologies and companies that facilitate lifestyle changes (through distributed support). We can compare these two contrasting scenarios' characteristics and impacts.

Table 6-2: The IMAGE Lifestyles Scenarios detailed information.

Scenario Pocket Lifestyles	*Tagline: Peer-to-peer lifestyle platforms* People adopt ambitious sustainable lifestyle behaviours and practices and rapidly spread them through peer-to-peer interaction and digital technology.
Scenario Designed World	*Tagline: Sustainable lifestyles by default* Governments, corporations and cities leverage existing values and market systems to shape citizen and consumer preferences and everyday practices.

Table 6-3: Scenario characteristics

Scenarios Characteristics	**Pocket Lifestyles**	**Designed World**
Individual agency	High	Low-medium
Public / Private / Community	Market / Private	Public – Private and City
Pace of lifestyle transition	Fast	Low-medium
Uptake of lifestyle actions	Low-medium	High

In Table 6-2, we introduce the taglines and descriptions of the lifestyle scenarios and, in Table 6-3, we identify the distinguishing characteristics. Designed World focuses more on public-private and city-level action, to facilitate a high uptake of lifestyle changes as it becomes the default, with a low to medium transition pace. Pocket Lifestyles are driven by individuals with high agency, changing their lifestyles, and sharing their experiences through peer-to-peer interaction for cumulative actions at a fast pace in a private and market-dominant system. A lower share of the population is involved in lifestyle behaviours in Pocket Lifestyles than in Designed World.

In Figure 6-2, we illustrate the two lifestyle scenario narratives modelled across different levels of change. We frame the scenario changes through levels of society, enablers, lifestyles and behaviours. The behaviours and lifestyle descriptions are positioned in relation to other scenarios. These changes described are not exhaustive, as many could emerge in and across the scenario narratives. However, we show the most notable changes in each scenario for improved readability.

In Designed World (blue section of Figure 6-2), people elect sustainable leaders to make sustainable decisions, providing radically sustainable subsidies incentivising sustainable lifestyles. These lifestyles are fast-paced and focused on sustainable innovations. Shifts to low-carbon and frugality are central to the motivation behind the changes. These lifestyles lead to the following behavioural actions. People replace personal cars with taxi use in transport and use autonomous electric vehicles. Residential behavioural actions include heat recovery (e.g. shower heat recovery), adopting heat pumps, insulating homes and installing rooftop solar panels. Behavioural actions in food include eating in eco-restaurants and replacing meat with lab-grown meat.

The overlapping characteristics in Designed World and Pocket Lifestyles (pink section of Figure 6-2) include the acceptance of sustainable shifts, either facilitated by enacted by sustainable leaders or bottom-up initiatives, respectively. Furthermore, the provision of sustainable innovations enables the level of sustainable shifts. Technology to support lifestyles is critical to both Pocket Lifestyles and Designed World.

In Pocket Lifestyles (pink section of Figure 6-2), societal changes are based on the desirability of sustainable actions to the masses. Key enablers include peer-to-peer apps facilitating lifestyle changes to become more convenient and accessible. Lifestyle changes related to social exchanges, minimalism, trendy/tech-savvy changes and digitalisation are amplified by peer-to-peer sharing and a desire to be more sustainable. In Pocket Lifestyles, the food-related behavioural actions vary from meal sharing and prepping to adopting vegetarian diets. In the residential sector, the emphasis is on renting out rooms, adjusting thermostats, hang-drying laundry and living in minimalist homes. Behavioural changes related to transport include peer-to-peer car sharing, active transport, smaller vehicles and telecommuting.

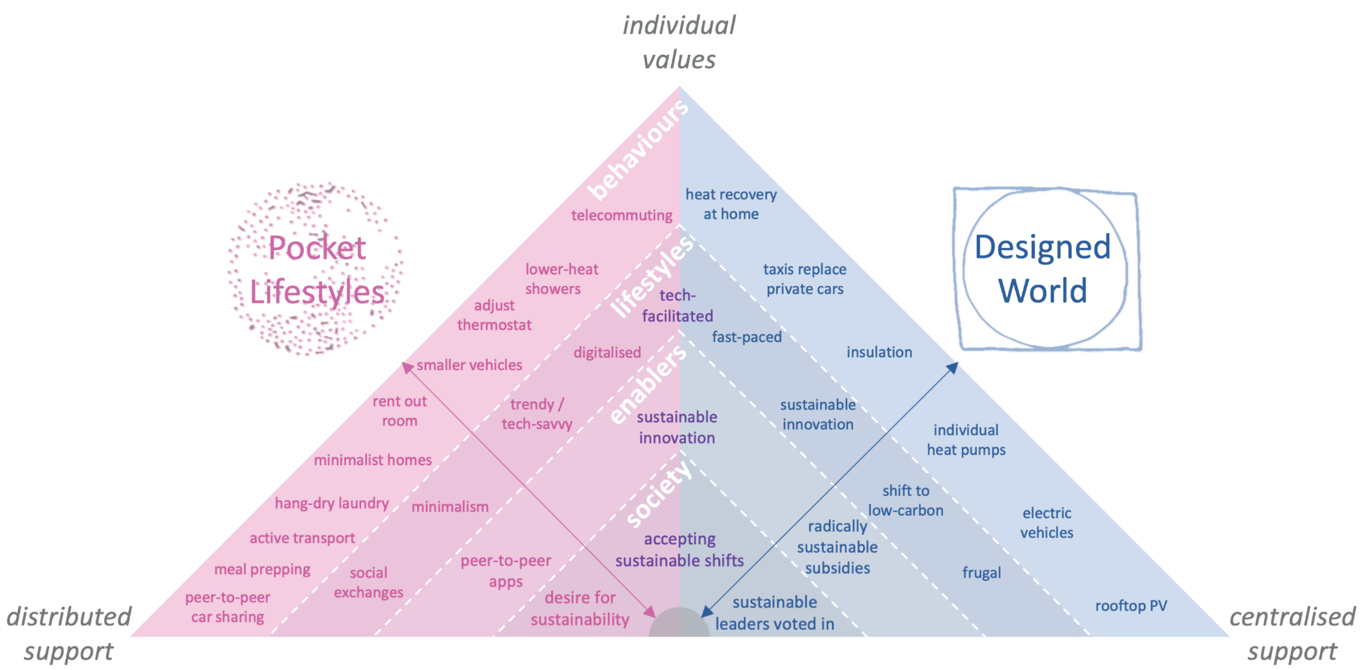


Figure 6-2: IMAGE Lifestyles Scenarios Pocket Lifestyles and Designed World

6.2.3. Lifestyle scenario quantification

This section describes the scenario inputs for integrated assessment modelling, the IMAGE integrated assessment model, and the reference scenarios used to quantify the lifestyle scenarios.

6.2.3.1. Quantitative assumptions of lifestyle scenarios

The SLIM scenario narratives were used to derive a set of explicit descriptions of behavioural change. We sent this scenario framework out for review to various experts, from qualitative experts on sustainable lifestyles to quantitative experts in modelling. These experts provided feedback on the scenario framework based on their diverse perspectives. By incorporating this multidisciplinary feedback, we strengthened and substantiated the scenario inputs for a more robust representation of lifestyles in long-term mitigation scenarios. The overview of the scenario framework and advisors' feedback is summarised in S6.1 and S6.2, respectively.

Table 6-4: Quantitative assumptions for stakeholder engagement

Inputs	Questions addressed
Behavioural actions	What behaviours do people adopt?
Motivations	Why do people adopt these behaviours?
Contextual factors	What influences people to adopt these behaviours?
Assumptions by 2050	What changes from behavioural actions happen by 2050?
Adoption rate in Global North	What percentage of people adopt these behaviours in the Global North?
Adoption rate in Global South	What percentage of people adopt these behaviours in the Global South?
Speed of adoption	How fast do people adopt these behaviours?
References	What references substantiate these assumptions?

We translated the adoption rates and speed of adoption from the stakeholder engagements (see Table 6-4), into model assumptions. We applied the 'Diffusion of Innovation theory' (Rogers, 2010) and the adopter groups: Innovators, Early Adopters, Early Majority, Late Majority and Laggards. We adapted the figure and theory to identify adoption speed by allocating saturation years to each adopter group (see Figure 6-3). The earlier the Innovators group reaches saturation, and consequently the other adopter groups, the faster the adoption speed. For example, for a particular behavioural action, 'living in a minimalistic apartment or a tiny house', we identify a year (y_{IV}) in which the first adopter group 'Innovators' (2.5% of the market share) would reach saturation. We do the same for the other adopter groups (Early Adopters, Early Majority, Late Majority, Laggards) and their corresponding saturation years (y_{EA}, y_{EM}, y_{LM}, y_{LG}). This process details the adoption extent (i.e. how many people adopt) and speed of behavioural actions (i.e. how fast does the change happen). We replicate this approach for all behavioural actions modelled in this research.

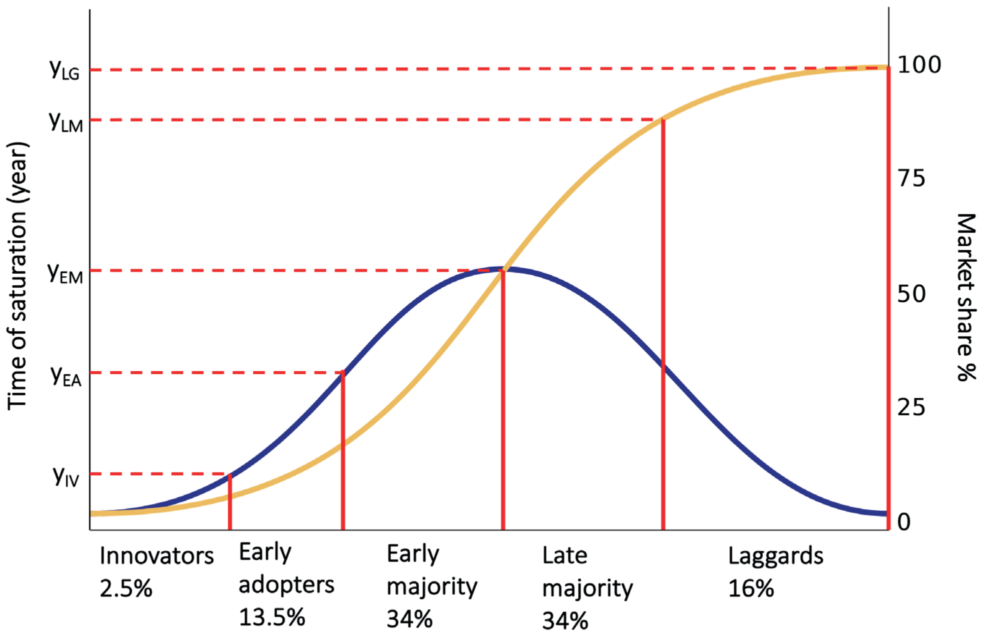


Figure 6-3: Adoption speed based on adopter groups from the diffusion of innovation theory: On the x-axis are the adopter groups and their percentage, the cumulative market share on the right y-axis with the time of saturation on the left y-axis indicating adoption speed (adapted from Rogers (2010))

6.2.3.2. Scenario modelling using the IMAGE framework

The IMAGE integrated assessment model describes the future energy and land use development. The model has been used frequently to calculate greenhouse emission pathways to support climate research and the IPCC assessments. The model includes detailed descriptions of future human activities, allowing the description of the impact of behavioural changes explicitly. 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 sub-models, TIMER, models the annual energy demand and supply of 26 global regions within the sectors industry, passenger and freight transport, residential, services, non-energy and other. In this research, we translate the descriptions of behavioural change adoption over time (see Section 6.2.3) to derive input parameters for *passenger transport* and the *residential sector* to explore the impacts of lifestyle changes. We focus on passenger transport and the residential sector as they are most directly related to behavioural changes in the TIMER model. The emissions quantified include direct and indirect (i.e. emissions related to electricity use) emissions from energy demand. However, the model does not account for indirect emissions from material demand (e.g. the production of electric vehicles).

The decision-making processes are not explicitly modelled, but rather proxies to account for degrees of behavioural variation (van Sluisveld et al., 2016). A multinominal logit function determines the market share of technologies or energy carriers, accounting for differences in preferences and relative costs per option (Van Vuuren et al., 2011). Preferences account for government policies and consumer preferences and aim to represent factors other than costs that are important for decision-making (e.g., choice to shift transport modes and smaller homes) (van Sluisveld et al., 2016).

The model accounts for regional diversity, by calibrating regional differences in energy demand. For example, there is a stronger preference for travelling by car in the USA than in Japan where public transport has a larger share in total passenger transport. Japan also has a significantly lower floor space per capita than the USA, which is being accounted for (Daioglou et al., 2012). We explain the specific details of how these sectors are modelled below.

6.2.3.2.1. Modelling details of the passenger transport sector

We model the travel behavioural actions of the scenario narratives in TIMER, by adjusting inputs (see Figure 2-5) to match the assumptions on adoption rates and speed of transition. For example, a sustainable shift in travel mode is implemented by adjusting the preference factor for modes. This affects the Travel Money Budget (TMB)[6] constraint, which adjusts the travel demand for each mode, and affects the Travel Time Budget (TTB)[7] determining the time weight and mode price. A higher electric vehicle adoption is achieved by adjusting the non-energy price of electric vehicle technologies, affecting the (perceived) cost of vehicles and the fleet composition.

[6] Travel Money Budget (TMB): refers to the share of income per day spent on transportation

[7] Travel Time Budget (TTB): refers to the time per day spent on transportation

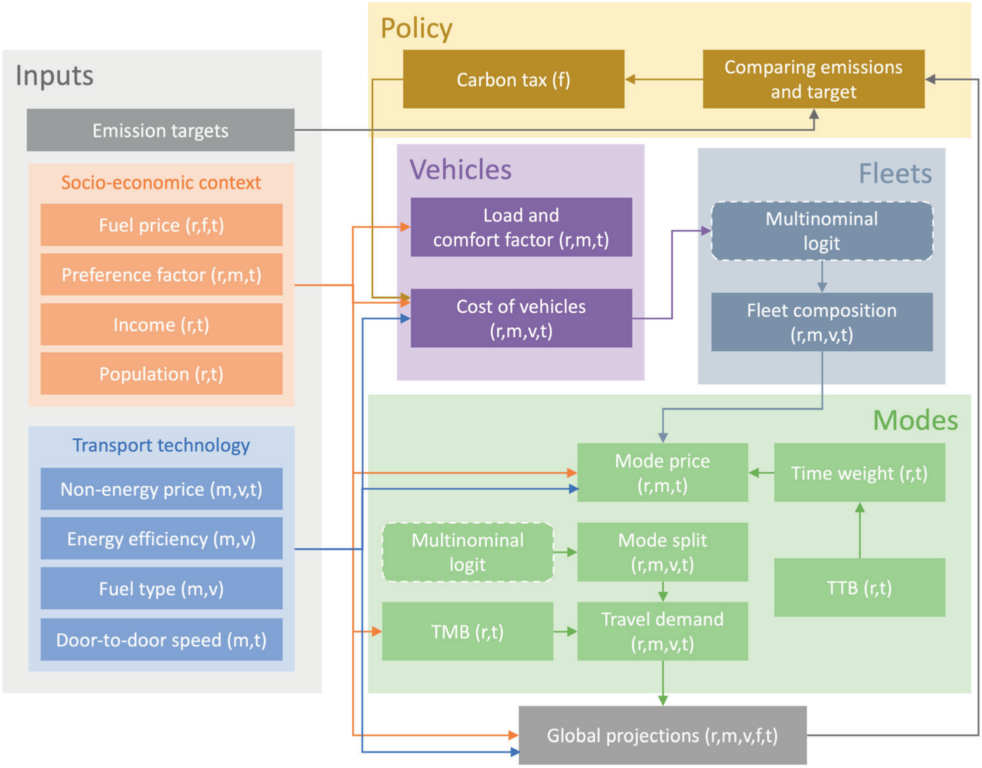


Figure 6-4: TRAVEL model in TIMER-IMAGE with factors dependent on region (r), travel mode (m), vehicle type (v), fuel type (f) and time (t) (adapted from (Girod et al., 2013)).

6.2.3.2.2. Modelling details of the residential sector

For behaviour related to the residential sector, a similar approach was used Figure 6-5). However, the socioeconomic context (population, household expenditure and size) is modelled in more detail, with explicit income quintiles and urban/rural classes (Daioglou et al., 2012). This allows for a more heterogeneous and equitable representation of lifestyle changes. For example, smaller living space only affects the groups with already high floor space per capita (i.e. often rural and high-income groups), as we implement an upper cap (i.e. a maximum m^2/capita) rather than a relative reduction. The primary drivers, population, household expenditure, population density, household size and temperature, affect the intermediate drivers: floorspace and electrification. Both these types of drivers affect the demand for energy services: cooking, appliances, space heating and cooling, water heating and lighting (Daioglou et al., 2012).

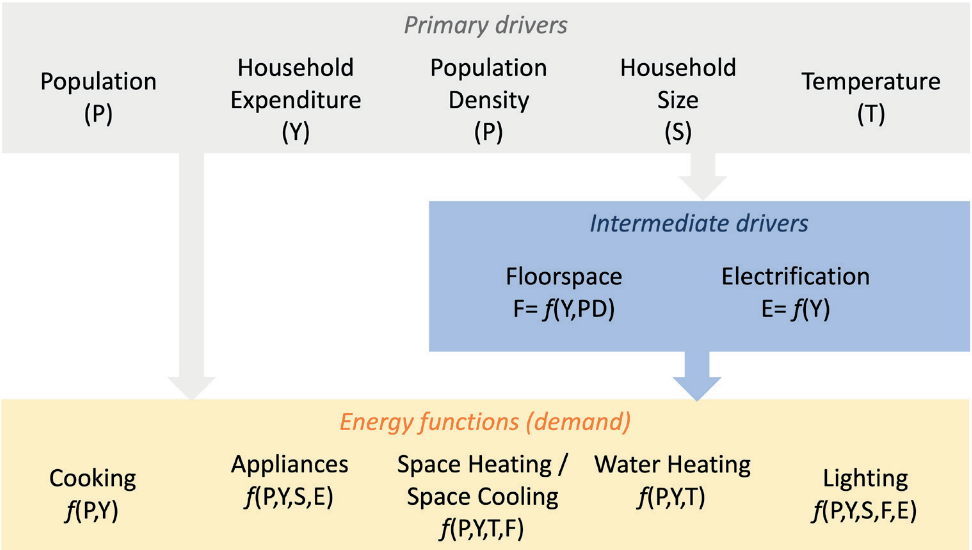


Figure 6-5: Relationship between residential energy functions and drivers (adapted from (Daioglou et al., 2012)).

6

6.2.3.3. *Reference scenarios SSP2 'Middle-of-the-Road'*

Our lifestyle scenarios are built upon one of the Shared Socio-Economic Pathways (SSPs), namely SSP2 "Middle of the Road" (O'Neill et al., 2017), in which society follows current trends. We chose this reference scenario, as it is very low in sustainable lifestyle changes, and thus highlights the impacts of the behavioural actions and lifestyle changes in our lifestyle scenarios. We have included both SSP2 reference (without climate policy) and a mitigation pathway (with a carbon price) to reach emissions in line with a 2°C climate target.

Scenarios	Description
SSP2 reference	The "Middle-of-the-road" (O'Neill et al., 2017) SSP2 scenario assumes a continuing trend of current economic and social patterns until 2100, with consumption patterns following trends in GDP. Includes already-implemented climate policies.
SSP2 Mitigation (2-deg and 1.5-deg)	The SSP2 2°C and 1.5°C scenarios assume the same trends as SSP2 reference but with climate policies (i.e. carbon pricing) so that GHG emission concentrations stabilize to 450 ppm CO_2-eq by 2100, with a 2°C maximum global average temperature above pre-industrial levels.

6.3. SCENARIO NARRATIVE DETAILS AND SCENARIO INPUTS

The outcomes of developing explicit descriptions of behaviour changes (see stages 3 and 4 in Section 6.2.1, 'Feedback review' in Table 6-1, and methodological details in Section 6.2.2) are summarised in Table 6-5, Table 6-6 and Table 6-7. These are shown per domain, categorised as 'cross-cutting', 'passenger transport', 'residential' actions.

Since lifestyle changes happen across domains and not within, we identify the cross-cutting actions (see Table 6-5) that could influence the behavioural actions within the domains (see passenger transport in Table 6-6 and residential in Table 6-7).

For the cross-cutting actions in Designed World, money is invested in low-carbon solutions and innovations, such as in infrastructure, which amplifies convenience for fast and efficient lifestyles. In contrast, for Pocket Lifestyles, digitalisation and strong social media presence and exchanges are prominent, motivated by tech-savviness, social interactions and long-distant learning and facilitated by peer-to-peer apps.

For each domain-specific behavioural action, Table 6-6 and Table 6-7 shows the motivations and the contextual factors affecting them, the different adoption rates for Global North and Global South reached by 2050 for each action, and the speed of the transition. In S6.3, we detail how the behavioural actions from the scenario assumptions are translated into IMAGE inputs and which model parameters are developed and used.

In Designed World, people use electric vehicles mainly because of the lower costs in use and status, facilitated by financial incentives and adequate charging infrastructure. High adoption rates in Global North and medium adoption rates in Global South are assumed, but with a relatively slow transition speed due to a reliance on infrastructure. The use of peer-to-peer taxi services is primarily motivated by convenience and enabled by availability. Global North would have a lower adoption rate than Global South. The transition to peer-to-peer taxi service is assumed to happen fast due to the relative ease of implementation (e.g. Uber).

In Pocket Lifestyles, telecommuting is motivated by being more cost-effective than travelling and tech-savviness, facilitated by telecommuting innovation. We assume a medium adoption rate for Global North and low for Global South due to the digital divide, but the transition is fast for those adopting the behaviours. Peer-to-peer car sharing is motivated by cost-effectiveness compared to car ownership and amplified by the platforms mediating the service. Car sharing is assumed to be medium in Global North and low in Global South regarding adoption rates, but with a moderately fast transition speed. Active transport, such as walking and cycling, is cost-effective, trendy, healthy for exercise, and encouraged by influencers and marketing. We assume a medium adoption rate for Global North and South with a fast transition speed.

In the residential sector, insulating homes, installing heat pumps, water heat recovery and rooftop PV are executed in Designed World because of the cost-savings on energy bills and improved indoor air quality and comfort. The government promotes these measures through prepaid subsidies, with extra incentives for housing associations and landlords at a larger scale and stricter regulation for new buildings. We assume a medium uptake of these actions in the Global North and a lower uptake in the Global South, a fast transition for insulation and moderately slow heat pump adoption. For water heat recovery, we assume a high uptake for Global North and a medium uptake for Global South, with a relatively slow transition speed. For rooftop solar panels, uptake is medium but fast for the Global North and Global South.

In Pocket Lifestyles, living in micro-apartments and tiny houses is motivated by cost-savings, energy prices and minimalist lifestyles, facilitated by adjustments in regulation to accommodate smaller living and social norm changes. Uptake is high in the Global North and Global South, but the transition is relatively slow. Adjustments in thermostats and lower heat showers are driven by cost-effectiveness and trendiness, facilitated by social norms changes and influencers. The uptake is high and fast in both Global North and South. Renting out a guest room or couch is motivated by social connections and cost savings, facilitated by platforms with proper regulation (e.g. Couchsurfing). We assume a medium and high adoption rate for Global North and South, respectively, with a fast transition. Hang-drying laundry is motivated by cost-effectiveness and amplified by social norm changes and influencers. A fast but medium uptake for Global North and a high uptake for Global South is assumed. Furthermore, meal prepping is driven by convenience and time savings, cumulated by marketing, social media and influencers. Adoption is high and fast.

Table 6-5: Cross-cutting scenario assumptions

Scenarios	CROSS-CUTTING actions	Motivations	Contextual factors
Designed World	Money is shifted to invest in low-carbon solutions	Cost savings; status; convenience	financial incentives and expenditures; infrastructure; availability & options
	Innovating to support fast and efficient lifestyles	Convenience	Infrastructure
Pocket Lifestyles	Digitalisation	Social interaction; long-distance learning; trendy; tech-savvy	Peer-to-peer apps
	Strong social media presence and exchange	Social interaction; trendy; tech-savvy	Influencers / innovators; design of sustainable goods and services

Table 6-6: Passenger transport scenario assumptions

Scenarios	PASSENGER TRANSPORT Actions	Motivations	Contextual factors	Adoption rates		Speed of transition
				Global North	Global South	
Designed World	Electric vehicles	Electric vehicles are cheaper in use; status	financial incentives; EV charging infrastructure (e.g. charging lanes)	High	Med	Moderately slow
	Peer-to-peer taxi services	Convenience of being driven	availability and options (e.g. Uber, Lift)	Low	Med	Fast
Pocket Lifestyles	Telecommuting	Tech-savvy; cost-effective	Strong tech innovation for improved telecommuting	Med	Low	Fast
	Peer-to-peer car sharing	Social; tech-savvy; cost-effective	Platforms for shared car ownership or renting out own car (e.g. Snapp-car)	Med	Low	Moderately fast
	Active transport	Trendy; cost-effective; healthy	Influencers; social media; marketing to encourage active transport	Low	Low	Fast
	Smaller vehicles	Trendy; cost-effective	Influencers; marketing to encourage smaller vehicles	Med	Med	Fast

Table 6-7: Residential scenario assumptions

Scenarios	RESIDENTIAL Actions	Motivations	Contextual factors	Adoption rates		Speed of transition
				Global North	Global South	
Designed World	Insulation	Cost-savings on energy bills; comfort; improved indoor air quality	Prepaid subsidies; extra incentives for housing associations, stricter regulation for new buildings	Med	Low	Fast
	Heat pumps			Med	Low	Moderately slow
	Quookers / shower heat recovery			High	Med	Moderately slow
	Rooftop PV			Med	Med	Fast
Pocket Lifestyles	Micro apartments & tiny houses	Cost-savings in rentals or owned homes and energy prices; minimalism	Regulation adjusted to accommodate for smaller living; social norm changes	High	High	Moderately slow
	Adjust thermostat	Cost-effective; trendy	Social norm changes; influencers	High	High	Fast
	Lower-heat showers			High	High	Fast
	Rent out room/house/couch	Social, cost-effective	house/room sharing platforms become more prominent with proper regulation (e.g. couch surfing, Airbnb); influencers	Low	Med	Moderately fast
	Hang dry on clothing lines	Cost-effective on energy bills	Social norm changes; influencers	Med	High	Fast
	Meal prepping (i.e. less cooking energy demand)	Convenience; time-saving	Marketing; social media; influencers	High	High	Fast

6

6.4. IMPACT OF LIFESTYLE CHANGES ON EMISSIONS

We first discuss results in terms of emission pathways and how they relate to reaching climate targets, followed by identifying the driving factors of emission reductions through decomposition analysis.

6.4.1. Scenario emissions pathways in the context of 2°C climate target

Figure 6-6 shows per capita emission pathways for reference, mitigation and lifestyle scenarios (see S6.5 for associated values). We show the reference scenario SSP2 without a carbon price (in grey) and mitigation scenarios with a carbon price to reach 2°C and 1.5°C climate targets (dark and light green, respectively). We show the SLIM lifestyle scenarios, Designed World (in blue) and Pocket Lifestyles (in pink). The solid lines represent the Global North regions, while the dotted lines represent the Global South regions. Note that the sudden shocks around 2020 represent the effects of Covid-19.

In the SSP2 reference scenario, per-capita transport emissions are decreasing strongly in the Global North and are increasing in the Global South. As a result, the difference in baseline emissions between Global North and Global South would decrease from a factor 6 in 2020 to slightly more than a factor 2 in 2050. Residential per-capita emissions in Global North would decrease in the SSP2 baseline, but less strongly, while residential per-capita emissions in Global South remain relatively constant.

The lifestyle scenarios reduce emissions significantly, but there are significant differences in the uptake and speed. By far, the most substantial reductions occur in transport emissions in Designed World, where passenger transport per-capita emissions reach levels below the default SSP2 2-deg scenario by 2050, both in Global North and Global South. Both lifestyle scenarios have hardly any impact on Global South residential emissions. Pocket Lifestyles' implications for transport and residential emissions are more modest, especially in Global North. Furthermore, the transition is initially quicker for Pocket Lifestyles but slows down, while for Designed World, it is a slower start but a more significant reduction overall.

The following section applies a decomposition analysis to understand better the drivers of the substantial differences in emissions between the lifestyle scenarios and between the Global North and the Global South.

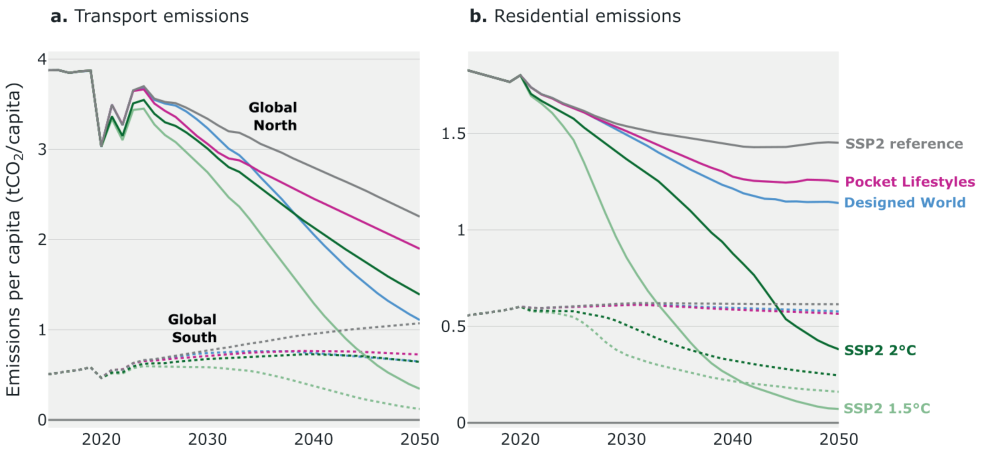


Figure 6-6: Long-term scenarios between different regions Global North and Global South (shown by solid and dashed lines, respectively) on transport (a) and residential per capita emissions (b). The scenarios include SSP2 scenarios without (see SSP2 reference in dark grey) and with a carbon price to reach climate targets (see SSP2 2°C and SSP2 1.5°C), and the lifestyle scenarios Designed World (in blue) and Pocket Lifestyles (in pink).

6.4.2. Breakdown of changes in emissions

In the decomposition analysis of the scenario results, we illustrate the breakdown of the total emissions changes per sector (see Figure 6-7 and Figure 6-8 and Tables in S6.5.1 and S6.5.2). These figures and tables show the factors contributing to changes in emissions based on the Kaya Identity, namely, population (P), activity (A), mode shift (M) or service (S), efficiency (E) and CO_2 intensity (I). For the SSP2 reference scenario, we decomposed the emissions from 2015 and 2050 to show why emissions change over time in the baseline. For the lifestyle scenarios, emissions are decomposed from the SSP2 reference scenario in 2050 to the lifestyle change scenarios in 2050 to isolate the impacts of the behavioural actions of the scenarios.

6.4.2.1. Passenger transport

While total passenger transport emissions in the Global North decrease by 36% in SSP2 (2.2 to 1.4 $GtCO_2$), they increase by 175% in the Global South in the same scenario (1.6 to 4.3 $GtCO_2$) (see Figure 6-7). The reason why transport emissions decrease in Global North, despite a significant increase in transport activity, is the substantial improvement in efficiency and CO_2 intensity. This is mainly due to a shift to more efficient cars and especially electric vehicle adoption, even in the SSP2 reference scenario. Global South, activity increases substantially, and people shift from bus transport to less sustainable car transport, explained by increasing per-capita income levels in developing regions. The improvement in efficiency only partially offsets this increase.

The lifestyle measures in Designed World (see Table 6-6) reduce CO_2 emissions from passenger transport by 51% (0.7 Gt CO_2) in Global North and 40% (1.7 Gt CO_2) in Global South compared to the SSP2 scenario (see Figure 6-7). The emission reductions are almost entirely caused by efficiency and CO_2 intensity improvements, notably through the increased use of electric vehicles.

The lifestyle changes in Pocket Lifestyles (see Table 6-6) have a lower impact on emissions: they reduce emissions by 12% (0.17 Gt CO_2) in Global North and 27% (1.15 Gt CO_2) in Global South. In contrast to Designed World, emission reductions in Pocket Lifestyles are due to changes in activity (8% in Global North and 5% in Global South) and mode shifts (8% in Global North and 23% Global South) (see Figure 6-7). The impact of mode shifts in the Global South of the Pocket Lifestyles scenario is partly explained by the counteracting effect of the substantial increase in car use in the SSP2 reference scenario. Therefore, the increase from 2015 in Pocket Lifestyles compared to SSP2 is much lower, as buses are used more to meet the demand for increased passenger transport activity.

In the lifestyle scenarios, the differences between Global North and Global South regions can be explained by various factors. Firstly, the input assumptions differed for regions based on motivations and other influencing factors, such as infrastructure consistent with the narratives. For example, EV adoption is assumed to be lower in Global South regions. Charging infrastructure is essential for widespread EV driving. Therefore, it is realistic to assume that infrastructural changes might be costly and, thus, slower to develop. Secondly, we account for differences within the regional classifications of Global North and Global South since IMAGE models different assumptions for 26 regions. For example, the modal split for China and USA differs substantially, so the change assumptions depend on the existing modal split.

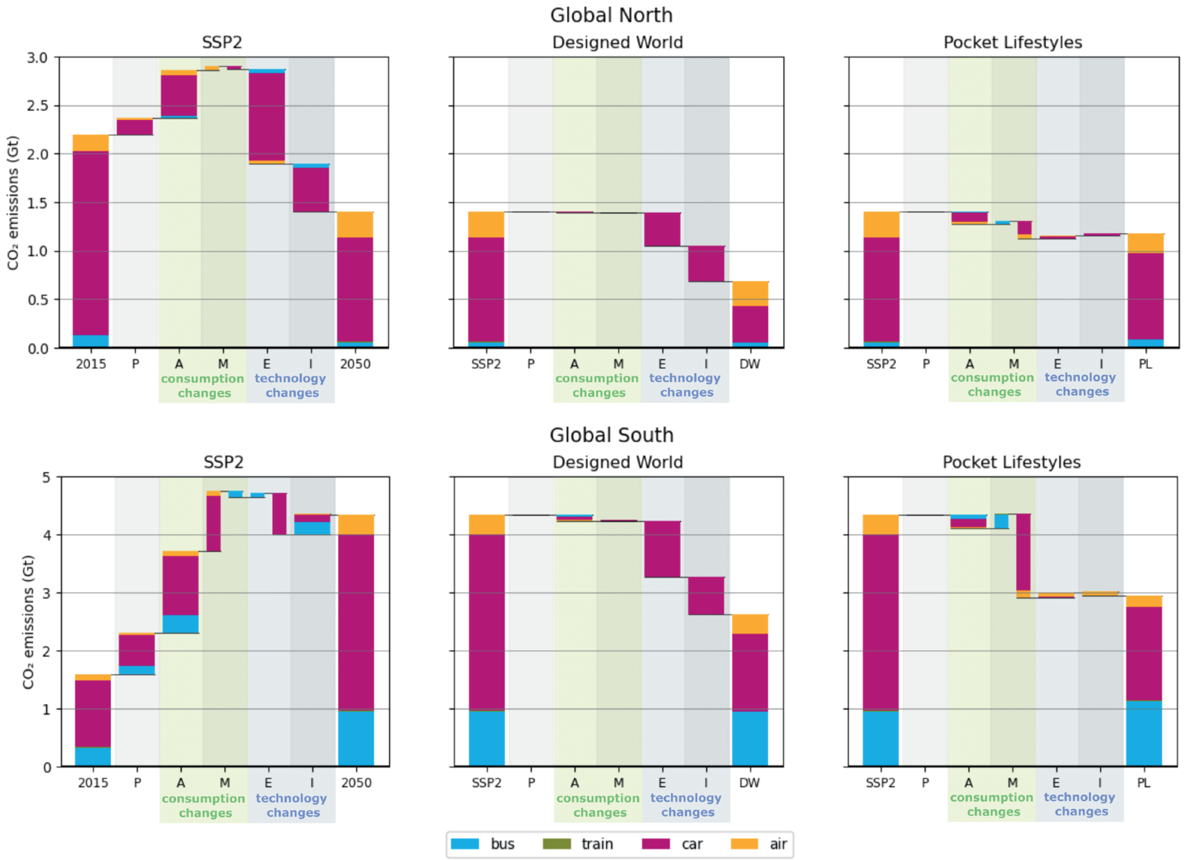


Figure 6-7: Passenger transport decomposition results of the reference scenario SSP2 and the lifestyle scenarios, Designed World and Pocket Lifestyles. The different colours represent the different transport modes. The waterfall charts represent the change in emissions from different factors, population (P), activity (A), mode structure (M), efficiency (E) and CO_2 intensity (I).

6.4.2.2. Residential

In the SSP2 scenario, total residential emissions decrease by 13% in Global North (2.07 to 1.81 $GtCO_2$), which is less substantial than the decrease in transport emissions (see Figure 6-8). The main reasons for the reduction in emissions are improvements in efficiency and CO_2 intensity. These improvements offset the increasing impact of activity and service changes on emissions. The underlying reason why CO_2 intensity improves is that the carbon intensity of electricity generation decreases, leading to lower indirect emissions from appliances.

In Global South, residential emissions increase by 43% (from 3.48 to 4.98 $GtCO_2$) in the SSP2 reference scenario, which is less than the increase in transport emissions (see Figure 6-8). The most important reason for the rise in emissions is strong growth in activity (especially in cooking and space cooling). The projected strong economic development again explains this in these regions. This trend is partially offset by improvements in efficiency (notably in space heating) and CO_2 intensity (particularly from electrification in space cooling and appliances).

The lifestyle changes in Designed World would lead to a 21% (0.39 Gt CO_2) emission reduction in Global North and 6% (0.31 Gt CO_2) in Global South relative to the SSP2 scenario (see Figure 6-8). In Global North, most emission reductions result from efficiency improvements (especially from the switch to heat pumps in space heating). In Global South, emissions reduction is mainly due to decreased activity compared to baseline trends (notably from appliances, cooking and water heating). Reductions from efficiency improvements are also noteworthy (particularly from heat pumps and insulation affecting space heating and electrification in space cooling).

The lifestyle changes in Pocket Lifestyles reduce emissions by 9% (0.17 Gt CO_2) in Global North and 8% (0.39 Gt CO_2) in Global South compared to the SSP2 reference (see Figure 6-8). In Global North, a notable effect on emissions in 2050 is a reduction of per-capita floor space, mainly affecting emissions from space heating. In Global South, the reductions in emissions are mainly caused by a decrease in activity and service changes.

In the lifestyle scenarios, the impacts of emissions are higher in Global North than in Global South, partially due to the equity considerations and temperature differences in the assumptions. For example, in Pocket Lifestyles, a cap on floor space per capita affects mainly regions with larger homes, while Global South regions with smaller homes would need to reduce less space or some not at all. In Designed World, we assumed a higher adoption of heat pumps for Global North regions than in Global South.

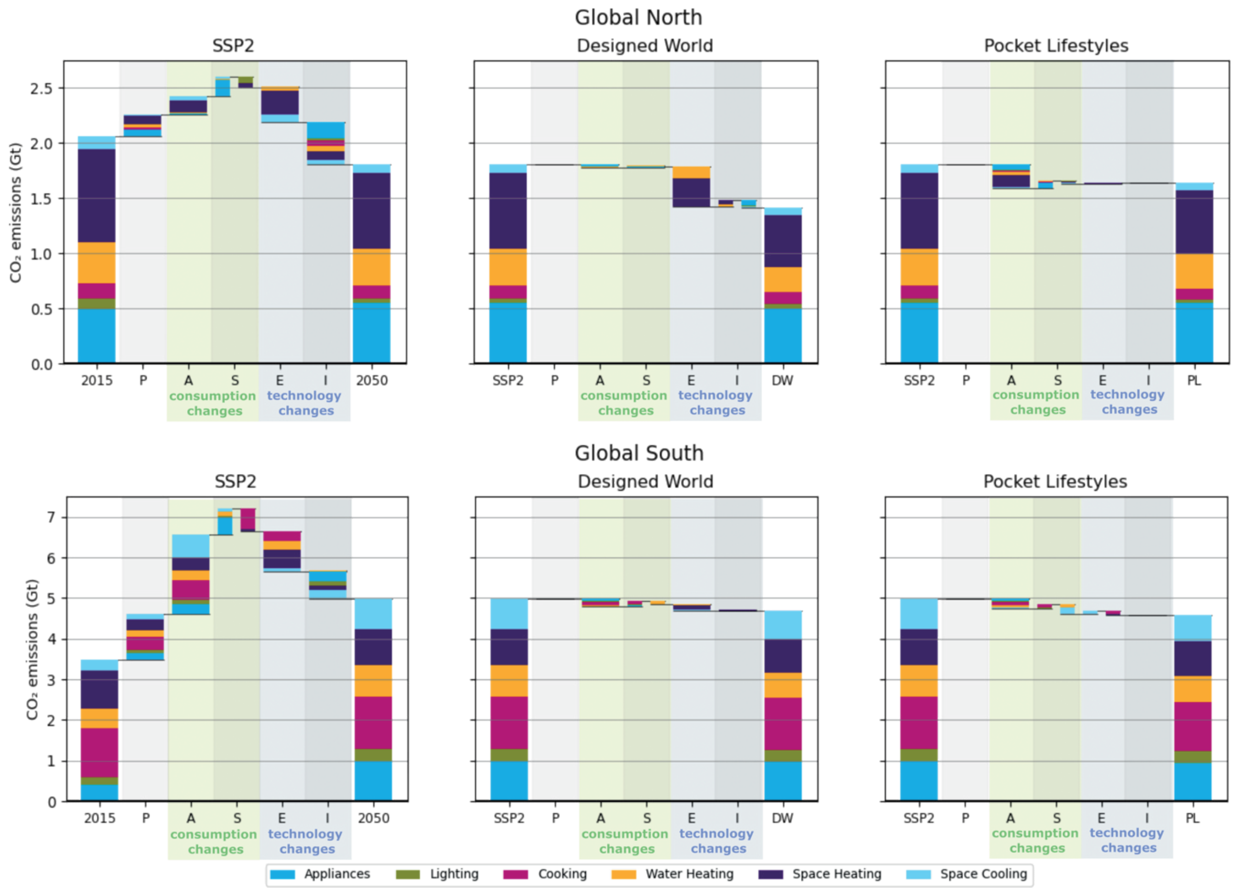


Figure 6-8: Residential decomposition results of the reference scenario SSP2 and the lifestyle scenarios: Designed World and Pocket Lifestyles. The different colours represent the energy services that make up the residential sector. The waterfall charts depict the change in emissions from various factors, population (P), activity (A), service (S), efficiency (E) and CO_2 intensity (I).

6.5. DISCUSSION

This research bridges qualitative with quantitative methodologies to create SLIM scenarios with lifestyle changes. Translating qualitative narratives into quantitative inputs to develop scenarios has allowed for a more nuanced representation of lifestyle and systems changes in IAMs. The following discussion points are most noteworthy from quantifying the SLIM scenarios.

Different trends are observed in SLIM scenarios compared to earlier scenarios with behaviour change. Compared to the previously-developed behaviour change scenarios (van Sluisveld et al., 2016), Pocket Lifestyles and Designed World show different trends. Overall, the SLIM scenarios have more considerable emission reductions than the Behaviour Change scenario (van Sluisveld et al., 2016). However, for Pocket Lifestyles, transport emissions in Global North are higher. This is most notably due to the more minor efficiency improvements and shifts to sustainable fuels, and fewer people travelling by public transport. As the assumptions in the Behaviour Change scenario (van Sluisveld et al., 2016) were more stylised than those in the SLIM scenarios, behaviour change in the former scenario could have been overestimated. For instance, in the Behavioural Change scenario (van Sluisveld et al., 2016), it was assumed that everyone would change behaviours similarly. However, overlooking cross-cutting lifestyle changes could also lead to underestimating the impact of the behaviour changes. The SLIM scenarios accounted for regional differences and enabling factors and motivations affecting the extent and speed of transition. These could account for the differences between the previous and SLIM scenarios.

The SLIM scenarios show results close to the 40-70% emission reductions from demand-side measures stated by IPCC. The latest IPCC report states, “Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end-use sectors by 40-70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources” (Creutzig et al., 2022). It should be noted that this refers to the sum of all measures implemented in end-use sectors, including fuel switching and efficiency improvement. Considering only Global North regions, the modelled SLIM scenarios’ emission reductions from 2015 to 2050 are well within the range. For Designed World and Pocket Lifestyles, emissions would reduce by 45% and 61% for Global North. However, emissions would increase for Global South regions due to their expected economic development, i.e. by 15 and 21%, respectively, in Designed World and Pocket Lifestyles. A few points should be highlighted about these values. Firstly, The SLIM scenarios assume only lifestyle changes and no additional climate policy. Emission reductions would be significantly higher in the lifestyle changes combined with other technology changes, possibly induced by carbon pricing (as in the IPCC numbers). Secondly, the 40-70% values from IPCC indicate potential, while the SLIM scenarios are based on informed assumptions with limitations on the speed and extent of lifestyle changes adopted. For example, instead of assuming all people will adopt a heat pump, the SLIM scenarios assume a lower adoption and regional differentiation based on availability, facilitation, willingness or capability, to name a few. Thirdly, a combination of Designed World and Pocket Lifestyles, or the other SLIM scenarios, Global Commons and Big Village (not modelled in this research) could lead to higher emission reductions.

A subjective interpretation of the narratives is needed. Subjectivity is inevitable in scenario development. In the scenario narratives, this subjectivity refers to the descriptions and assumptions of what type of lifestyles would change. The quantification process refers to the adoption rates, transition speeds and how lifestyle changes are modelled in the quantitative scenarios. We partially addressed the subjectivity by including an extensive range of experts at various steps in the process. The multidisciplinary co-creation approach stimulated discussions from different perspectives and resulted in diverse scenarios. This goes beyond the ad-hoc lifestyle scenarios previously developed, with richer assumption details regarding the depth and speed of change.

There are some model limitations. While some assumptions about the adoption rates and adopter groups were explicitly modelled within TIMER (especially in the residential sector), other assumptions were challenging to implement directly (see S6.3). The model parameters are not directly linked to the scenario assumptions in the transport sector. For example, to encourage more EV adoption, a lower technology cost for EVs is assumed, which leads to higher adoption. We could not directly link the adopter groups to the technology costs of vehicles. For residential, however, we could improve the narratives' translation to scenario inputs by creating adopter groups as an extra layer of heterogeneity. Still, there are opportunities to further enhance the translation of lifestyle changes into the model. One way is via a designated lifestyle module outside the passenger transport and residential sectors with linkages to these sectors.

Other sectors than transport and residential are not represented in this research (such as food and consumer goods). In future work, the food demand of these lifestyle scenarios could be modelled (like implementing food-related behaviour changes in (van Sluisveld et al., 2016)). The scenario framework for the food sector of the lifestyle scenarios is available (see S6.6) to be translated to model inputs. Furthermore, the representation of consumer goods is limited in this research. Even though we account for appliance use in the residential sector and the use of cars and bikes, the upstream production emissions for the materials are not. Therefore, the impacts of some lifestyle changes still need to be fully captured. For example, the emission reduction of car-sharing would be most evident in the production of cars rather than the energy demand in use. As such, there is potential for future work to model consumer goods for these lifestyle scenarios through a better representation of material demand in IAMs (Deetman et al., 2021).

The other scenario narratives from Global Commons and Big Village were excluded from the scenario modelling. As discussed in Section 6.2.2, we chose Designed World and Pocket Lifestyles due to the similar value system and contexts of these scenarios to IMAGE model structure and previously modelled scenarios. Therefore, we could better represent them in IMAGE, while Global Commons and Big Village require substantial changes. However, this is not to say that it is impossible. There are vast opportunities to represent more transformative value shifts to collective values, such as those in Global Commons and Big Village. In future work, these scenarios should be explored in IAMs for a more holistic analysis.

A just transition is central to these lifestyle scenarios. We differentiated between Global North and South regions in the scenario input assumptions. In the residential sector, we implemented certain measures that sometimes only affect specific income quintiles, such as a cap on floor space per capita. We still see significant emission reductions in Global South regions due to lifestyle change, which could be interpreted as leapfrogging rather than limiting economic development. For example, there is a substantial mode shift away from cars in Pocket Lifestyles. Many regions in the Global South have the potential to circumvent CO_2-intensive modes of passenger transport and costly road infrastructure that Global North regions are reliant on. Of course, these changes can also be argued as unjust, as much of the burden still falls on Global South regions to act and, thus, could limit development.

These scenarios show the potential of lifestyle and system changes to reduce emissions. However, they do not detail how and why people would make these changes. The qualitative article of this research project (van den Berg et al., in review) does elaborate on why people would adopt these lifestyle changes in different scenarios.

6.6. CONCLUSION

The scenarios created in this research were translated from qualitative narratives to model inputs and subsequently modelled to show emission pathways. We developed these scenarios with experts from different disciplines and policymakers. The quantification of the scenarios illustrates the impacts that lifestyle change could have on emissions. It emphasises the absolute differences between Global South and Global North in per-capita emissions and reductions.

Detailed narratives allow for detailed quantification and scenario modelling. Of the few lifestyle scenarios previously modelled in IAMs, they have primarily stylised assumptions. However, we used diverse qualitative scenario narratives, Designed World and Pocket Lifestyles and translated them to quantitative assumptions for scenario modelling. These were with various advisors and policymakers through a transdisciplinary and iterative process. Consequently, we were able to model less-stylised lifestyle scenarios.

Regional differentiation in the scenario narratives and modelling of intra-regional differences allows for increased heterogeneity and accounts for equity in lifestyle changes. We distinguished Global North and Global South in the scenario assumptions, accounting for context-dependent factors for different regions. Furthermore, in the residential sector, we modelled some behavioural actions so that different groups (i.e. different incomes, rural or urban households) were implemented differently. Certain assumptions for Pocket Lifestyles, especially in the residential sector (e.g. smaller floorspace per capita), affect only higher-income groups or the highest emitters. For Designed World, since it relies more on technology changes, emission reductions are higher in residential, primarily for Global North regions with higher GDP, to pay for the electrification and infrastructure. This implementation allows for a more nuanced representation of lifestyle changes in the context of fairness.

Of the SLIM scenarios modelled, emissions in Pocket Lifestyles are reduced primarily through consumption changes, while emissions in Designed World are reduced primarily through technology-enabled behavioural changes. The SLIM scenarios show different types of changes. The results show that technology-enabled lifestyle changes would be vital in reducing emissions in Designed World, whereas consumption changes would significantly impact emissions in Pocket Lifestyles. In Designed World, reductions would be mainly achieved through lifestyle changes related to efficiency and CO_2 intensity improvements. For Global North, transport and residential emission reductions would be 50% and 20%, and for Global South, 37% and 3%, respectively). In Pocket Lifestyles, consumption changes (i.e. less and shifts in activity) play a major role. For Global North, emission reductions for transport and residential would be 16% and 10%, and for Global South, 27% and 8%, respectively. For Pocket Lifestyles, the impacts are notable for teleworking, shifts to sustainable transport modes and smaller homes. In contrast, in Designed World, considerable impacts come from electric vehicles, peer-to-peer taxi services and home insulation, heat pumps and electrification.

6

Lifestyle changes contribute substantially to climate change mitigation, but other measures, such as larger systems change supporting these changes, are also vital. This study shows that in Designed World, emissions are reduced more strongly than in Pocket Lifestyles. This is mainly because Designed World is characterised by larger systems change (e.g. electrification of vehicles). The extent to which this happens and when, differs between the scenarios. By far, the most substantial reductions occur in transport emissions in Designed World (51% in Global North and 39% in Global South compared to SSP2 reference), reaching levels below the default SSP2 2-deg scenario by 2050. Reductions in residential emissions for Designed World are also noteworthy but not as substantial (21% for Global North and 5% for Global South). The Pocket Lifestyles scenario with less systems change and more distributed access to support for lifestyle changes has more modest emission reductions for transport (16% for Global North and 32% for Global South) and residential (14% for Global North and 7% for Global South). Furthermore, the transition is initially quicker for Pocket Lifestyles. Still, it slows down because of distributed and even fragmented support. For Designed World, it is a slower start but a more considerable reduction overall because of the increased infrastructure of support for lifestyle changes. Combining aspects of Designed World and Pocket Lifestyles could also be realistic, incorporating technological solutions *and* lifestyle measures for larger systems change.

The SLIM scenarios' improved representation of lifestyle changes in model-based scenarios and IAMs can better inform policymakers about facilitating lifestyles as strategies for mitigating climate change. Since IAMs generally represent behaviour and lifestyle changes with stylised assumptions or not at all. This entails that lifestyle changes are often underexplored as strategies for mitigating climate change. We propose that with these SLIM scenarios, for example, policymakers can explore possible pathways for lifestyle changes and their impacts for more informed decisions about strategies for mitigating climate change.

ACKNOWLEDGEMENTS

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


JOOP
MCMXL

7

SUMMARY AND CONCLUSIONS

7.1. INTRODUCTION

Anthropogenic greenhouse gas (GHG) emissions have increased almost continuously since 1850, and it has been unequivocally proven to contribute to climate change (IPCC, 2022). In the Paris Agreement of 2015 (UN, 2015), countries agreed to limit the global mean temperature increase to well below 2°C, and possibly even 1.5°C, compared to the preindustrial level. Fundamental changes in land use and energy systems are vital to meet these goals. This thesis mainly focuses on energy systems. Traditionally, changes in energy supply have been explored and considered extensively as solutions to combat climate change. More recently, scenario analysis also provided detailed analyses of reducing energy demand through efficient technologies. Overall, there has been much less focus on demand-side changes through lifestyle and behavioural changes. However, in the last few years this has changed, with increasing attention to sustainable lifestyles and behaviour (Creutzig et al., 2021), for example, in the UNEP Emission Gap Report and IPCC AR6 (Capstick et al., 2020; Creutzig et al., 2022). In the latter report, IPCC AR6 states that "demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end-use sectors by 40-70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources." (Creutzig et al., 2022).

Previous quantitative studies have focused on the impact on emissions of different stylised lifestyle options (Costa et al., 2021; Grubler et al., 2018; Ivanova et al., 2020; van Sluisveld et al., 2016; van Vuuren et al., 2018; Vita et al., 2019). More specifically, model-based scenarios with behaviour and lifestyle changes are often represented via stylised assumptions (e.g. assuming everyone adopts a healthier diet). However, the stylised assumptions could be improved with insights from qualitative disciplines, such as environmental psychology, sociology and social practice theory. Qualitative studies often focus on providing insights about how lifestyles could change based on motivations and enabling factors (Echegaray, 2021; Green & Vergragt, 2002; Manzini & Jégou, 2003; Mont et al., 2014; Quist et al., 2001; Quist & Leising, 2016; Schmidt-Scheele et al., 2022). Such studies could complement the quantitative modelling of lifestyle changes for more informed strategies on climate change mitigation. Therefore, further exploring lifestyle changes is vital to identify diverse strategies for climate change mitigation, considering the magnitude, urgency and scale of the problem.

While behaviour, lifestyle and consumption changes are often used interchangeably, there is an important distinction between them. Behaviour refers to individual changes in behaviour within a domain (e.g. choosing to travel by bicycle instead of a car). Lifestyle changes, however, refer to consistent behavioural changes across the typical domains of food, residential and transport choices. In contrast to behaviour and lifestyle, consumption changes refer to the outcomes of those changes in terms of activity and structural changes. These distinctions highlight the possible focus on intent (i.e.

motivation) or impact (i.e. outcomes) of behaviour and lifestyle changes (Gifford et al., 2011), which is highly dependent on the scope, aim and questions of the research.

This thesis explores lifestyle changes from an intent-oriented approach using qualitative approaches and from an impact-oriented approach with IAMs. This allows us to produce knowledge of qualitative storylines, quantitative and exploratory pathways, mediation through participatory approaches, and holistic framing of possible transitions to inform policymaking.

7.2. RESEARCH AIM AND QUESTIONS

This research builds on early efforts to explore the role of lifestyle change in climate mitigation including in integrated assessment models. The qualitative and quantitative scenarios reveal rich insights about alternative future pathways to sustainable lifestyles and shed light on opportunities for modeling, policy and other climate stakeholders to reflect these insights in their work and action. It is clear that 'demand side strategies' and lifestyle and consumption-oriented solutions are a prerequisite for achieving our climate targets. The scenarios and modeling efforts in this research aim to advance work to clarify this potential contribution of lifestyle change and to inform climate solutions for thriving everyday living equitably within the Earth's limits.

This research aims to show how to improve the representation of lifestyle changes in IAMs, to establish the possible role of changes in lifestyles in climate change mitigation strategies. With this aim in mind, the chapters, their research questions, and their analytical focus are presented below in Table 7-1.

Table 7-1: Overview of research questions, analytical focus and chapters

#	Research questions	Intent	Impact	Ch.
	How can IAMs improve the representation of lifestyle changes to show the possible role of lifestyles in climate change mitigation strategies?	X	X	all
1	What are key insights from existing literature on different approaches for analysing lifestyle changes?	X	X	2, 3, 5 & 6
2	What is the impact of changes in consumption on emission reductions, compared to technology changes in existing IMAGE lifestyle scenarios?		X	3 & 4
3	How do emissions from current lifestyles compare to the emission levels consistent with climate targets?		X	4
4	What are possible future scenarios towards sustainable living?	X	X	5
5	What are the implications of possible future sustainable living scenarios for emissions?	X	X	6

7.3. MAIN FINDINGS

7.3.1. What are key insights from existing literature on different approaches for analysing lifestyle changes?

There is a rich and varied literature on sustainable lifestyles covering different scientific disciplines. Some of the work focuses on the intent of lifestyle change, while others focus on impact. Through a systematic review, this research analysed how different perspectives on lifestyle changes could be used to adopt a more nuanced and rich approach to representing lifestyles in IAMs. We distinguish between studies adopting an intent (i.e. focused on motivations) or impact orientation (i.e. focused on outcomes) regarding lifestyle changes (see Figure 7-1). The studies analysed varied across disciplines, scope, aim and methods, with useful insights around lifestyle changes (Chapter 2). Some key insights of this review are given below.

Predominantly qualitative and social sciences take the intent-oriented perspective, analysing or determining the motivations behind behaviour and lifestyle changes. This perspective informs us based on what, how many, why, how, and when lifestyles could change. Many disciplines adopt this perspective. For example, environmental psychology studies factors that help predict behaviour and environmental sociology studies the interactions between the natural environment and societies. Behavioural economics informs us about the bounds of rationality and susceptibility to factors influencing our choices (e.g. nudges, default-setting and marketing). Social practice theory contributes to understanding practices instead of individuals by studying everyday social practices (e.g. washing, cooking, exercising). Innovation and socio-technical transition studies contribute to understanding lifestyle changes in socio-technical change dynamics (Chapter 2).

Another strand of studies focuses on the outcomes of lifestyle changes. These studies generally use models to quantify the impact of lifestyle change on the environment. There are various types of models, assessments, and analyses that investigate the impact of lifestyle changes. For example, life cycle assessments can quantify lifestyle-related impacts over the life cycles of products and services. Consumption-based carbon accounting, often via multi-regional input-output models, allocates emissions to end-users (e.g. Lifestyle Carbon Footprints), providing insights about different types of consumers, lifestyles, and drivers of change. Agent-based modelling analyses behaviours by modelling interactions between agents. Integrated Assessment Models (IAMs) have also contributed to quantifying lifestyle changes by modelling the impact of specific behavioural changes on greenhouse gas emissions (Chapter 2).

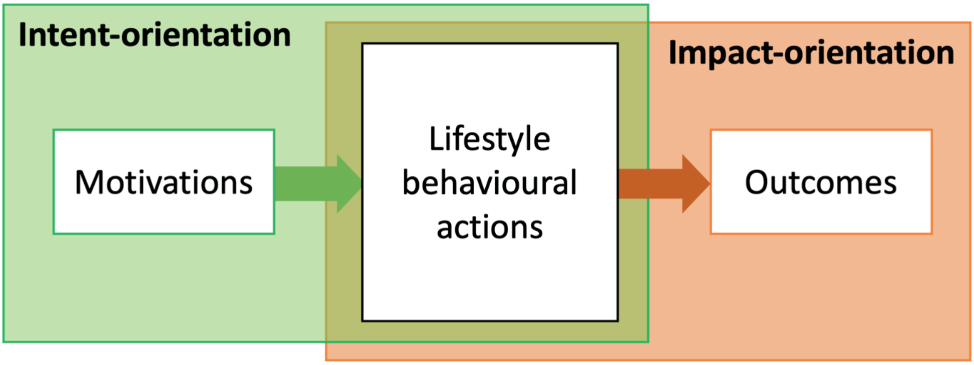


Figure 7-1: A holistic approach: intent and impact-orientations to lifestyle and behaviour actions

It is vital to distinguish between behaviours, lifestyles and consumption, as they fundamentally differ from each other. Researchers in different disciplines often use different terms (e.g. lifestyle, behaviour, consumption patterns, sustainable living, social practices, etc.), with those terms sometimes used interchangeably, and sometimes used intentionally distinct. To interpret concepts and guide strategy and action effectively, there needs to be consistency between disciplines, and harmonisation of terminology is crucial. This research harmonises lifestyle change definitions across various frameworks and tools. Throughout the chapters, the term 'lifestyle' is used as cross-cutting the dominant domains (e.g. transport, residential, food), while 'behaviour' describes the actions within the domains. These types of actions can be categorised within the ASI framework. Furthermore, the term 'consumption' is used to describe the outcomes of the actions (i.e. impact-oriented approach), for instance on the activity and structure/service changes in the ASIF* decomposition tool (Chapter 3). Through the AFI framework motivations and enabling/contextual factors can be identified that are important for representing or affecting the intent of lifestyle and behaviour changes (Chapter 2).

It is worthwhile combining intent and impact orientations in single studies. Typically, studies choose either an intent or an impact-oriented approach, rather than combination of the two. While, for example, modelling studies typically only focus on behavioural actions in terms of outcomes, environmental psychology studies would focus predominantly on motivations of behaviours. By modelling lifestyle changes with the intent and impact of lifestyle changes (see Figure 7-1), why, how *and* what lifestyles change can be addressed. Without considering the other, one perspective can only communicate half the story. As such, this joint perspective would benefit lifestyle change modelling *and* effective communication with policymakers and other key stakeholders (Chapter 2, Chapter 5 and Chapter 6).

Modelling a broader range of lifestyle changes and enablers that crosscut dominant domains is vital due to climate change's magnitude, scale and urgency. While most studies focus on the dominant domains (e.g. transport, residential and food), some analyse cross-domain aspects central to lifestyle changes (e.g. shifts in time-use patterns and social change movements reinforcing sustainable living). Covering a broader range of lifestyle changes, IAMs should focus on cross-domain entry points, which indirectly affect the dominant sectors in IAMs. These lifestyle changes can lead to more transformative actions within domains. For example, smaller living spaces would lead to both reduced energy consumption and a reduction of goods per household, teleworking would reduce commuter transport and energy use and material needs at the office. These transformative actions are generally modelled less extensively in IAMs. Furthermore, by representing enabling factors, modellers can depict lifestyle changes within the larger systems change. Therefore, vital decision makers (e.g. government, companies, consumers) responsible for specific changes can be identified (Chapter 2).

Each modelling approach has trade-offs that should be weighed based on the research aim. There are trade-offs between exogenous and endogenous modelling detail, ranging from ad-hoc and informed exogenous inputs to partially and fully endogenous modelling. The trade-offs include ease of implementation and coverage of system versus dynamic modelling and more representative changes. Using exogenous inputs, for example through the modelling of scenario narratives, more of the lifestyle system and lifestyle energy use from empirical studies can be covered, and it is easier to implement. Therefore, exogenous modelling has a higher potential for empirical representation. However, this approach lacks a dynamic representation of the uptake of specific lifestyle changes. Adopting an endogenous modelling approach, for example adding consumer segments, limits the coverage of the lifestyle change system but allows a better representation of changes in specific lifestyle choices. No approach is stronger or weaker than the other: each has its strengths and weaknesses, and the most insightful chosen approach depends on the question (Chapter 2).

The adapted ASIF* decomposition tool can be tailored to behaviours, for interpreting consumption and technology changes from model outputs. This ASIF* (Activity, Structure/Service, Intensity, Fuel mix) decomposition tool for IAMs allows highlighting the impact of behaviour change on per-capita emissions in scenarios (see Figure 7-2). The ASIF factors are also connected to the ASI (Avoid, Shift, Improve) framework. Activity changes result from Avoid interventions, structure/service from Shift interventions and intensity and fuel mix from Improve interventions. By emphasising the required variables and parameters for measuring consumption and technology changes, IAMs can improve the translation of behaviour-related scenarios to model parameters. Moreover, the decomposition tool can visualise differences in trends in the ASIF* factor changes between Global North and Global South regions. The tool can present changes between two points in time, over time with multiple time steps, and between different endpoints. While this tool is applied on the outputs from the IMAGE integrated assessment model, it can also be applied on outputs from other process-based IAMs, especially those with a high spatio-technological resolution. It is also possible to further decompose factors for a more detailed representation of consumption and technology changes (Chapter 3).

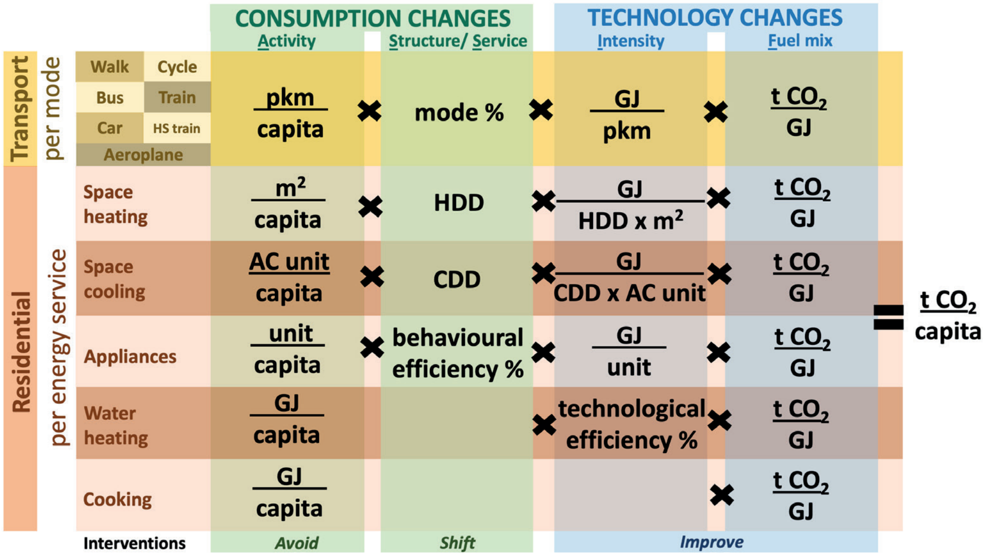


Figure 7-2: Breakdown of variables and units for decomposition analysis in transport modes and residential energy services in terms of the Activity, Structure/Service, Intensity and Fuel Mix (ASIF*) impact factors, HDD = Heating Degree Days, CDD = Cooling Degree Days, pkm = passenger-kilometres, AC unit = air-conditioning unit

7.3.2. What is the impact of changes in consumption on emission reductions compared to technology changes in future scenarios?

Consumption change is a critical factor in terms of future carbon emission levels, resulting in an increase in current emissions ranging from 75% (when following trends) to 26% (with measures in place). Consumption change plays a role in all model-based scenarios published in the literature. Differences in lifestyle, for instance, are critical in defining the differences in the Shared-Socio-economic Pathways (SSPs). Moreover, in nearly all scenarios consumption changes over time – often as a function of economic development: consumers are assumed to shift towards more meat-intensive diets and to change transport behaviour and living practices. These changes (often towards higher emissions) are typically not addressed or explored in terms of mitigation potential. At the same time, only a few scenarios exist that explicitly consider the impact of shifts towards more sustainable behaviours – including the scenarios of van Sluisveld et al. (2016) using IMAGE (henceforward referred to as VS scenarios), albeit based on stylised assumptions. The ASIF* decomposition tool can make the impacts of consumption change explicit in all scenarios. The earlier IMAGE VS scenarios show that behaviour change leads to a 13-31% reduction in per capita emissions from consumption changes compared to an SSP2 baseline scenario (see Figure 7-3). Consumption changes can make society less reliant on technology changes to achieve climate targets (see Figure 7-3). Even with more sustainable behavioural changes, global per-capita emissions are projected to increase if technologies do not change towards more low-carbon options, but less drastically so. This means that the dependence on technological advancement to reach a 2°C climate target is reduced if lifestyles become more sustainable (Chapters 3 and 4). According to the 2022 IPCC reports (Creutzig et al., 2022), shifting demand is required for achieving current climate goals.

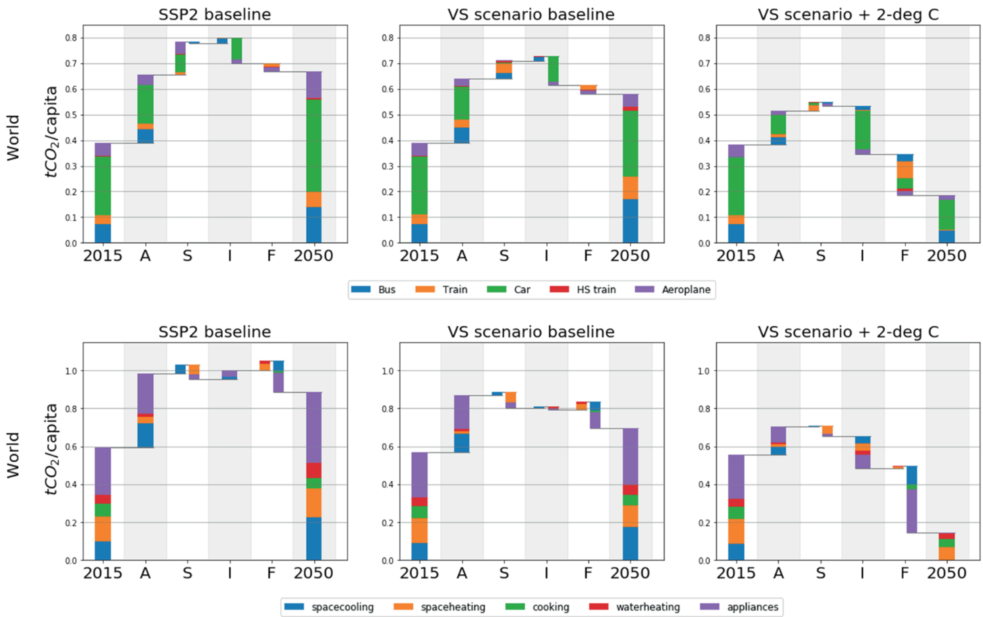


Figure 7-3: Decomposition of per capita transport (top) and residential emissions (bottom) for the business-as-usual scenario (SSP2 baseline) and two behaviour scenarios that exclude (VS scenario) and include (VS scenario + 2-deg) climate policy. The categories A (Activity changes), S (Structure/Service changes), I (Intensity changes) and F (Fuel mix changes) represents the contribution of these factors to the change in emissions between 2015 and 2050 for various regions.

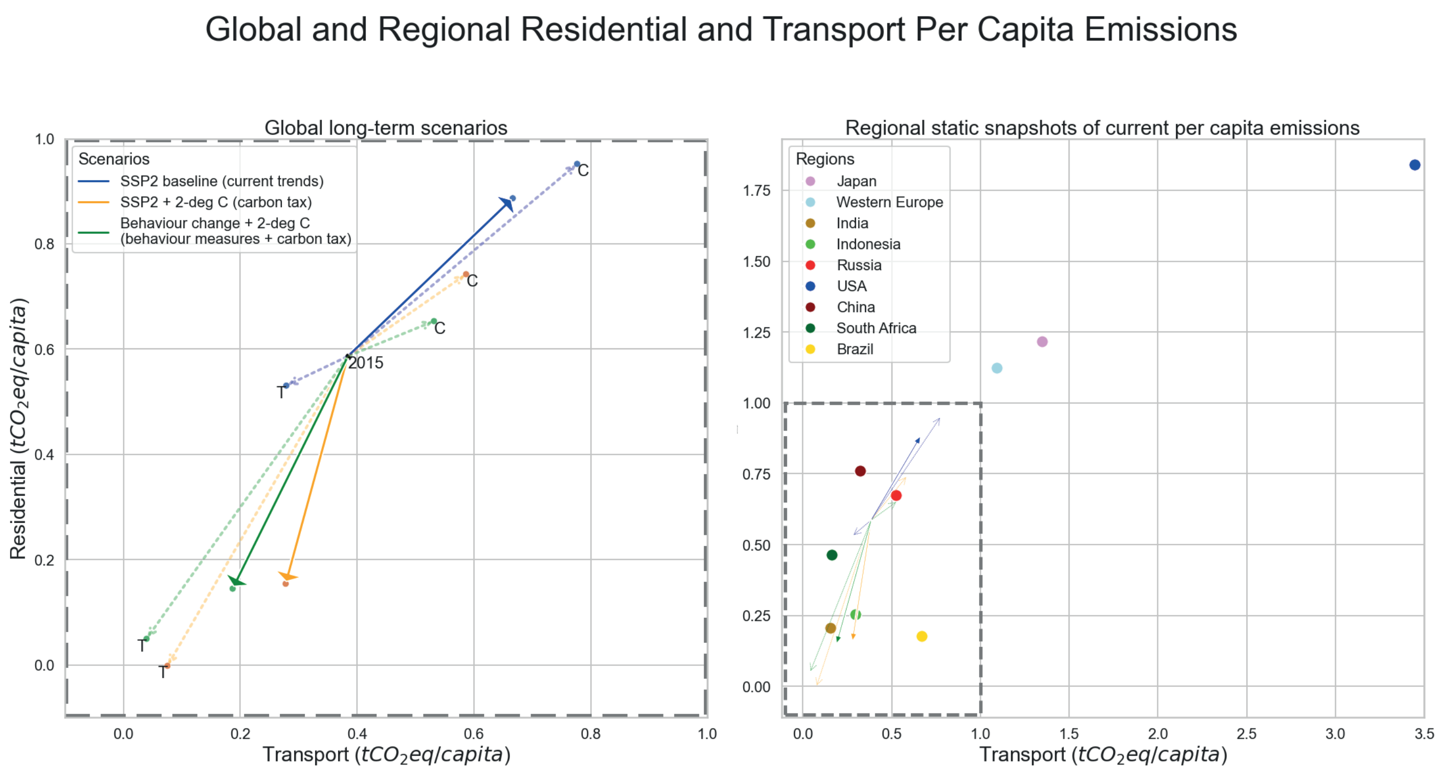


Figure 7-4 Left: Global long-term scenarios and impacts from different types of changes, C=consumption changes (without technology changes), T=technology changes (without consumption changes); Right: Global long-term scenarios (zoomed-out, as shown by the grey, dotted boxes) in context of regional current per-capita emissions.

7

7.3.3. How do emissions from current lifestyles compare to the emission levels consistent with climate targets?

Heterogeneous segments within and between regions show a variety of lifestyles and contexts affecting CO_2 emissions. Multi-regional comparisons (see left side of Figure 7-4) show notable differences in CO_2 emissions from transport and the residential sector, caused by different consumption patterns and contextual factors affecting technologies. A within-region comparison for Japan shows significant differences in consumer segments, primarily in residential CO_2 emissions. The diversity sheds light on high-emitting behaviours and guides targeted interventions for achieving high-quality lives with lower emissions in equitable ways (e.g. cost-effective and convenient options). This diversity also highlights the importance of accounting for heterogeneity in scenario analysis, development and modelling.

Carbon emissions associated with transport patterns of some large consumer segments in Japan are close to those in a 2°C climate scenario in 2050. Due to Japan's sustainable transport system and consumer preferences, many consumer segments in Japan have relatively low emissions in the transport sector (see right side Figure 7-4). They are thus close to per-capita emissions in line with 2°C (i.e. Behaviour change + 2-deg C scenario). This also reinforces the importance of enabling infrastructures to shift to low-emission behaviours. However, Japanese per-capita residential emissions of many consumer groups are way above those needed in 2°C pathways by 2050.

7.3.4. What are possible future scenarios towards sustainable living?

The SLIM scenarios illustrate how structural support and value systems shape lifestyles differently and change dynamically in response to enablers and societal shifts while emphasising other vital drivers of change. The SLIM (Sustainable Living in Models) (see Table 7-2, Figure 7.5 and Figure 7-6) were developed with input from various advisors and selected policymakers. Through a scenario planning approach, scenarios narratives were created drawing on insights from social sciences, modellers and policymakers. The scenario development process led to the identification of two critical uncertainties and drivers: level of centralised or distributed support for lifestyle changes, and more individualistic or collectivist values in a society. This led to the identification of four divergent plausible scenarios of lifestyle change. Decentralised support is evident in Designed World and Global Commons, whereas Pocket Lifestyles and Big Village reflect futures in which lifestyle changes occur in the context of more distributed support. Individualistic values drive lifestyle change in Designed World and Pocket Lifestyles, whereas Global Commons and Big Village reflect plausible future societies in which collectivist values are dominant. These divergences shape the characteristics of the contrasting scenario narratives in which lifestyles could change (see Box 2). Furthermore, societal changes, enablers, lifestyles, and behaviours are all vital to the scenario narratives (see Figure 7-5). These contrasting characteristics allow for a holistic discussion of the types of futures that are plausible, especially in combination with their impact on emissions. By asking 'what could the world look like in 2050' and exploring divergent lifestyle and emission implications, it becomes possible to rehearse possible interventions, check their robustness against plausible future scenarios, and ultimately guide action toward preferred futures. Furthermore, it helps us identify innovative responses under deep uncertainty and complexity and understand implications for decision-making, in multiple futures. Various other vital drivers of change affect lifestyles (see Table 7-3), such as individual agency, the pace of life, equity, security and safety, and technology support (public, private or community) (Chapter 5).

The extent and speed of lifestyle changes are vital for modelling the SLIM scenarios and, consequently, for enabling analysis of lifestyle change contributions to climate change mitigation. Detailing these scenarios into dominant domains with recognisable characteristics (i.e. behaviours), allows a scenario narrative to paint a fuller picture of what life may be like in 2050 and beyond. This, in turn, translates into scenario inputs for quantitative modelling in integrated assessment models. For example, the SLIM scenarios captured the extent and speed of choosing to live in a minimalist apartment or tiny house in the Pocket Lifestyles scenario. This was implemented through a cap on floor space per capita reducing over the years until 2050. This allows for differentiation between regions and income quintiles because the cap only affects those regions/quintiles with a floor space per capita above the cap. Therefore, the assumptions made are more nuanced considering regional context and consumption patterns (Chapter 5 and Chapter 6).

The emphasis on regional differentiation and equity considerations in modelling the SLIM scenarios affect the extent of lifestyle change adoption and impacts on climate change mitigation. The scenarios distinguished between Global North and Global South in the scenario assumptions, accounting for context-dependent factors for different regions. Furthermore, in the residential sector, some behavioural actions were modelled so that different groups (i.e. different incomes, rural or urban households) implemented actions in a different manner. Certain assumptions for Pocket Lifestyles, especially in the residential sector (e.g. appliance ownership), affect only higher-income groups or the highest emitters. In Designed World, which relies more on technology changes, residential emissions are lower, primarily for households or governments that can invest in low-carbon technologies. This implementation allows for a more nuanced representation of lifestyle changes in the context of fairness (Chapter 6).

Box 2. What are the SLIM scenarios?

The SLIM (Sustainable Living in Models) scenarios are contrasting 'what-if' futures of lifestyles and larger systems change. They diverge in the type of support (distributed vs. centralised) and on values (individual vs collective). **Designed World** leans towards individual values and centralised support and is labelled as "sustainable lifestyles by default". **Global Commons** likewise has access to centralised support, is represented by collective values, and is characterised as "inclusive global governance system". **Big Village**, also reflects more collective values, and is a society with access to more distributed support for sustainable lifestyles, and has the tagline "community-based sustainable living". **Pocket Lifestyles** similarly reflects access to distributed support, however, it is driven mostly by individualistic values, and is described as "peer-to-peer lifestyle platforms".

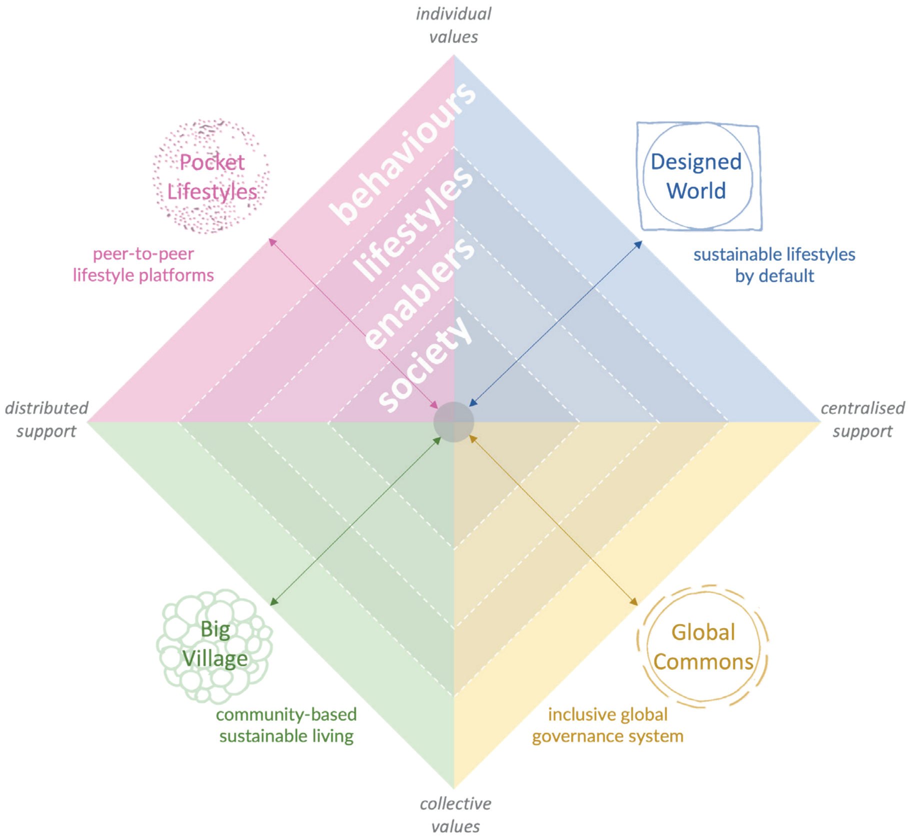


Figure 7-5: Overview of the lifestyle scenario narratives (i.e. Designed World, Global Commons, Big Village and Pocket Lifestyles) varying in type of support (distributed vs. centralised) and values (individualist vs collective) across different characteristics, namely changes in society, enablers, lifestyles and behaviours, diverging from the reference scenario narrative (i.e. Tech-Innovation represented by the circle in the middle).

Table 7-2: Overview of value positions and summary statements regarding each scenario narrative

Reference Scenario **Tech-Innovation**	*Tagline:* **net-zero by tech change** Technological innovation is the dominant climate mitigation strategy, and lifestyle change plays a minor role.
Lifestyle Scenario **Designed World**	*Tagline:* **sustainable lifestyles by default** *Individualistic values / Centralised access to structural support* Governments, corporations and cities leverage existing values and market systems to shape citizen and consumer preferences and practices.
Lifestyle Scenario **Global Commons**	*Tagline:* **inclusive global governance system** *Group / Collectivist values / Centralised access to structural support* Universal values shape ways of living, new institutions, and a global governance structure with less emphasis on sovereignty, with a more active Global South participation.
Lifestyle Scenario **Big Village**	*Tagline:* **community-based sustainable living** *Group / Collectivist values / Distributed access to structural support* People band together in communities regionally while remaining networked globally to support bottom-up innovation, shared infrastructures, and belonging.
Lifestyle Scenario **Pocket Lifestyles**	*Tagline:* **peer-to-peer lifestyle platforms** *Individualistic values / Distributed access to structural support* People take it upon themselves to adopt and rapidly spread ambitious sustainable lifestyles, behaviours and practices through digital technology.

Table 7-3: Qualitative characteristics

Scenario narratives Characteristics	**Tech-Innovation**	**Designed World**	**Global Commons**	**Big Village**	**Pocket Lifestyles**
Individual agency	Low	Low	Medium	High	High
Technology support for lifestyle change	Digitally enhanced	Digitally enhanced	Digital, low-tech	Low-tech	Digitally enhanced
Pace of life	Fast pace	Fast pace	Medium pace	Slower pace	Fast pace
Inclusive access / Social equity	Low	Medium	High	Medium	Low
Security and safety	Low	High	High	Medium	Medium
Public / Private / Community	Private	Public-private with city	More public	Community public	Market / Private
Speed of lifestyle transition	Low	Low-medium	Medium	Medium-fast	Fast
Extent of lifestyle change adoption	Low	High	Medium-high	Low-medium	Low-medium

Figure 7-6: Visualisation of the lifestyle scenario narratives

7.3.5. What are the emission implications of possible future scenarios towards sustainable living?

Lifestyle changes contribute substantially to climate change mitigation, but other measures, such as larger systems change, are also vital to support these changes and to achieve more transformative outcomes. Figure 7-7 shows that in Designed World, emissions are reduced more strongly than in Pocket Lifestyles. This is mostly because Designed World is characterised by larger systems change (e.g. electrification of vehicles). The extent to which this happens, and when, differs between scenarios. By far the most substantial reductions occur in transport emissions in Designed World (51% in Global North and 39% in Global South compared to SSP2 reference), reaching levels below the default SSP2 2-deg scenario by 2050. Reductions in residential emissions for Designed World are also noteworthy but not as substantial (21% for Global North and 5% for Global South). Pocket Lifestyles with less systems change, have more modest emission reductions for transport (16% for Global North and 32% for Global South) and residential (14% for Global North and 7% for Global South). Furthermore, the transition to more sustainable ways of living is initially quicker for Pocket Lifestyles but slows down because of lower and distributed systems support, while for Designed World, lifestyle changes experience a slower start but a larger reduction overall as systems supports become more widespread and significant. Combining aspects of Designed World and Pocket Lifestyles could also be realistic, incorporating technological solutions *and* lifestyle measures for larger systems change (Chapter 6).

The SLIM scenarios show plausible future pathways that align with results close to the 40-70% emission reductions from demand-side measures stated by IPCC. The latest IPCC report states that "Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end use sectors by 40-70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources" (Creutzig et al., 2022). It should be noted that this refers to the sum of all measures implemented in end-use sectors, including fuel switching and efficiency improvement. When considering only Global North regions, the emission reductions from 2015 to 2050 of the modelled SLIM scenarios are well within the range. For Designed World and Pocket Lifestyles emissions would reduce by 45% and 61% for Global North. However, emissions would increase for Global South regions due to their expected economic development, i.e. by 15% and 21% in Designed World and Pocket Lifestyles, respectively. A few points should be highlighted about these percentages. Firstly, the SLIM scenarios assume only lifestyle changes and no additional climate policy. Emission reductions would be significantly higher if lifestyle changes would be combined with other technology changes, as possibly induced by carbon pricing (as in the IPCC numbers). Secondly, the 40-70% values from IPCC are indicating potential, while the SLIM scenarios are based on informed assumptions with limitations on the speed and extent of lifestyle changes adopted. For example, instead of assuming all people will adopt a heat pump, the SLIM scenarios assume a lower adoption and regional differentiation based on availability, facilitation, willingness or capability, to name a few. Thirdly, a combination of Designed World and Pocket Lifestyles, or the other SLIM scenarios, Global Commons and Big Village (not modelled in this research) could lead to higher emission reductions (Chapter 6).

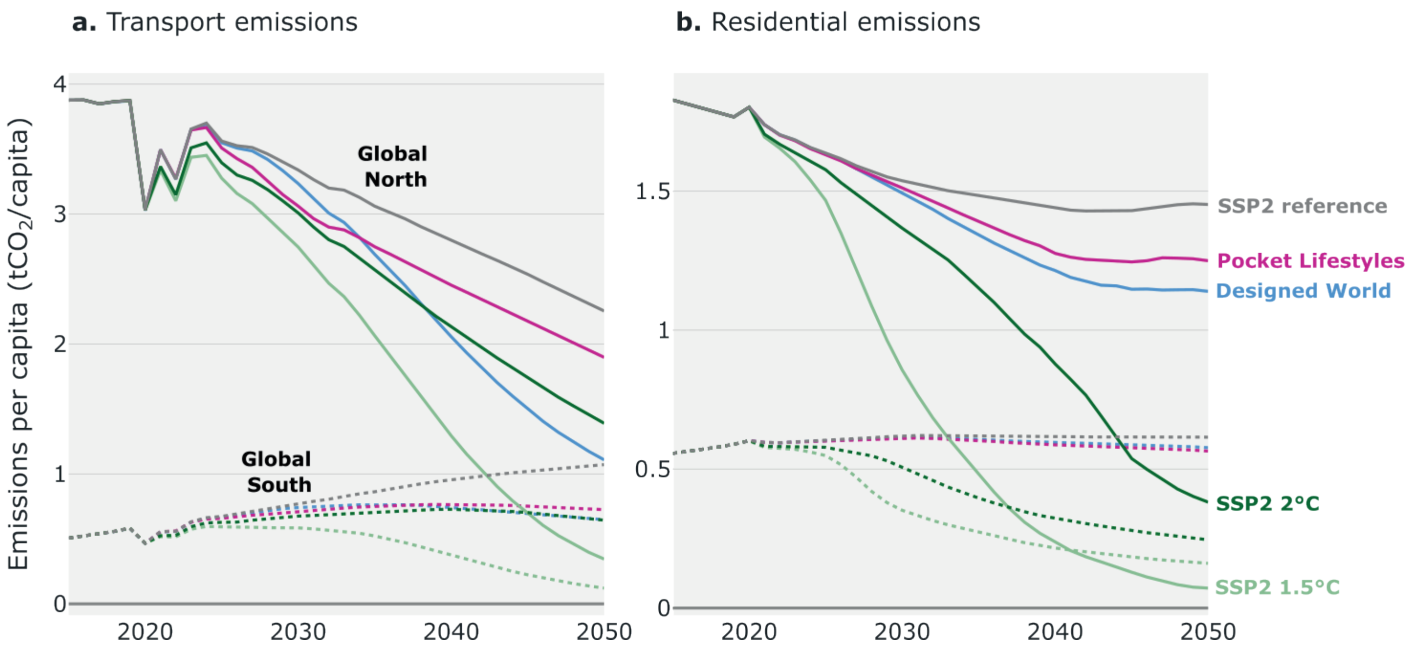
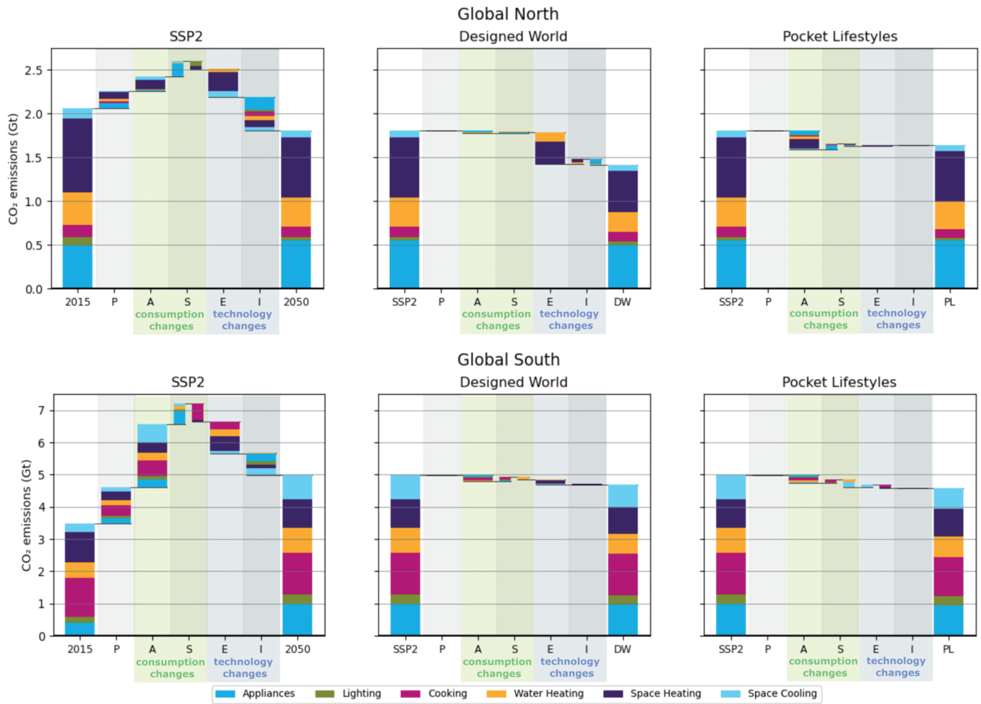


Figure 7-7: Long-term scenarios between different regions Global North and Global South (shown by solid and dashed lines, respectively) on transport and residential per capita emissions.


Global North
SSP2
Designed World
Pocket Lifestyles
Global South
CO₂ emissions (Gt)
2015
P
A
S
E
I
2050
SSP2
DW
PL
consumption changes
technology changes
Appliances
Lighting
Cooking
Water Heating
Space Heating
Space Cooling

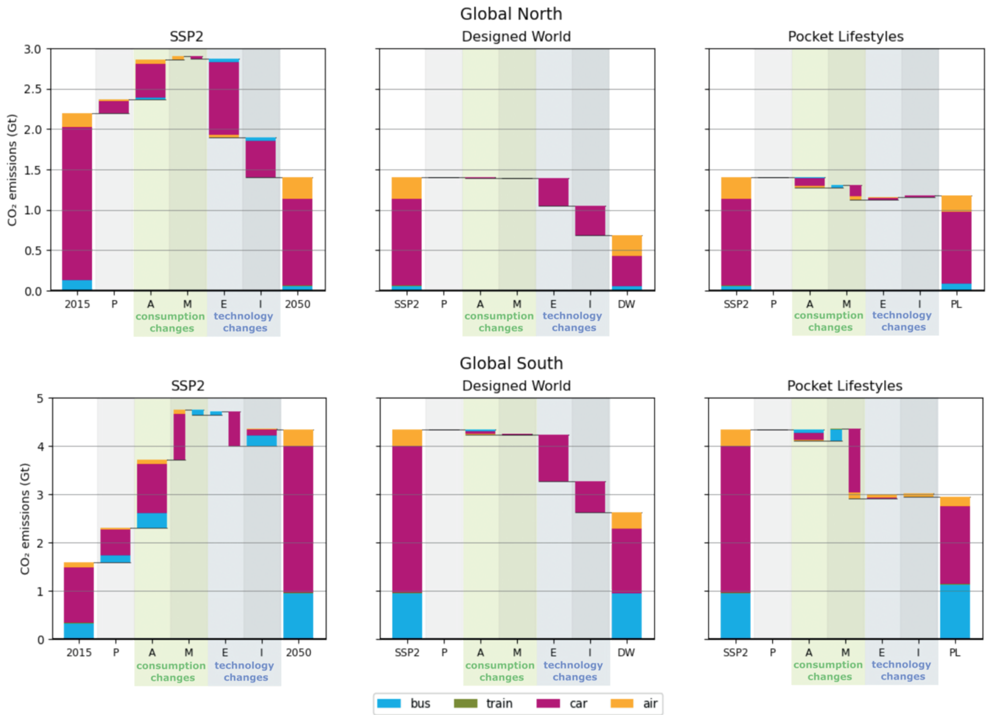

Global North
SSP2
Designed World
Pocket Lifestyles
Global South
CO₂ emissions (Gt)
2015
P
A
M
E
I
2050
SSP2
DW
PL
consumption changes
technology changes
bus
train
car
air

Figure 7-8: SLIM scenarios Designed World and Pocket Lifestyles compared to reference SSP2 scenario. Residential (top two rows) and passenger transport decomposition results (bottom two rows). The different colours represent the passenger transport modes and residential energy services, respectively. The waterfall charts depict the change in emissions from various factors, population (P), activity (A), mode shares (M)/service (S), efficiency (E) and CO_2 intensity (I).

Of the SLIM scenarios modelled, emissions in Pocket Lifestyles are reduced primarily through consumption changes, while emissions in Designed World are reduced primarily through technology changes. The SLIM scenarios show different types of changes. Figure 7-8 shows that technology-related lifestyle changes would be key to reducing emissions in Designed World, whereas consumption changes would significantly impact emissions in Pocket Lifestyles. In Designed World, reductions would be mainly achieved through lifestyle changes related to efficiency and CO_2 intensity improvements. For Global North, transport and residential emission reductions would be 50% and 20%, and for Global South, 37% and 3%, respectively. In Pocket Lifestyles, consumption changes (i.e. less and shifts in activity) play a major role. For Global North, emission reductions for transport and residential would be 16% and 10%, and for Global South 27% and 8%, respectively. For Pocket Lifestyles, the impacts are notable for teleworking, shifts to sustainable transport modes and smaller homes. In contrast, in Designed World, considerable impacts come from electric vehicles, peer-to-peer taxi services and home insulation, heat pumps and electrification (Chapter 6).

Different trends are observed in SLIM scenarios compared to earlier scenarios with behaviour change. Compared to the previously-developed VS scenario (van Sluisveld et al., 2016) as shown in Figure 7-3, Pocket Lifestyles and Designed World show different trends. Overall, the SLIM scenarios have larger emission reductions than the VS scenario. However, for Pocket Lifestyles, transport emissions in Global North are higher. This is most notably due to the smaller efficiency improvements and shifts to sustainable fuels, and also due to fewer people projected to be travelling by public transport. As the assumptions in the VS scenario were more stylised than the assumptions in the SLIM scenarios, behaviour change in the former scenario could have been overestimated. For instance, in the VS scenario, it was assumed that everyone would change behaviours in the same way. In addition, overlooking cross-cutting lifestyle changes that can have cascading effects on lowering consumption and emissions across domains could also lead to an underestimation of the impact of the behaviour changes. The SLIM scenarios accounted for regional differences and enabling factors and motivations affecting the extent and speed of transition. The different approaches and more nuanced modeling of the SLIM scenarios reflect in different results compared with previous work (Chapter 6).

7.4. MAIN CONCLUSION

By addressing the research questions discussed above, we were able to answer the main research question **"How can IAMs improve the representation of lifestyle changes to show the possible role of lifestyles in climate change mitigation strategies?".**

Both intent and impact orientations should be addressed when modelling lifestyle changes. A holistic approach focusing on both motivations and outcomes of behaviour and lifestyle changes allows for more insights into lifestyle changes.

It is crucial to make use of frameworks and tools to harmonise definitions and characterise types of lifestyle changes. Researchers often use different terms relating to lifestyle changes, varying across disciplines. These are sometimes used interchangeably, but other times intentionally distinct from each other. Therefore, harmonising the use of these terms is particularly important. Frameworks and tools can help align different approaches and disciplines for modelling lifestyle changes effectively. Table 7-4 presents the frameworks and tools applied in this research, and we emphasise their usefulness for other research and models.

Table 7-4: Application of frameworks and tools in this research

Framework / tool	Application
ASI framework	The ASI (Avoid, Shift, Improve) framework was used to analyse literature and methodologies. It has been included in the development of the ASIF* decomposition tool, and the quantification of the SLIM lifestyle scenarios. This framework enables modelers to partially bring an intent-oriented and partially an impact-oriented perspective on lifestyle changes.
AFI framework	The AFI (Attitudes, Facilitators, Infrastructure) framework was used to analyse relevant literature and methodologies and incorporate motivations and contextual factors to scenario narrative development.
ASIF* decomposition tool	The ASIF* (Activity, Structure/Service, Energy Intensity, Fuel Mix) tool was developed to distinguish between consumption and technology changes of emissions in the IMAGE output. The decomposition tool is already implemented as an add-on tool to IMAGE scenario runs. It was tested with existing scenarios, a case study in Japan, and SLIM scenarios. The decomposition tool adopts a fully impact-oriented perspective to analyse scenarios with insights into lifestyle changes.

Creating qualitative scenario narratives and quantitative emission pathways together is vital for representing lifestyle changes. As identified in the trade-offs between different modelling approaches, using exogenous inputs (e.g. narratives) in models for creating emission pathways allows the capturing of a fuller qualitative representation of lifestyle changes. Therefore, combining the qualitative with intent-orientation and the quantitative with an impact orientation, results in valuable insights from various perspectives for informing a range of audiences from modelers to policymakers, as was done in this research (see Table 7-5).

Endogenous modelling of lifestyle changes needs to improve to capture dynamic systems. As identified in the trade-offs between different modelling approaches, endogenous modelling of lifestyle changes allows for a more dynamic representation, yet, makes it more difficult to represent a fuller system. To model the SLIM scenarios, further heterogeneity with the adopter groups (Rogers, 2010) was modelled for explicit representation of the extent and speed of transition. The model development adopts mostly an impact-oriented perspective focusing on how to model parameters and variables. However, applying the Diffusion of Innovation theory (Rogers, 2010), on which the adopter groups are based, requires an intent-oriented perspective, adding a different perspective within the model and not just in the narratives. Therefore, the endogenous modelling helped better capture the SLIM scenarios in the IMAGE integrated assessment model. Other IAMs could approach the modelling of lifestyle changes endogenously similarly to better represent lifestyle changes (Chapter 6).

Table 7-5: New scenario outputs in this research

Scenario outputs	Details
Lifestyle scenario narratives	Four diverse qualitative scenario narratives focused on lifestyle changes were developed with stakeholders. These narratives include quantitative assumptions for translating these into model inputs. The development of the lifestyle scenario narratives mostly adopted an intent-oriented perspective, focusing on the why, how and who related to lifestyle changes. It also incorporates an impact-oriented perspective, with regards to the translation to model inputs, for which the scenario narratives were intended, in addition to informing policymakers and stakeholders.
Lifestyle scenario emission pathways	Two of the four lifestyle scenarios were modelled by translating the quantitative assumptions into model inputs. The modelling of the lifestyle scenarios adopted mostly an impact-oriented perspective, focusing on the model outputs (e.g. emissions). Because of the qualitative assumptions used in the scenario inputs, it also required an intent-oriented perspective.

Through a transdisciplinary co-creation process, the scenario narratives enable strategic discussion among various users. These scenario narratives provide valuable insights that can position lifestyle changes, in the context of systems change, as solutions in climate mitigation. The inclusion of lifestyle changes in scenarios can inform climate negotiations. Approaching this process via scenario planning allows us to explore possible pathways, make our assumptions about futures explicit, and explore various plausible future pathways to sustainable lifestyles in order to have a more strategic dialogue about what could emerge and to determine robust strategies for climate action (Chapters 5 and 6).

With the SLIM scenarios' improved representation of lifestyle changes in IAMs, stakeholders can make more informed decisions about facilitating lifestyles as strategies for mitigating climate change. IAMs generally represent behaviour and lifestyle changes with stylised assumptions, or not at all. This means that lifestyle changes are often overlooked or underexplored as strategies for mitigating climate change. This research emphasises that with the SLIM scenarios developed in this thesis, policymakers can explore possible pathways for lifestyle changes and their impacts for more informed decisions about strategies for mitigating climate change (Chapter 6).

7.5. RESEARCH RECOMMENDATIONS

This research recommends 1) broadening and improving the application of the ASIF* decomposition tool, 2) adding additional heterogeneity to models and scenarios, including more equity considerations in assumptions, 3) expanding and diversifying participation in scenario development, 4) incorporating more disciplinary perspectives in the qualification and quantification of scenarios, 5) explicitly modeling lifestyle changes, and 6) expanding the scenario modelling to model excluded scenarios and sectors.

The ASIF* decomposition tool could be improved for future scenario analyses.

It is interesting to explore more ways to present the decomposition outcomes. For example, instead of analysing the model responses between two points in time (as was done in this research), the decomposition tool could be applied for multiple time steps or even annually to show the results as emission pathways. This would show more detail on trends over time. Furthermore, the tool can be expanded with additional indicators. This research proposes a complete structure for the decomposition tool for the residential and transport sectors. Creating more relevant variables in IAMs forms a stronger basis for improved lifestyle and behaviour change modelling for future research.

The application of the ASIF* decomposition tool can be broadened. There are also other scenarios with behavioural change, but applying the decomposition tool is complex, given the differences in model outputs. For better model response interpretations, it would be valuable to harmonise and compare the results of this decomposition analysis with other scenarios on behavioural change. This decomposition tool could function as a basis for harmonising various scenarios. Process-based IAMs with a high spatio-technological resolution are considered most suitable to include in a broader application of the ASIF* decomposition tool, given their closest representation of consumer behaviour and decision-making. If IAMs could get their output variables to match the tool's variables, the tool could also find application in a broader set of modelling frameworks.

Adding more heterogeneity to IAMs and long-term scenarios allows a better representation of consumers and lifestyle changes. Figure 4-4 shows substantial differences between consumer segments within regions. To better represent consumers and behaviour change in models, modellers can add different 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 the 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), as was done in the modelling of the two SLIM scenarios. The additional detail per adopter group allows the consideration of different market segments and transition speeds and can inform tailored policies and climate action solutions to support diverse pathways to sustainable lifestyles.

Expanding the range of representatives in participatory scenario development improves future scenario work. A range of advisors from different disciplines and regions were included to provide input into the creation of these scenario narratives. This stimulated great discussions and challenged biases about lifestyle changes for more representative futures. Even though several Global South representatives were included as advisors or policymakers, a specific Global South focus could improve scenario narratives in future work. Due to their traditional practices and continued development, Global South leaders are important to climate change mitigation. Furthermore, business representatives were not included in the scenario development process, as they were not actively recruited. However, the business perspective is valuable, especially as they play a strong role as enablers for lifestyle changes. Therefore, for future work, the scenario narratives could be further refined with a range of business representatives.

Incorporating more disciplines in the qualification and quantification of scenarios leads to valuable new perspectives. In the development of the SLIM scenarios qualitative with quantitative methodologies were bridged to create scenarios of lifestyle changes. Translating qualitative narratives into quantitative inputs to develop scenarios has allowed for a more nuanced representation of lifestyle and systems changes in IAMs. The lifestyles scenarios built on quantitative modelling and qualitative research could be applied to specific regions to diversify individual and community motivations and may lead to new, vernacular, cross-disciplinary, and sustainable actions. Although this work draws on multiple disciplines, many disciplines have not been included in the scenario development. Health sciences, for instance, could inform us about lifestyle changes for health-related changes. This expansion of disciplinary input could be further explored in future work. Exploration of differentiating value evolution may result in new variations of adoption rates and climate mitigation solutions. When scenario planning is supported by integrated assessment modelling, further multidisciplinary scenario narratives give compelling outlooks to policies that allow for broader engagement from various climate community stakeholders.

There is an opportunity to create specific lifestyle modules within IAMs: rearranging lifestyle-related parameters and variables to be explicitly available in the model. In the modelling of the SLIM scenarios, while some assumptions about the adoption rates and adopter groups were explicitly modelled within TIMER (especially in the residential sector), other assumptions were challenging to implement directly. In the transport sector, the model parameters are not directly linked to the scenario assumptions. For example, to encourage more electric vehicle adoption, a lower technology cost for electric vehicles was assumed, which leads to higher adoption. The adopter groups could not be directly linked to the technology costs of vehicles. For residential, however, the narratives' translation to scenario inputs was improved by creating adopter groups as an extra layer of heterogeneity. Still, there are opportunities to further improve the translation of lifestyle changes into the model. One way is via a designated lifestyle module outside the passenger transport and residential sectors with linkages to these sectors.

Modelling other lifestyle scenarios and expanding to other sectors would enable additional comparisons and insights. Of the SLIM scenarios, Designed World and Pocket Lifestyles were modelled, but Global Commons and Big Village were excluded from the scenario modelling. The Designed World and Pocket Lifestyles could be better represented in IMAGE, while Global Commons and Big Village would require substantial changes. There are vast opportunities to represent more transformative value shifts to collective values such as those in Global Commons and Big Village. Furthermore, this research represents passenger transport and residential and can be expanded to other sectors such as food and consumer goods). In future work, these excluded scenarios and sectors should be explored in IAMs for a more holistic analysis.

7.6. POLICY RECOMMENDATIONS

For policymakers, this research recommends 1) centring a just energy transition when considering lifestyle changes, 2) including larger systems and lifestyle changes, 3) building capacity in using scenarios for decision-making and 4) taking a holistic approach.

Lifestyle change towards sustainable development depends on enabling conditions (e.g. infrastructure) – that need to be facilitated by governments. This research modelled the SLIM scenarios mainly driven by individualistic values. With lifestyle changes from centralised support (including enabling conditions such as sustainable infrastructural design) in Designed World, emissions would be lower than the SSP2 reference scenario by 39% for Global North and 27% for Global South. With distributed support, in Pocket Lifestyles, the reduction would be 15% for Global North and 23% for Global South. The other SLIM scenarios (yet to be modelled) are primarily driven by collective values and could show even larger emission reductions. The impact of lifestyle changes (in these modelled scenarios) is substantial, but larger systems change is also needed to enable these lifestyle changes and to reach the climate targets. Therefore, facilitation by governments is vital, and also require bottom-up initiatives.

Equity should be a key consideration in the lifestyle change discussion. The results from chapter 4 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. These insights can guide policy, infrastructural and supportive cultural interventions to enable these low-emission consumption patterns.

Use these scenario narratives and emission pathways effectively by imagining sustainable futures and the implications for policies and climate action. The scenario narratives (chapter 5) and emission pathways (chapter 6) are useful for imagining sustainable futures to fully understand how policies could affect global communities and people's everyday lives. These scenario narratives position 'demand drivers' and lifestyle change as key catalysts for change, highlighting the importance of individual and community actors and the multitude of sustainable directions that demand drivers can shift towards. These scenarios can help guide strategic dialogue and global climate change mitigation decisions and actions.

Consider lifestyle change in the context of larger systems change. As determined from all chapters, larger systems change and lifestyle change can be considered two sides of the same coin (Capstick et al., 2020). However, often these are considered separately, leading to 'consumer scapegoatism' (Akenji, 2014), in which the responsibility is put on consumers to change their lifestyles, while much is out of their control. Therefore, there are limitations in climate change mitigation with only lifestyle change (as evident in the Pocket Lifestyles of the SLIM scenarios). A broader mitigation strategy is necessary to include both sustainable lifestyles and larger systems change. The multidisciplinary nature of this research allows for an integrated systems approach and furthers the insight that our context significantly shape lifestyles.


KAPITTELZAAL
MCMXL

SAMENVATTING EN CONCLUSIES

8.1. INTRODUCTIE

De uitstoot van anthropogene broeikasgassen (BKG) is sinds 1850 vrijwel voortdurend toegenomen en het is ondubbelzinnig bewezen dat dit bijdraagt aan de klimaatverandering (IPCC, 2022). In het Akkoord van Parijs van 2015 (UN, 2015) zijn landen overeengekomen om de gemiddelde wereldwijde temperatuurstijging te beperken tot ruim onder de 2°C, en mogelijk zelfs 1,5°C, ten opzichte van het pre-industriële niveau. Fundamentele veranderingen in landgebruik en energiesystemen zijn van vitaal belang om deze doelen te bereiken. Dit proefschrift richt zich voornamelijk op energiesystemen. Traditioneel zijn veranderingen in de energievoorziening uitgebreid onderzocht en overwogen als oplossingen om klimaatverandering tegen te gaan. Meer recentelijk zijn in de scenarioanalyse ook gedetailleerde analyses gemaakt van de vermindering van de vraag naar energie door middel van efficiënte technologieën. In het algemeen is er veel minder aandacht geweest voor veranderingen aan de vraagzijde door middel van veranderingen in levensstijl en gedrag. De laatste jaren is daar echter verandering in gekomen, met toenemende aandacht voor duurzame leefstijlen en gedrag (Creutzig et al., 2021), bijvoorbeeld in het UNEP Emission Gap Report en IPCC AR6 (Capstick et al., 2020; Creutzig et al., 2022). In laatstgenoemd rapport stelt het IPCC AR6 dat “maatregelen aan de vraagzijde en nieuwe manieren van dienstverlening aan eindgebruikers de wereldwijde broeikasgasemissies in eindgebruikerssectoren tegen 2050 met 40-70% kunnen verminderen ten opzichte van de basisscenario’s, terwijl sommige regio’s en sociaaleconomische groepen extra energie en middelen nodig hebben.” (Creutzig et al., 2022).

Eerdere kwantitatieve studies hebben zich gericht op het effect op emissies van verschillende gestileerde levensstijlopties (Costa et al., 2021; Grubler et al., 2018; Ivanova et al., 2020; van Sluisveld et al., 2016; van Vuuren et al., 2018; Vita et al., 2019). Meer specifiek worden modelmatige scenario’s met gedrags- en leefstijlveranderingen vaak weergegeven via gestileerde aannames (bijvoorbeeld door aan te nemen dat iedereen een gezonder voedingspatroon aanneemt). De gestileerde aannames kunnen echter verbeterd worden met inzichten uit kwalitatieve disciplines, zoals omgevingspsychologie, sociologie en sociale praktijktheorie. Kwalitatieve studies richten zich vaak op het verschaffen van inzichten over hoe leefstijlen zouden kunnen veranderen op basis van motivaties en faciliterende factoren (Echegaray, 2021; Green & Vergragt, 2002; Manzini & Jégou, 2003; Mont et al., 2014; Quist et al., 2001; Quist & Leising, 2016; Schmidt-Scheele et al., 2022). Dergelijke studies kunnen de kwantitatieve modellering van leefstijlveranderingen aanvullen voor beter geïnformeerde strategieën voor het tegengaan van klimaatverandering. Gezien de omvang, urgentie en schaal van het probleem is verder onderzoek naar veranderingen in levensstijl van vitaal belang om diverse strategieën voor de beperking van klimaatverandering te identificeren.

Hoewel gedrag, levensstijl en consumptieveranderingen vaak door elkaar worden gebruikt, is er een belangrijk onderscheid tussen beide. Gedrag verwijst naar individuele gedragsveranderingen op een bepaald gebied (bijv. kiezen voor de fiets in plaats van de auto), terwijl veranderingen in levensstijl verwijzen naar consistente gedragsveranderingen op de typische gebieden van voeding, wonen en leven.

Dit proefschrift onderzoekt veranderingen in levensstijl vanuit een intentiegerichte benadering met behulp van kwalitatieve benaderingen en vanuit een effectgerichte benadering met IAM's. Dit stelt ons in staat kennis te produceren van kwalitatieve verhaallijnen, kwantitatieve en verkennende trajecten, bemiddeling via participatieve benaderingen en holistische inkadering van mogelijke transities om beleidsvorming te informeren.

8.2. ONDERZOEKSDOEL EN ONDERZOEKSVRAGEN

Dit onderzoek bouwt voort op eerdere pogingen om de rol van veranderingen in levensstijl bij klimaatmitigatie te onderzoeken, onder meer in geïntegreerde evaluatiemodellen. De kwalitatieve en kwantitatieve scenario's geven inzicht in alternatieve toekomstige paden naar duurzame leefstijlen en werpen licht op mogelijkheden voor modellen, beleid en andere belanghebbenden bij het klimaat om deze inzichten in hun werk en maatregelen te verwerken. Het is duidelijk dat "strategieën aan de vraagzijde" en levensstijl- en consumptiegerichte oplossingen een eerste vereiste zijn om onze klimaatdoelstellingen te bereiken. De scenario's en modellering in dit onderzoek zijn bedoeld om verder te werken aan het verduidelijken van deze potentiële bijdrage van veranderingen in levensstijl, en om informatie te verschaffen over klimaatoplossingen voor een rechtwaardig en bloeiend dagelijks leven binnen de grenzen van de aarde.

Dit onderzoek wil laten zien hoe de weergave van veranderingen in levensstijl in IAM's kan worden verbeterd, om de mogelijke rol van veranderingen in levensstijl in strategieën ter beperking van klimaatverandering vast te stellen. Met dit doel voor ogen worden de hoofdstukken, hun onderzoeksvragen en hun analytische focus hieronder gepresenteerd in Tabel 8-1.

Tabel 8-1: Overzicht van onderzoeksvragen, analytische focus en hoofdstukken

#	Onderzoeksvragen	Intent	Effect	H
	Hoe kunnen IAM's de weergave van leefstijlveranderingen verbeteren om de mogelijke rol van leefstijlen in strategieën ter bestrijding van klimaatverandering aan te tonen?	X	X	all
1	Wat zijn de belangrijkste inzichten uit de bestaande literatuur over verschillende benaderingen voor de analyse van veranderingen in levensstijl?	X	X	2, 3, 5 & 6
2	Wat is het effect van veranderingen in consumptie op emissiereducties, vergeleken met technologische veranderingen in bestaande IMAGE-leefstijlscenario's?		X	3 & 4
3	Hoe verhouden de emissies van de huidige leefstijlen zich tot de emissieniveaus die stroken met de klimaatdoelstellingen?		X	4
4	Wat zijn mogelijke toekomstige scenario's voor duurzaam leven?	X	X	5
5	Wat zijn de gevolgen van mogelijke toekomstige scenario's voor duurzaam leven voor de emissies?	X	X	6

8.3. VOORNAAMSTE RESULTATEN

8.3.1. Wat zijn de belangrijkste inzichten uit de bestaande literatuur over verschillende benaderingen voor het analyseren van veranderingen in levensstijl?

Er bestaat een rijke en gevarieerde literatuur over duurzame leefstijlen die verschillende wetenschappelijke disciplines bestrijkt. Een deel van deze studies richt zich op de intentie van leefstijlverandering, terwijl een ander deel zich richt op het effect. In dit onderzoek is aan de hand van een systematisch overzicht geanalyseerd hoe verschillende perspectieven op leefstijlveranderingen kunnen worden gebruikt voor een meer genuanceerde en rijke benadering van de weergave van leefstijlen in IAM's. We maken een onderscheid tussen studies die zich richten op intenties (d.w.z. gericht op motivaties) of op effecten (d.w.z. gericht op uitkomsten) met betrekking tot leefstijlveranderingen (zie Figure 8-1). De geanalyseerde studies varieerden in disciplines, bereik, doel en methoden, met nuttige inzichten rond leefstijlveranderingen. Enkele belangrijke inzichten van deze review worden gegeven (hoofdstuk 2).

Overwegend kwalitatieve en sociale wetenschappen hanteren het intentiegerichte perspectief, waarbij de motivaties achter gedrags- en leefstijlveranderingen worden geanalyseerd of vastgesteld. Dit perspectief informeert ons over wat, hoeveel, waarom, hoe en wanneer leefstijlen zouden kunnen veranderen. Meerdere disciplines hanteren dit perspectief. Zo bestudeert de omgevingspsychologie factoren die gedrag helpen voorspellen en bestudeert de milieusociologie de interacties tussen de natuurlijke omgeving en samenlevingen. Gedragseconomie informeert ons over de grenzen van rationaliteit en vatbaarheid voor factoren die onze keuzes beïnvloeden (bijv. *nudges*, *default-setting* en *marketing*). *Social practice theory* draagt bij tot het begrijpen van gebruiken in plaats van individuen door alledaagse *social practices* te bestuderen (bijv. wassen, koken, sporten). Studies naar innovatie en socio-technische transitie dragen bij tot het begrijpen van veranderingen in levensstijl in de dynamiek van socio-technische veranderingen (hoofdstuk 2).

Een andere tak van onderzoek richt zich op de uitkomsten van leefstijlveranderingen. Bij deze studies wordt doorgaans gebruik gemaakt van modellen om het effect van veranderingen in levensstijl op het milieu te kwantificeren. Er zijn verschillende soorten modellen, beoordelingen en analyses die het effect van veranderingen in levensstijl onderzoeken. Zo kunnen levenscyclusanalyses de gevolgen van de levensstijl voor de levenscyclus van producten en diensten kwantificeren. Consumptiegerichte koolstofboekhouding, vaak via multiregionale input-outputmodellen, wijst emissies toe aan eindgebruikers (bijv. *Lifestyle Carbon Footprints*) en verschaft inzicht in verschillende soorten consumenten, leefstijlen en drijvende krachten achter verandering. *Agent-based modelling* analyseert gedragingen door interacties tussen agenten te modelleren. *Integrated Assessment Models* (IAM's) hebben ook bijgedragen tot het kwantificeren van veranderingen in levensstijl door het effect van specifieke gedragsveranderingen op broeikasgasemissies te modelleren (hoofdstuk 2).

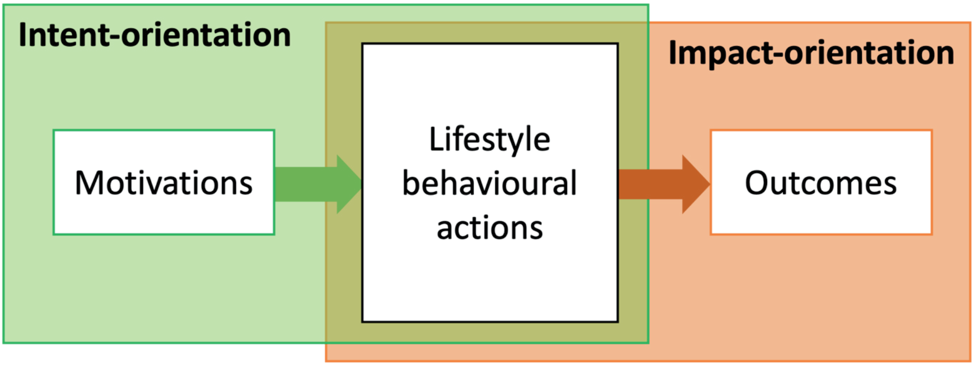


Figure 8-1: Een holistische benadering: intentie- en effectgerichtheid van leefstijl- en gedragsacties

Het is van vitaal belang onderscheid te maken tussen gedragingen, leefstijlen en consumptie, aangezien deze fundamenteel van elkaar verschillen. Onderzoekers in verschillende disciplines gebruiken vaak verschillende termen (bijv. levensstijl, gedrag, consumptiepatronen, duurzaam leven, sociale praktijken, enz.), waarbij die termen soms door elkaar en soms bewust verschillend worden gebruikt. Om concepten te interpreteren en strategie en actie effectief te sturen, moet er consistentie zijn tussen de disciplines, en is harmonisatie van de terminologie cruciaal. Dit onderzoek harmoniseert de definities van leefstijlverandering in verschillende kaders en instrumenten. In alle hoofdstukken wordt de term "leefstijl" gebruikt als een dwarsdoorsnede van de dominante domeinen (bijv. vervoer, wonen, voeding), terwijl "gedrag" de acties binnen de domeinen beschrijft. Deze soorten handelingen kunnen in het ASI-kader worden ingedeeld. Voorts wordt de term "consumptie" gebruikt om de resultaten van de acties te beschrijven (d.w.z. een effectgerichte aanpak), bijvoorbeeld op de veranderingen in activiteit en structuur/dienst in het ASIF*-decompositie-instrument (hoofdstuk 3). Via het AFI-kader kunnen motivaties en faciliterende/contextuele factoren worden geïdentificeerd die belangrijk zijn om de intentie van leefstijl- en gedragsveranderingen weer te geven of te beïnvloeden (hoofdstuk 2).

Het is de moeite waard intentie- en effectoriëntaties in afzonderlijke studies te combineren. Normaliter kiezen studies voor een intentie- of een effectgerichte aanpak, in plaats van een combinatie van beide. Modelleringsstudies richten zich bijvoorbeeld typisch alleen op gedragingen in termen van uitkomsten, terwijl milieupsychologische studies zich voornamelijk richten op de motivaties van gedragingen. Door leefstijlveranderingen te modelleren met de bedoeling en het effect ervan (zie Figure 8-1), kan worden nagegaan waarom, hoe en wat leefstijlen veranderen. Zonder rekening te houden met het andere kan het ene perspectief slechts het halve verhaal overbrengen. Dit gezamenlijke perspectief zou de modellering van leefstijlverandering en een doeltreffende communicatie met beleidsmakers en andere belangrijke belanghebbenden ten goede komen (hoofdstuk 2, hoofdstuk 5 en hoofdstuk 6).

Gezien de omvang, de schaal en de urgentie van de klimaatverandering is het van vitaal belang dat een breder scala van veranderingen in levensstijl wordt gemodelleerd die de dominante gebieden doorkruisen. Terwijl de meeste studies zich richten op de dominante domeinen (bijv. vervoer, wonen en voeding), analyseren sommige studies domeinoverschrijdende aspecten die centraal staan bij veranderingen in levensstijl (bijv. verschuivingen in tijdgebruikpatronen en sociale veranderingsbewegingen die duurzaam leven versterken). Om een breder scala aan veranderingen in levensstijl te bestrijken, moeten de IAM's zich richten op gebiedsoverschrijdende aanknopingspunten, die indirect van invloed zijn op de dominante sectoren in de IAM's. Deze veranderingen in levensstijl kunnen leiden tot meer transformatieve acties binnen domeinen. Zo zouden kleinere woonruimtes leiden tot zowel een lager energieverbruik als een vermindering van het aantal goederen per huishouden, zou telewerken het woon-werkverkeer en het energieverbruik en de materiaalbehoeften op kantoor verminderen. Deze transformatieve acties worden in IAM's doorgaans minder uitgebreid gemodelleerd. Bovendien kunnen modelleurs, door faciliterende factoren weer te geven, veranderingen in levensstijl weergeven binnen de grotere systeemverandering. Daarom kunnen essentiële besluitvormers (bijv. overheid, bedrijven, consumenten) die verantwoordelijk zijn voor specifieke veranderingen worden geïdentificeerd (hoofdstuk 2).

Elke modelbenadering heeft afwegingen die moeten worden gemaakt op basis van het onderzoeksdoel. Er zijn afwegingen tussen exogene en endogene modellering, variërend van ad hoc en geïnformeerde exogene inputs tot gedeeltelijk en volledig endogene modellering. De afweging omvat het gemak van de uitvoering en de dekking van het systeem versus dynamische modellering en meer representatieve veranderingen. Met exogene inputs, bijvoorbeeld via de modellering van scenarioverhalen, kan een groter deel van het leefstijlsysteem en het energieverbruik van de leefstijl uit empirische studies worden bestreken, en het is gemakkelijker uit te voeren. Daarom heeft een exogene modellering een groter potentieel voor empirische weergave. Deze aanpak ontbeert echter een dynamische weergave van de invoering van specifieke veranderingen in levensstijl. Een endogene modelbenadering, waarbij bijvoorbeeld consumentensegmenten worden toegevoegd, beperkt de dekking van het systeem van veranderingen in levensstijl, maar maakt een betere weergave van veranderingen in specifieke levensstijlkeuzes mogelijk. Geen enkele benadering is sterker of zwakker dan de andere: elke benadering heeft haar sterke en zwakke punten, en de meest inzichtelijke gekozen benadering hangt af van de vraagstelling (hoofdstuk 2).

Het aangepaste ASIF*-decompositie-instrument kan worden toegesneden op gedragingen, voor het interpreteren van consumptie- en technologieveranderingen uit modeloutputs. Met dit ASIF*-decompositie-instrument (Activity, Structure/Service, Intensity, Fuel mix) voor IAM's kan het effect van gedragsverandering op emissies per capita in scenario's worden belicht (zie Figure 8-2). De ASIF-factoren zijn ook verbonden met het ASI-kader (Avoid, Shift, Improve). Activiteitsveranderingen vloeien voort uit vermijdingsmaatregelen, structuur/service uit verschuivingsmaatregelen en intensiteit en brandstofmix uit verbeteringsmaatregelen. Door de nadruk te leggen op de vereiste variabelen en parameters voor het meten van verbruiks- en technologieveranderingen, kunnen IAM's de vertaling van gedragsgerelateerde scenario's naar modelparameters verbeteren. Bovendien kan het decompositie-instrument verschillen in trends in de ASIF*-factorveranderingen tussen regio's in de *Global North* en de *Global South* visualiseren. Het instrument kan veranderingen weergeven tussen twee punten in de tijd, gedurende de tijd met meerdere tijdstappen, en tussen verschillende eindpunten. Hoewel dit instrument wordt toegepast op de outputs van het geïntegreerde evaluatiemodel IMAGE, kan het ook worden toegepast op outputs van andere procesgebaseerde IAM's, met name die met een hoge ruimtelijk-technologische resolutie. Het is ook mogelijk factoren verder te ontleden voor een meer gedetailleerde weergave van veranderingen in consumptie en technologie (hoofdstuk 3).

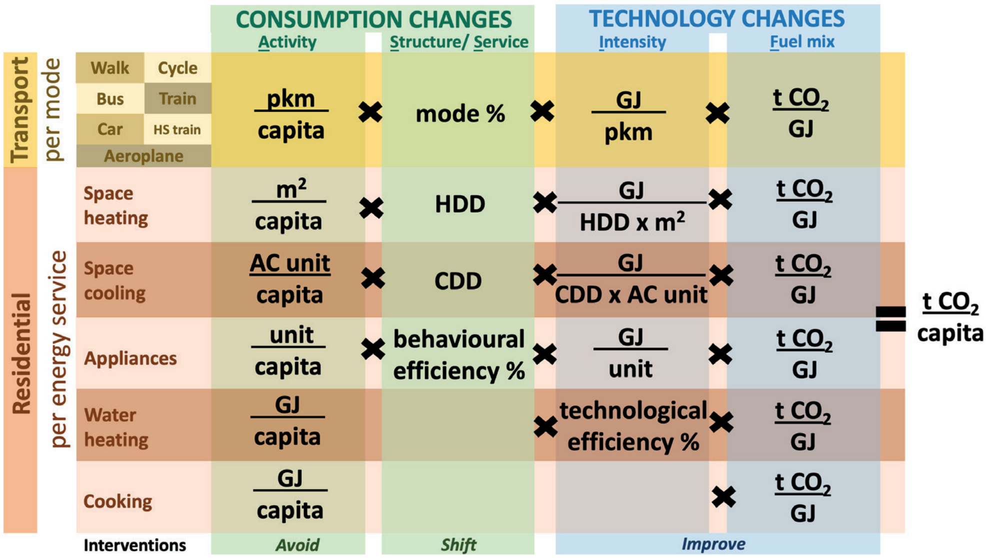


Figure 8-2: Uitsplitsing van variabelen en eenheden voor de decompositieanalyse in vervoerswijzen en huishoudelijke energiediensten in termen van de impactfactoren Activity, Structure/Service, Intensity and Fuel Mix (ASIF*), HDD = Heating Degree Days, CDD = Cooling Degree Days, pkm = passenger-kilometers, AC unit = air-conditioning unit.

8.3.2. Wat is het effect van veranderingen in het verbruik op de emissiereductie in vergelijking met technologische veranderingen in toekomstige scenario's?

Consumptieverandering is een kritieke factor voor de toekomstige koolstofemissieniveaus, die leidt tot een toename van de huidige emissies van 75% (wanneer de trends worden gevolgd) tot 26% (wanneer maatregelen worden genomen). Consumptieverandering speelt een rol in alle modelmatige scenario's die in de literatuur zijn gepubliceerd. Verschillen in levensstijl zijn bijvoorbeeld cruciaal bij het bepalen van de verschillen in de gedeelde sociaal-economische paden (SSP's). Bovendien verandert in bijna alle scenario's de consumptie in de loop der tijd - vaak als functie van de economische ontwikkeling: er wordt van uitgegaan dat de consument overschakelt op een vleesintensiever voedingspatroon en haar vervoersgedrag en leefgewoonten wijzigt. Deze veranderingen (vaak in de richting van hogere emissies) worden doorgaans niet aangepakt of onderzocht in termen van mitigatiepotentieel. Tegelijkertijd bestaan er slechts enkele scenario's die expliciet rekening houden met het effect van verschuivingen naar duurzamer gedrag - waaronder de scenario's van (van Sluisveld et al., 2016) met behulp van IMAGE (hierna VS scenario's genoemd), zij het op basis van gestileerde aannames. Het ASIF*-decompositie-instrument kan de effecten van consumptieverandering in alle scenario's expliciet maken. Uit de eerdere IMAGE VS scenario's blijkt dat gedragsverandering leidt tot een vermindering van de uitstoot per capita door consumptieveranderingen met 13-31% ten opzichte van een SSP2-basisscenario (zie Figure 8-3). Consumptieveranderingen kunnen de samenleving minder afhankelijk maken van technologische veranderingen om de klimaatdoelstellingen te halen (zie Figure 8-3). Zelfs met meer duurzame gedragsveranderingen zullen de wereldwijde emissies per capita naar verwachting toenemen als de technologieën niet veranderen in de richting van meer koolstofarme opties, maar minder drastisch. Dit betekent dat de afhankelijkheid van technologische vooruitgang om een 2°C klimaatdoelstelling te bereiken, afneemt als de levensstijl duurzamer wordt (hoofdstukken 3 en 4). Volgens de IPCC-rapporten van 2022 (Creutzig et al., 2022) is een verschuiving van de vraag nodig om de huidige klimaatdoelstellingen te halen.

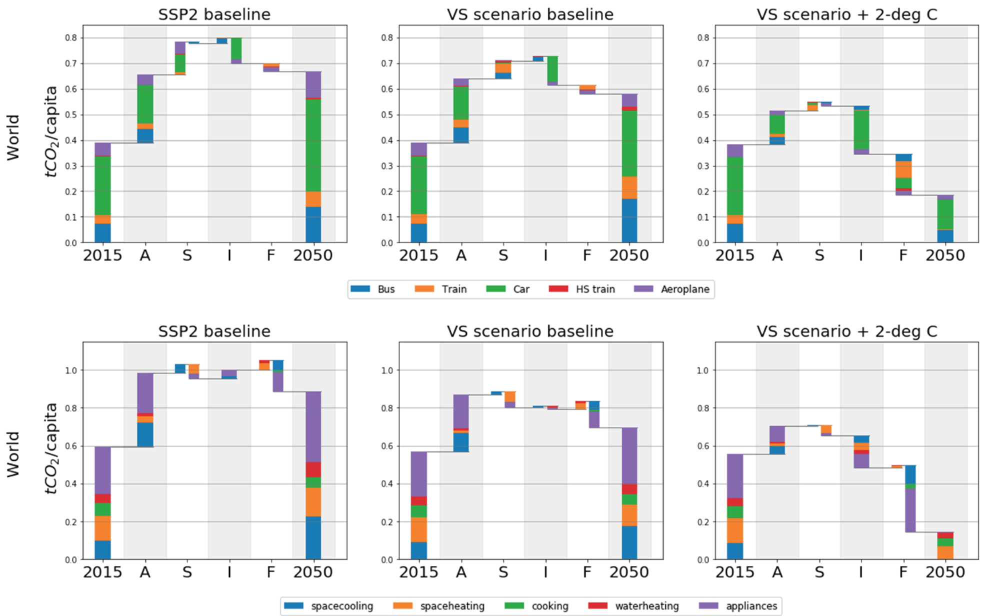


Figure 8-3: Decompositie van emissies per capita voor vervoer (boven) en woningen (onder) voor het business-as-usual scenario (SSP2-basisscenario) en twee gedragsscenario's zonder (VS scenario) en met (VS scenario + 2-deg) klimaatbeleid. De categorieën A (Activity changes), S (structure/service changes), I (Intensity changes) en F (Fuel mix changes) geven de bijdrage van deze factoren aan de verandering in emissies tussen 2015 en 2050 voor verschillende regio's weer.

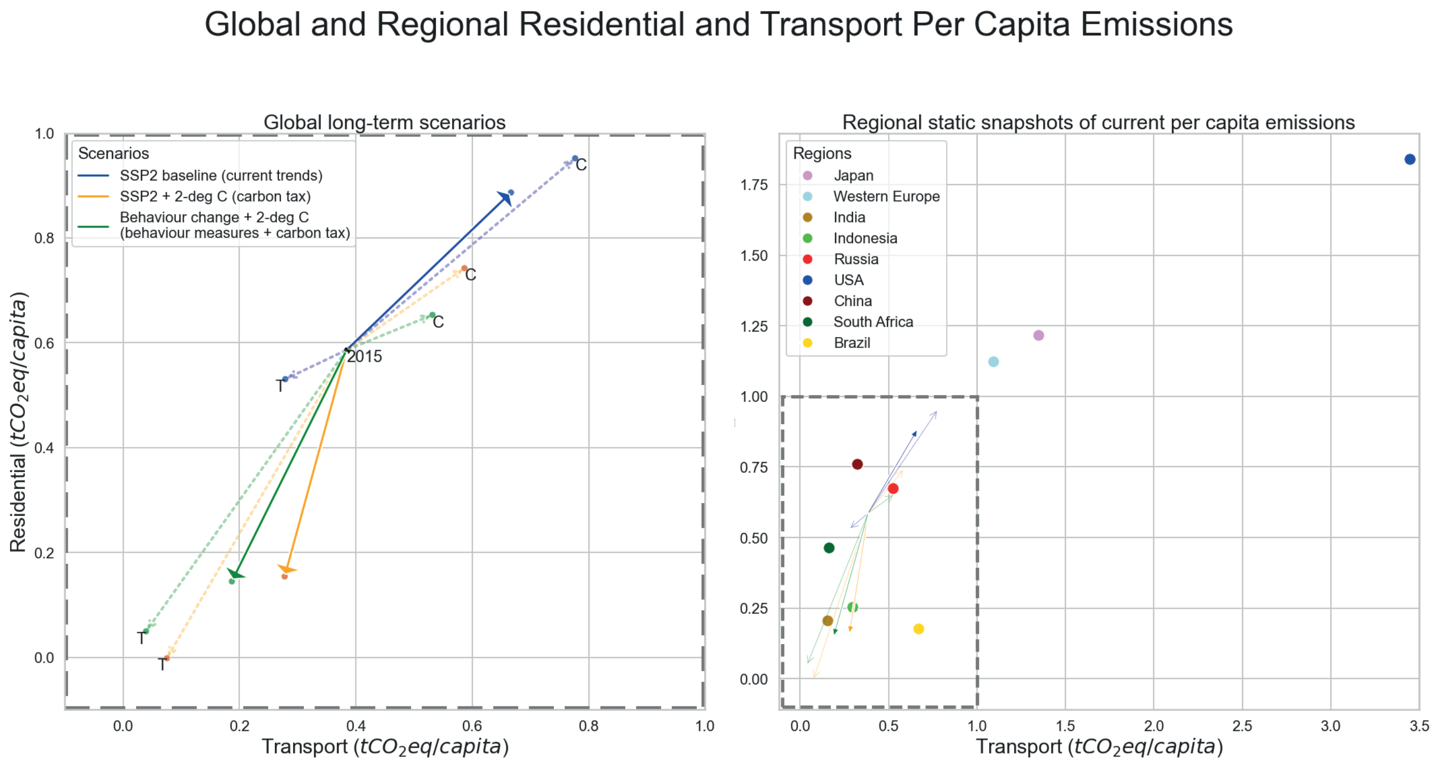


Figure 8-4: Links: Mondiale langetermijnscenario's en effecten van verschillende soorten veranderingen, C=consumptieveranderingen (zonder veranderingen in technologie), T=technologieveranderingen (zonder veranderingen in consumptie); Rechts: Wereldwijde langetermijnscenario's (uitgezoomd, zoals aangegeven door de grijze, gestippelde vakken) in de context van regionale huidige emissies per capita.

8.3.3. Hoe verhouden de emissies van de huidige levensstijl zich tot de emissieniveaus die in overeenstemming zijn met de klimaatdoelstellingen?

Heterogene segmenten binnen en tussen regio's laten een verscheidenheid aan levensstijlen en contexten zien die de CO2-emissies beïnvloeden. Multiregionale vergelijkingen (zie de linkerkant van Figure 8-4) tonen opmerkelijke verschillen in CO2-emissies van vervoer en de woonsector, veroorzaakt door verschillende consumptiepatronen en contextuele factoren die van invloed zijn op technologieën. Een vergelijking binnen een regio voor Japan toont aanzienlijke verschillen in consumentensegmenten, voornamelijk in CO2-emissies van woningen. Deze diversiteit werpt licht op gedrag met een hoge uitstoot en vormt een leidraad voor gerichte maatregelen om op rechtvaardige wijze een leven van hoge kwaliteit met minder uitstoot te bereiken (bijv. kosteneffectieve en gemakkelijke opties). Deze diversiteit maakt ook duidelijk hoe belangrijk het is om bij de analyse, ontwikkeling en modellering van scenario's rekening te houden met heterogeniteit.

Vervoerspatroon-gerelateerde koolstofemissies van sommige grote consumentensegmenten in Japan liggen dicht bij die in een 2°C-klimaatscenario in 2050. Door het duurzame vervoerssysteem van Japan en de voorkeur van de consument hebben veel consumentensegmenten in Japan relatief lage emissies in de vervoerssector (zie rechterzijde Figure 8-4). Zij zitten dus dicht bij de uitstoot per capita die overeenkomt met 2°C (d.w.z. Behaviour Change + 2°C-scenario). Dit versterkt ook het belang van het mogelijk maken van infrastructuur om over te schakelen op lage-emissiegedragingen. De Japanse per-capita woonhuisemissies van vele consumentengroepen liggen echter veel hoger dan die welke nodig zijn in de 2°C-trajecten naar 2050.

8

8.3.4. Wat zijn mogelijke toekomstscenario's voor duurzaam leven?

De SLIM-scenario's illustreren hoe structurele steun- en waardesystemen levensstijlen anders vormgeven en dynamisch veranderen in reactie op enablers en maatschappelijke verschuivingen, terwijl de nadruk wordt gelegd op andere essentiële drijvende krachten voor verandering. De SLIM (Sustainable Living in Models) (zie Table 8-2, Figure 8-5 en Figure 8-6) zijn ontwikkeld met inbreng van diverse adviseurs en geselecteerde beleidsmakers. Via een benadering van scenarioplanning werden scenario's opgesteld op basis van inzichten van sociale wetenschappers, modelleurs en beleidsmakers. Het scenario-ontwikkelingsproces leidde tot de identificatie van twee kritieke onzekerheden en drijvende krachten: de mate van gecentraliseerde of gedistribueerde steun voor veranderingen in levensstijl, en meer individualistische of collectivistische waarden in een samenleving. Dit leidde tot de vaststelling van vier uiteenlopende plausibele scenario's voor leefstijlverandering. Gedecentraliseerde steun is duidelijk in Designed World en Global Commons, terwijl Pocket Lifestyles en Big Village toekomstscenario's weerspiegelen waarin veranderingen in levensstijl plaatsvinden in de context van meer gedistribueerde steun. Individualistische waarden sturen leefstijlverandering in Designed World en Pocket Lifestyles, terwijl Global Commons en Big Village plausibele toekomstige samenlevingen weerspiegelen waarin collectivistische waarden dominant zijn. Deze verschillen geven vorm aan de kenmerken van de contrasterende scenario's waarin leefstijlen zouden kunnen veranderen (zie Box 2). Bovendien zijn maatschappelijke veranderingen, factoren die dit mogelijk maken, levensstijlen en gedragingen alle essentieel voor de scenario's (zie Figure 8-5). Deze contrasterende kenmerken maken een holistische discussie mogelijk over de soorten toekomsten die plausibel zijn, vooral in combinatie met hun effect op de emissies. Door de vraag te stellen "hoe zou de wereld er in 2050 uit kunnen zien" en de uiteenlopende gevolgen voor levensstijl en uitstoot te onderzoeken, wordt het mogelijk mogelijke maatregelen te repeteren, hun robuustheid te toetsen aan plausibele toekomstscenario's, en uiteindelijk maatregelen te sturen in de richting van de gewenste toekomst. Bovendien helpt het ons innovatieve antwoorden te vinden bij grote onzekerheid en complexiteit en de gevolgen te begrijpen voor de besluitvorming in verschillende toekomstscenario's. Diverse andere vitale factoren van verandering beïnvloeden de levensstijl (zie Table 8-3), zoals individuele agency, het tempo van het leven, rechtvaardigheid, veiligheid en zekerheid, en technologische ondersteuning (openbaar, particulier of communautair) (hoofdstuk 5).

De omvang en de snelheid van de veranderingen in levensstijl zijn van vitaal belang voor het modelleren van de SLIM-scenario's en, bijgevolg, voor het analyseren van de bijdrage van de veranderingen in levensstijl aan de beperking van de klimaatverandering. Door deze scenario's uit te splitsen in dominante domeinen met herkenbare kenmerken (d.w.z. gedragingen) kan in een scenarioverhaal een vollediger beeld worden geschetst van hoe het leven er in 2050 en daarna kan uitzien. Dit vertaalt zich dan weer in scenario-input voor kwantitatieve modellering in geïntegreerde evaluatiemodellen. De SLIM-scenario's legden bijvoorbeeld de omvang en snelheid vast van de keuze voor een minimalistisch appartement of tiny house in het scenario Pocket Lifestyles. Dit werd geïmplementeerd door een plafond voor het vloeroppervlak per capita dat in de loop van de jaren tot 2050 afneemt. Dit maakt differentiatie tussen regio's en inkomenskwintielen mogelijk omdat het plafond alleen gevolgen heeft voor regio's/kwintielen met een vloeroppervlak per capita boven het plafond. De gemaakte aannames zijn dus genuanceerder gezien de regionale context en de consumptiepatronen (hoofdstuk 5 en 6).

De nadruk op regionale differentiatie en rechtvaardigheidsoverwegingen bij het modelleren van de SLIM-scenario's is van invloed op de mate waarin de levensstijl verandert en op de gevolgen voor de beperking van de klimaatverandering. In de scenario's werd een onderscheid gemaakt tussen het *Global North* en *Global South*, waarbij rekening werd gehouden met contextafhankelijke factoren voor verschillende regio's. Voorts werden in de woonsector sommige gedragsacties gemodelleerd, zodat verschillende groepen (d.w.z. verschillende inkomens, huishoudens op het platteland of in de stad) de acties op een verschillende manier uitvoeren. Bepaalde aannames voor Pocket Lifestyles, met name in de woonsector (bijv. het bezit van apparaten), hebben alleen gevolgen voor groepen met hogere inkomens of de grootste vervuilers. In Ontwerpwereld, dat meer gebaseerd is op technologische veranderingen, zijn de emissies van woningen lager, vooral voor huishoudens of overheden die kunnen investeren in koolstofarme technologieën. Deze implementatie maakt een meer genuanceerde weergave mogelijk van veranderingen in levensstijl in de context van rechtvaardigheid (hoofdstuk 6).

Box 2. Wat zijn de SLIM-scenario's?

De SLIM-scenario's (Sustainable Living in Models) zijn contrasterende 'wat-als' toekomstbeelden van levensstijlen en grotere systeemveranderingen. Ze verschillen in het type ondersteuning (gedistribueerd vs. gecentraliseerd) en in waarden (individueel vs. collectief). **Designed World** neigt naar individuele waarden en gecentraliseerde ondersteuning en wordt bestempeld als "duurzame levensstijl bij gebrek aan beter". **Global Commons** heeft eveneens toegang tot gecentraliseerde ondersteuning, wordt vertegenwoordigd door collectieve waarden en wordt gekarakteriseerd als "inclusief mondiaal bestuurssysteem". **Big Village** weerspiegelt ook meer collectieve waarden, en is een samenleving met toegang tot meer gedistribueerde steun voor duurzame levensstijlen, en heeft als slogan "community-based sustainable living". **Pocket Lifestyles** weerspiegelt eveneens de toegang tot gedistribueerde ondersteuning, maar wordt vooral gedreven door individualistische waarden, en wordt omschreven als "peer-to-peer lifestyle platforms".

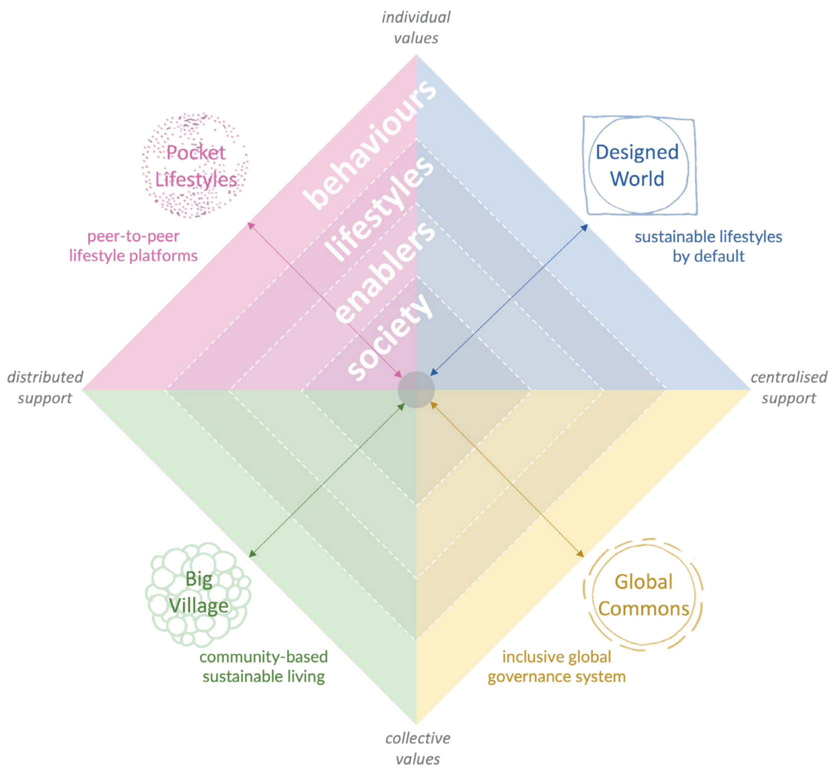


Figure 8-5: Overzicht van de levensstijlscenario's (d.w.z. Designed World, Global Commons, Big Village en Pocket Lifestyles) variërend in type ondersteuning (gedistribueerd vs. gecentraliseerd) en waarden (individualistisch vs. collectief) voor verschillende kenmerken, namelijk veranderingen in de samenleving, enablers, levensstijlen en gedragingen, die afwijken van het referentiescenario (d.w.z. Tech-Innovation vertegenwoordigd door de cirkel in het midden).

Table 8-2: Overzicht van de waardeposities en samenvattende verklaringen betreffende elk scenarioverhaal

Reference Scenario **Tech-Innovation**	*Tagline:* **net-zero by tech change** Technological innovation is the dominant climate mitigation strategy, and lifestyle change plays a minor role.
Lifestyle Scenario **Designed World**	*Tagline:* **sustainable lifestyles by default** *Individualistic values / Centralised access to structural support* Governments, corporations and cities leverage existing values and market systems to shape citizen and consumer preferences and practices.
Lifestyle Scenario **Global Commons**	*Tagline:* **inclusive global governance system** *Group / Collectivist values / Centralised access to structural support* Universal values shape ways of living, new institutions, and a global governance structure with less emphasis on sovereignty, with a more active Global South participation.
Lifestyle Scenario **Big Village**	*Tagline:* **community-based sustainable living** *Group / Collectivist values / Distributed access to structural support* People band together in communities regionally while remaining networked globally to support bottom-up innovation, shared infrastructures, and belonging.
Lifestyle Scenario **Pocket Lifestyles**	*Tagline:* **peer-to-peer lifestyle platforms** *Individualistic values / Distributed access to structural support* People take it upon themselves to adopt and rapidly spread ambitious sustainable lifestyles, behaviours and practices through digital technology.

Table 8-3: Kwalitatieve eigenschappen

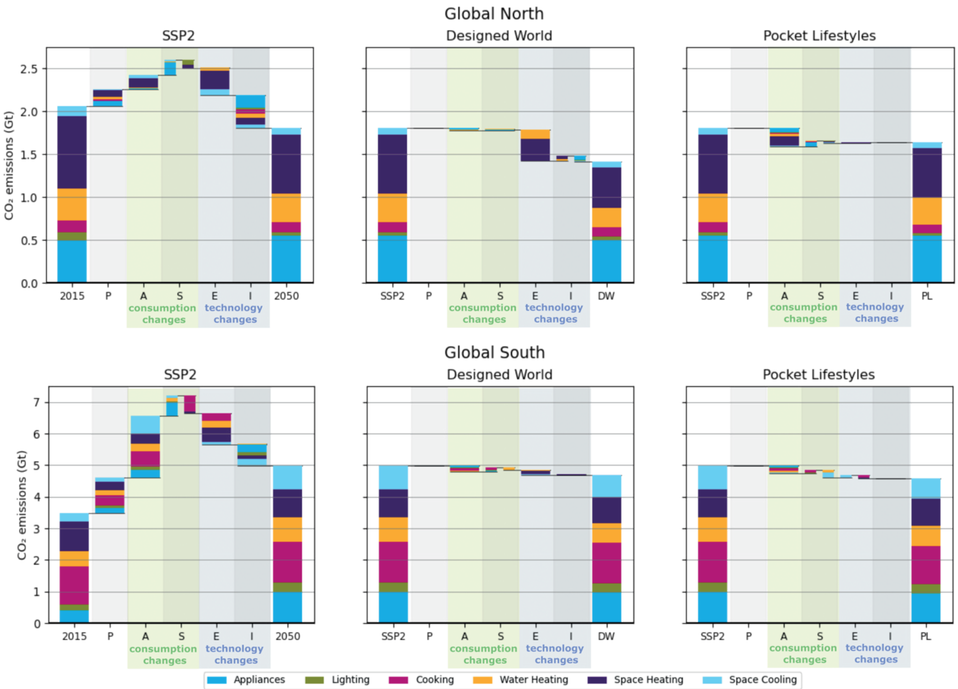
Scenario narratives Characteristics	**Tech-Innovation**	**Designed World**	**Global Commons**	**Big Village**	**Pocket Lifestyles**
Individual agency	Low	Low	Medium	High	High
Technology support for lifestyle change	Digitally enhanced	Digitally enhanced	Digital, low-tech	Low-tech	Digitally enhanced
Pace of life	Fast pace	Fast pace	Medium pace	Slower pace	Fast pace
Inclusive access / Social equity	Low	Medium	High	Medium	Low
Security and safety	Low	High	High	Medium	Medium
Public / Private / Community	Private	Public-private with city	More public	Community public	Market/ Private
Speed of lifestyle transition	Low	Low-medium	Medium	Medium-fast	Fast
Extent of lifestyle change adoption	Low	High	Medium-high	Low-medium	Low-medium

Figure 8-6: Visualisatie van de verhalen van de levenstijlscenario's

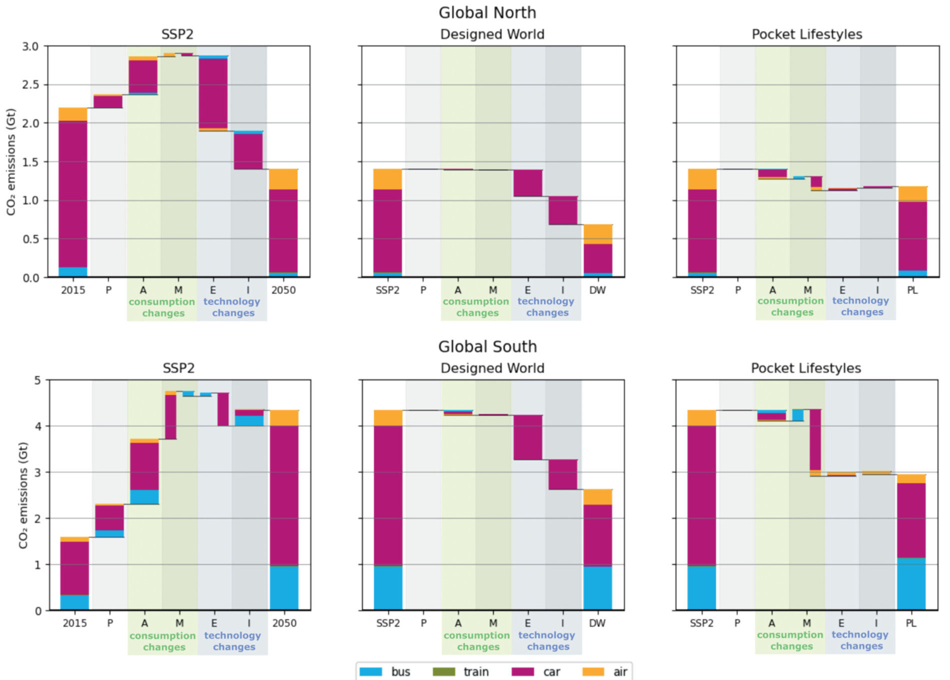
8.3.5. Wat zijn de emissiegevolgen van mogelijke toekomstscenario's voor duurzaam leven?

Veranderingen in de levensstijl dragen aanzienlijk bij tot de beperking van de klimaatverandering, maar ook andere maatregelen, zoals grotere systeemveranderingen, zijn van vitaal belang om deze veranderingen te ondersteunen en meer transformatieve resultaten te bereiken. Figure 8-8 laat zien dat in de Designed World de uitstoot sterker wordt verminderd dan in de Pocket Lifestyles scenario. Dit komt vooral doordat Designed World gekenmerkt wordt door grotere systeemveranderingen (bijv. elektrificatie van voertuigen). De mate waarin dit gebeurt, en wanneer, verschilt per scenario. Verreweg de grootste reductie vindt plaats in de transportemissies in Designed World (51% in de *Global North* en 39% in de *Global South* ten opzichte van de SSP2-referentie), waarbij tegen 2050 niveaus worden bereikt die onder het standaard SSP2 2 graden-scenario liggen. De reducties in woonhuisemissies voor Designed World zijn ook opmerkelijk, maar niet zo substantieel (21% voor de *Global North* en 5% voor de *Global South*). Pocket Lifestyles met minder systeemverandering hebben bescheidener emissiereducties voor vervoer (16% voor de *Global North* en 32% voor de *Global South*) en woningen (14% voor de *Global North* en 7% voor de *Global South*). Bovendien verloopt de overgang naar duurzamere levenswijzen aanvankelijk sneller bij Pocket Lifestyles, maar vertraagt deze vanwege de geringere en verspreide systeemondersteuning, terwijl bij Designed World de veranderingen in levensstijl langzamer op gang komen, maar over het geheel genomen een grotere reductie vertonen naarmate de systeemondersteuning ruimer en significanter wordt. Een combinatie van aspecten van Designed World en Pocket Lifestyles zou ook realistisch kunnen zijn, met technologische oplossingen en leefstijlmaatregelen voor grotere systeemveranderingen (hoofdstuk 6).

De SLIM-scenario's laten plausibele toekomstige trajecten zien die in de buurt komen van de door het IPCC genoemde emissiereducties van 40-70% door maatregelen aan de vraagzijde. In het meest recente IPCC-rapport staat: "Maatregelen aan de vraagzijde en nieuwe manieren van dienstverlening bij het eindgebruik kunnen de mondiale broeikasgasemissies in eindgebruiksectoren tegen 2050 met 40-70% verminderen ten opzichte van de referentiescenario's, terwijl sommige regio's en sociaaleconomische groepen extra energie en middelen nodig hebben" (Creutzig et al., 2022). Dit heeft betrekking op de som van alle maatregelen die in de eindgebruiksectoren worden uitgevoerd, inclusief overschakeling op andere brandstoffen en verbetering van de efficiëntie. Wanneer alleen naar de regio's van de *Global North* wordt gekeken, liggen de emissiereducties van 2015 tot 2050 van de gemodelleerde SLIM-scenario's ruim binnen de marge. Voor Designed World en Pocket Lifestyles zouden de emissies in de *Global North* met 45% en 61% dalen. Voor de *Global South* regio's zou de uitstoot echter toenemen als gevolg van hun verwachte economische ontwikkeling, namelijk met 15% en 21% voor respectievelijk Designed World en Pocket Lifestyles. Bij deze percentages moet op een aantal punten worden gewezen. Ten eerste gaan de SLIM-scenario's alleen uit van veranderingen in levensstijl en geen aanvullend klimaatbeleid. De emissiereducties zouden aanzienlijk hoger uitvallen als veranderingen in levensstijl zouden worden gecombineerd met andere technologische veranderingen, die weer het resultaat zouden kunnen zijn van koolstofbeprijzing (zoals in de IPCC-cijfers). Ten tweede geven de 40-70%-waarden van het IPCC het potentieel aan, terwijl de SLIM-scenario's gebaseerd zijn op onderbouwde aannames met beperkingen ten aanzien van de snelheid en de omvang van de aangenomen veranderingen in levensstijl. Bijvoorbeeld, in plaats van aan te nemen dat alle mensen een warmtepomp zullen invoeren, gaan de SLIM-scenario's uit van een lagere invoering en regionale differentiatie op basis van onder andere beschikbaarheid, facilitering, bereidheid of vermogen. Ten derde zou een combinatie van Designed World en Pocket Lifestyles, of de andere SLIM-scenario's, Global Commons en Big Village (niet gemodelleerd in dit onderzoek) tot grotere emissiereducties kunnen leiden (hoofdstuk 6).



Global North
SSP2
Designed World
Pocket Lifestyles
Global South
SSP2
Designed World
Pocket Lifestyles
CO₂ emissions (Gt)
2015
P
A
S
E
I
2050
SSP2
DW
PL
consumption changes
technology changes
Appliances
Lighting
Cooking
Water Heating
Space Heating
Space Cooling



Global North
SSP2
Designed World
Pocket Lifestyles
Global South
SSP2
Designed World
Pocket Lifestyles
CO₂ emissions (Gt)
2015
P
A
M
E
I
2050
SSP2
DW
PL
consumption changes
technology changes
bus
train
car
air

Figure 8-7: SLIM-scenario's Designed World en Pocket Lifestyles vergeleken met het referentiescenario SSP2. Resultaten decompositie van woningen (bovenste twee rijen) en personenvervoer (onderste twee rijen). De verschillende kleuren staan voor respectievelijk het personenvervoer en de energiediensten voor woningen. De watervaldiagrammen geven de verandering in emissies weer van verschillende factoren, population (P), activity (A), mode shares (M)/service (S), efficiency (E) and CO_2 intensity (I).

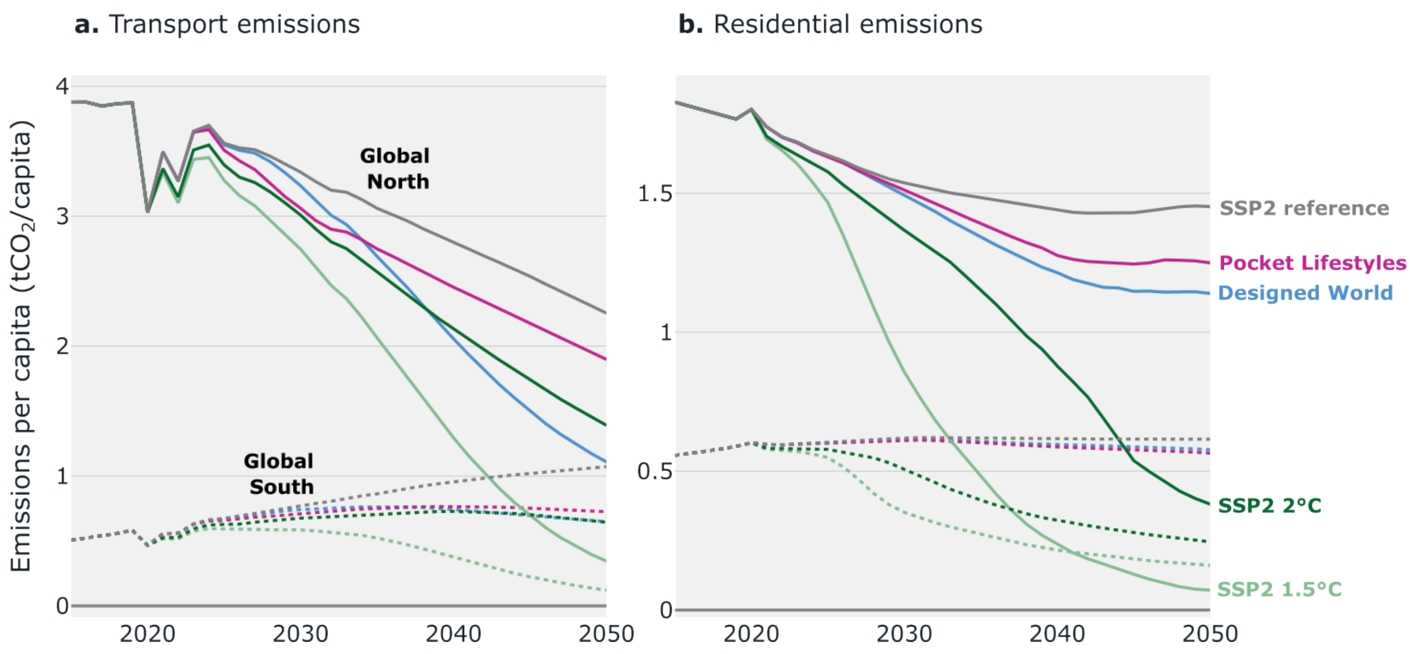


Figure 8-8: Langetermijnscenario's tussen verschillende regio's in de Global North en Global South (respectievelijk aangegeven met ononderbroken en gestippelde lijnen) met betrekking tot de uitstoot per capita door vervoer en woningen.

Van de gemodelleerde SLIM-scenario's worden de emissies in Pocket Lifestyles vooral verminderd door veranderingen in consumptie, terwijl de emissies in Designed World vooral worden verminderd door veranderingen in technologie. De SLIM-scenario's laten verschillende soorten veranderingen zien. Figure 8-7 laat zien dat veranderingen in levensstijl die verband houden met technologie van doorslaggevend belang zouden zijn voor de vermindering van de emissies in Designed World, terwijl veranderingen in de consumptie de emissies in de Pocket Lifestyles aanzienlijk zouden beïnvloeden. In Designed World zouden reducties voornamelijk worden bereikt door veranderingen in levensstijl die verband houden met verbeteringen van de efficiëntie en de CO2-intensiteit. Voor de *Global North* zouden de emissiereducties voor vervoer en woningen respectievelijk 50% en 20% bedragen, en voor de *Global South* 37% en 3%. In de Pocket Lifestyles spelen veranderingen in consumptie (d.w.z. minder en verschuivingen in activiteit) een grote rol. Voor de *Global North* zouden de emissiereducties voor vervoer en woningen respectievelijk 16% en 10% bedragen, en voor de Global South respectievelijk 27% en 8%. Voor Pocket Lifestyles zijn de effecten opmerkelijk voor telewerken, verschuivingen naar duurzame vervoerswijzen en kleinere woningen. In Designed World daarentegen zijn de voornaamste effecten afkomstig van elektrische voertuigen, *peer-to-peer* taxidiensten en woningisolatie, warmtepompen en elektrificatie (hoofdstuk 6).

In de SLIM-scenario's worden andere trends waargenomen dan in eerdere scenario's met gedragsverandering. In vergelijking met het eerder ontwikkelde VS scenario (van Sluisveld et al., 2016) te zien in Figure 8-3, laten Pocket Lifestyles en Designed World andere trends zien. Over het algemeen hebben de SLIM-scenario's grotere emissiereducties dan het VS scenario. Voor Pocket Lifestyles zijn de transportemissies in Global North echter hoger. Dit is met name te wijten aan de geringere efficiëntieverbeteringen en verschuivingen naar duurzame brandstoffen, en ook aan het feit dat naar verwachting minder mensen met het openbaar vervoer zullen reizen. Aangezien de aannames in het VS scenario meer gestileerd waren dan de aannames in de SLIM-scenario's, zou de gedragsverandering in het eerstgenoemde scenario overschat kunnen zijn. In het VS scenario werd bijvoorbeeld aangenomen dat iedereen zijn gedrag op dezelfde manier zou veranderen. Bovendien zou het over het hoofd zien van transversale veranderingen in levensstijl die cascade-effecten kunnen hebben op het verlagen van de consumptie en de emissies op verschillende gebieden, ook kunnen leiden tot een onderschatting van het effect van de gedragsveranderingen. In de SLIM-scenario's is rekening gehouden met regionale verschillen en faciliterende factoren en motivaties die de omvang en snelheid van de overgang beïnvloeden. De verschillende benaderingen en de meer genuanceerde modellering van de SLIM-scenario's leiden tot andere resultaten dan bij eerder werk (hoofdstuk 6).

8.4. HOOFDCONCLUSIE

Door de hierboven besproken onderzoeksvragen te behandelen, konden wij de belangrijkste onderzoeksvraag beantwoorden: **“Hoe kunnen IAM’s de weergave van veranderingen in levensstijl verbeteren om de mogelijke rol van levensstijlen in strategieën ter bestrijding van klimaatverandering te laten zien?”.**

Bij het modelleren van leefstijlveranderingen moeten zowel intentie- als effectoriëntaties aan bod komen. Een holistische benadering waarbij zowel de motieven als de resultaten van gedrags- en leefstijlveranderingen centraal staan, biedt meer inzicht in leefstijlveranderingen.

Het is van cruciaal belang gebruik te maken van kaders en instrumenten om de definities te harmoniseren en typen leefstijlveranderingen te karakteriseren. Onderzoekers gebruiken vaak verschillende termen met betrekking tot leefstijlveranderingen, die van discipline tot discipline verschillen. Deze worden soms door elkaar gebruikt, maar soms ook bewust van elkaar onderscheiden. Daarom is harmonisatie van het gebruik van deze termen bijzonder belangrijk. Kaders en instrumenten kunnen helpen de verschillende benaderingen en disciplines voor het modelleren van veranderingen in levensstijl effectief op elkaar af te stemmen. Table 8-4 presenteert de kaders en instrumenten die in dit onderzoek zijn toegepast, en wij benadrukken hun nut voor ander onderzoek en andere modellen.

Table 8-4: Toepassing van raamwerken en instrumenten in dit onderzoek

Raamwerken / instrumenten	Applicatie
ASI raamwerk	Het ASI-raamwerk (Avoid, Shift, Improve) is gebruikt om de literatuur en de methodologieën te analyseren. Het is opgenomen in de ontwikkeling van het ASIF*-decompositie-instrument en de kwantificering van de SLIM-leefstijlscenario’s. Met dit kader kunnen modelleurs deels een intentiegericht en deels een effectgericht perspectief op leefstijlveranderingen inbrengen.
AFI raamwerk	Het AFI-raamwerk (Attitudes, Facilitators, Infrastructure) werd gebruikt om relevante literatuur en methodologieën te analyseren en motivaties en contextuele factoren te integreren in de ontwikkeling van scenarioverhalen.
ASIF* decompositie instrument	Het ASIF*-instrument (Activity, Structure/Service, Energy Intensity, Fuel Mix) is ontwikkeld om in de IMAGE-output onderscheid te maken tussen verbruiks- en technologieveranderingen van emissies. Het decompositie-instrument is reeds geïmplementeerd als een add-on-instrument voor IMAGE-scenarioruns. Het is getest met bestaande scenario’s, een casestudy in Japan en SLIM-scenario’s. Het decompositie-instrument hanteert een volledig effectgericht perspectief om scenario’s te analyseren met inzicht in veranderingen in levensstijl.

Het samen creëren van kwalitatieve scenarioverhalen en kwantitatieve emissiepaden is essentieel voor het weergeven van veranderingen in levensstijl. Zoals aangegeven in de afwegingen tussen verschillende modelbenaderingen, maakt het gebruik van exogene input (bijv. verhalen) in modellen voor het creëren van emissiepaden het mogelijk om een vollediger kwalitatieve weergave van veranderingen in levensstijl vast te leggen. Daarom levert het combineren van de kwalitatieve benadering met een intentiegerichtheid en de kwantitatieve benadering met een effectgerichtheid waardevolle inzichten op vanuit verschillende perspectieven voor het informeren van een reeks doelgroepen, van modelleurs tot beleidsmakers, zoals in dit onderzoek is gedaan (zie Figure 8-5).

De endogene modellering van veranderingen in levensstijl moet worden verbeterd om dynamische systemen in kaart te brengen. Zoals aangegeven in de afwegingen tussen verschillende modelbenaderingen, maakt endogene modellering van leefstijlveranderingen een meer dynamische weergave mogelijk, maar is het moeilijker om een vollediger systeem weer te geven. Om de SLIM-scenario's te modelleren, werd verdere heterogeniteit met de adoptiegroepen (Rogers, 2010) gemodelleerd voor een expliciete weergave van de omvang en snelheid van de overgang. De modelontwikkeling is vooral gebaseerd op een effectgericht perspectief dat zich richt op het modelleren van parameters en variabelen. De toepassing van de Diffusie van Innovatietheorie (Rogers, 2010), waarop de adoptergroepen zijn gebaseerd, vereist echter een intentiegericht perspectief, dat een ander perspectief toevoegt binnen het model en niet alleen in de verhalen. Daarom hielp de endogene modellering om de SLIM-scenario's beter in het *Integrated Assessment Model* IMAGE te vatten. Andere IAM's zouden de modellering van leefstijlveranderingen op soortgelijke wijze kunnen benaderen om leefstijlveranderingen beter weer te geven (hoofdstuk 6).

Table 8-5: New scenario outputs in this research

Scenario uitkomsten	Details
Lifestyle scenario narratives	Met de stakeholders zijn vier uiteenlopende kwalitatieve scenario's over veranderingen in levensstijl ontwikkeld. Deze verhalen omvatten kwantitatieve aannames voor de vertaling ervan in model-input. Bij de ontwikkeling van de leefstijlscenario's is meestal uitgegaan van een intentiegericht perspectief, gericht op het waarom, hoe en wie met betrekking tot leefstijlveranderingen. Ook is een effectgericht perspectief gehanteerd, met betrekking tot de vertaling naar model-input, waarvoor de scenarioverhalen bedoeld waren, naast het informeren van beleidsmakers en stakeholders.
Lifestyle scenario emission pathways	Twee van de vier SLIM scenario's werden gemodelleerd door de kwantitatieve aannames te vertalen naar model-input. De modellering van de leefstijlscenario's had vooral een effectgericht perspectief, waarbij de nadruk lag op de model-output (bijv. emissies). Vanwege de kwalitatieve aannames die in de scenario-input werden gebruikt, was ook een intentiegericht perspectief nodig.

Via een transdisciplinair co-creatieproces maken de scenarioverhalen een strategische discussie tussen verschillende gebruikers mogelijk. Deze scenarioverhalen bieden waardevolle inzichten die levensstijlveranderingen, in de context van systeemverandering, kunnen positioneren als oplossing voor klimaatmitigatie. Het opnemen van leefstijlveranderingen in scenario's kan informatie opleveren voor klimaatonderhandelingen. Door dit proces te benaderen via scenarioplanning kunnen we mogelijke paden verkennen, onze aannames over de toekomst expliciet maken en verschillende plausibele toekomstige paden naar duurzame leefstijlen onderzoeken, om een meer strategische dialoog te voeren over wat er zou kunnen ontstaan en om robuuste strategieën voor klimaatactie te bepalen (hoofdstukken 5 en 6).

Met de verbeterde weergave van levensstijlveranderingen in de SLIM-scenario's kunnen belanghebbenden beter geïnformeerde beslissingen nemen over het faciliteren van levensstijlen als strategieën om klimaatverandering tegen te gaan. IAM's geven gedrags- en leefstijlveranderingen doorgaans weer met gestileerde aannames, of helemaal niet. Dit betekent dat veranderingen in levensstijl vaak over het hoofd worden gezien of onvoldoende worden onderzocht als strategieën om klimaatverandering tegen te gaan. Dit onderzoek benadrukt dat beleidsmakers met de in dit proefschrift ontwikkelde SLIM-scenario's mogelijke trajecten voor veranderingen in levensstijl en de gevolgen daarvan kunnen verkennen voor beter geïnformeerde beslissingen over strategieën om klimaatverandering tegen te gaan (hoofdstuk 6).

8.5. AANBEVELINGEN VOOR ONDERZOEK

Dit onderzoek beveelt aan 1) de toepassing van het ASIF*-decompositie-instrument te verbreden en te verbeteren, 2) extra heterogeniteit toe te voegen aan modellen en scenario's, met inbegrip van meer rechtvaardigheidsoverwegingen in aannames, 3) de deelname aan de scenario-ontwikkeling uit te breiden en te diversifiëren, 4) meer disciplinaire perspectieven op te nemen in de kwalificatie en kwantificering van scenario's, 5) veranderingen in levensstijl expliciet te modelleren, en 6) de scenariomodellering uit te breiden om uitgesloten scenario's en sectoren te modelleren.

Het ASIF*-decompositie-instrument zou kunnen worden verbeterd voor toekomstige scenarioanalyses. Het is interessant om meer manieren te onderzoeken om de decompositie-uitkomsten te presenteren. In plaats van de modelresponsen tussen twee tijdstippen te analyseren (zoals in dit onderzoek is gedaan), zou het decompositie-instrument bijvoorbeeld voor meerdere tijdstappen of zelfs jaarlijks kunnen worden toegepast om de resultaten als emissietrajecten weer te geven. Dit zou meer details geven over trends in de tijd. Voorts kan het instrument worden uitgebreid met aanvullende indicatoren. In dit onderzoek wordt een volledige structuur voorgesteld voor het decompositie-instrument voor de woon- en vervoerssector. Het creëren van meer relevante variabelen in IAM's vormt een sterkere basis voor verbeterde modellering van levensstijl en gedragsverandering voor toekomstig onderzoek.

De toepassing van het ASIF*-decompositie-instrument kan worden verbreed. Er zijn ook andere scenario's met gedragsverandering, maar de toepassing van het decompositie-instrument is complex, gezien de verschillen in modeloutputs. Voor een betere interpretatie van de modelrespons zou het waardevol zijn de resultaten van deze decompositieanalyse te harmoniseren en te vergelijken met andere scenario's inzake gedragsverandering. Dit decompositie-instrument zou als basis kunnen dienen voor de harmonisatie van verschillende scenario's. Procesgebaseerde IAM's met een hoge ruimtelijk-technologische resolutie worden het meest geschikt geacht om in een ruimere toepassing van het ASIF*-decompositie-instrument te worden opgenomen, omdat zij het gedrag en de besluitvorming van de consument het dichtst benaderen. Indien IAM's hun outputvariabelen kunnen afstemmen op de variabelen van het instrument, zou het instrument ook in een bredere reeks modelleringskaders kunnen worden toegepast.

Door meer heterogeniteit toe te voegen aan IAM's en langetermijnscenario's kunnen consumenten en veranderingen in levensstijl beter worden weergegeven. Figure 4-4 toont aanzienlijke verschillen tussen consumentensegmenten binnen regio's. Om consumenten en gedragsverandering in modellen beter weer te geven, kunnen modelleurs verschillende consumentensegmenten in IAM's toevoegen. Een optie is het toevoegen van empirische gegevens of het gebruik van emissies per huishouden, zoals de Japanse studie die in dit onderzoek is gebruikt. Het zou echter moeilijk kunnen blijken om deze gegevens voor alle regio's te verkrijgen. Voorts zou downscaling en differentiatie van archetypes uit de nationale enquêtegegevens (Hanmer et al., 2022) een alternatieve manier kunnen zijn om heterogeniteit toe te voegen aan modelmatige scenario's. Een andere optie is het opnemen van meer generieke consumentensegmenten zoals de adoptergroepen op basis van de diffusie van innovatietheorie (Rogers, 2010), zoals is gedaan in de modellering van de twee SLIM-scenario's. Het extra detail per adoptergroep maakt de mogelijk rekening te houden met verschillende marktsegmenten en overgangssnelheden en kan informatie opleveren voor beleid en klimaatmaatregelen op maat ter ondersteuning van diverse trajecten naar een duurzame levensstijl.

Het uitbreiden van het aantal vertegenwoordigers bij participatieve scenario-ontwikkeling verbetert het toekomstige scenariowerk. Een reeks adviseurs uit verschillende disciplines en regio's werd bij de totstandkoming van deze scenario's betrokken om input te leveren. Dit stimuleerde discussies en stelde vooroordelen over veranderingen in levensstijl ter discussie met het oog op een meer representatieve toekomst. Hoewel verschillende vertegenwoordigers van de *Global South* werden opgenomen als adviseurs of beleidsmakers, zou een specifieke focus op de *Global South* de scenario's in toekomstige werkzaamheden kunnen verbeteren. Vanwege hun traditionele gebruiken en voortdurende ontwikkeling zijn de leiders van de *Global South* belangrijk voor de beperking van de klimaatverandering. Voorts werden vertegenwoordigers van het bedrijfsleven niet betrokken bij het scenario-ontwikkelingsproces, aangezien zij niet actief werden geworven. Het perspectief van het bedrijfsleven is echter waardevol, vooral omdat het een belangrijke rol speelt als katalysator van veranderingen in levensstijl. Daarom zouden de scenario's in de toekomst verder kunnen worden verfijnd met een aantal vertegenwoordigers van het bedrijfsleven.

Het betrekken van meer disciplines bij de kwalificatie en kwantificering van scenario's leidt tot waardevolle nieuwe perspectieven. Bij de ontwikkeling van de SLIM-scenario's werd een brug geslagen tussen kwalitatieve en kwantitatieve methoden om scenario's voor veranderingen in levensstijl op te stellen. De vertaling van kwalitatieve verhalen naar kwantitatieve input voor de ontwikkeling van scenario's heeft een meer genuanceerde weergave van veranderingen in levensstijl en systemen in IAM's mogelijk gemaakt. De op kwantitatieve modellering en kwalitatief onderzoek gebaseerde leefstijlscenario's kunnen worden toegepast op specifieke regio's om de motivaties van individuen en gemeenschappen te diversifiëren en kunnen leiden tot nieuwe, volkse, interdisciplinaire en duurzame acties. Hoewel dit werk op meerdere disciplines steunt, zijn veel disciplines niet bij de scenario-ontwikkeling betrokken. Gezondheidswetenschappen zouden ons bijvoorbeeld kunnen informeren over veranderingen in levensstijl met het oog op de gezondheid. Deze uitbreiding van de disciplinaire inbreng kan in toekomstig werk verder worden onderzocht. Verkenning van differentiërende waardeontwikkeling kan resulteren in nieuwe variaties van adoptiepercentages en oplossingen voor klimaatmitigatie. Wanneer scenarioplanning wordt ondersteund door geïntegreerde beoordelingsmodellen, geven verdere multidisciplinaire scenario's overtuigende vooruitzichten voor beleid dat een bredere betrokkenheid van verschillende belanghebbenden in de klimaatgemeenschap mogelijk maakt.

Er is een mogelijkheid om specifieke leefstijlmodules te creëren binnen IAM's: het herschikken van leefstijlgerelateerde parameters en variabelen zodat deze expliciet beschikbaar zijn in het model. Bij de modellering van de SLIM-scenario's werden sommige aannames over de adoptiepercentages en adoptiegroepen expliciet gemodelleerd binnen TIMER (vooral in de woonsector), maar andere aannames waren een uitdaging om rechtstreeks te implementeren. In de vervoersector zijn de modelparameters niet rechtstreeks gekoppeld aan de scenario-aannames. Om het gebruik van elektrische voertuigen aan te moedigen, werd bijvoorbeeld uitgegaan van lagere technologiekosten voor elektrische voertuigen, wat tot een hoger gebruik leidt. De adoptiegroepen konden niet rechtstreeks worden gekoppeld aan de technologiekosten van voertuigen. Voor woningen werd de vertaling van de verhaallijnen naar scenario-input echter verbeterd door adoptergroepen te creëren als extra laag van heterogeniteit. Toch zijn er mogelijkheden om de vertaling van leefstijlveranderingen naar het model verder te verbeteren. Eén manier is via een speciale leefstijlmodule buiten de sectoren personenvervoer en wonen met koppelingen naar deze sectoren.

Het modelleren van andere levensstijlscenario's en het uitbreiden naar andere sectoren zou aanvullende vergelijkingen en inzichten mogelijk maken. Van de SLIM-scenario's zijn Designed World en Pocket Lifestyles gemodelleerd, maar Global Commons en Big Village zijn buiten de scenariomodellering gehouden. Designed World en Pocket Lifestyles zouden beter kunnen worden weergegeven in IMAGE, terwijl Global Commons en Big Village ingrijpende wijzigingen zouden vergen. Er zijn enorme mogelijkheden om meer transformatieve waardeverschuivingen naar collectieve waarden weer te geven, zoals die in Global Commons en Big Village. Bovendien vertegenwoordigt dit onderzoek personenvervoer en woningen en kan het worden uitgebreid tot andere sectoren zoals levensmiddelen en consumptiegoederen). In toekomstig werk moeten deze uitgesloten scenario's en sectoren worden onderzocht in IAM's voor een meer holistische analyse.

8.6. AANBEVELINGEN VOOR BELEID

Voor beleidsmakers beveelt dit onderzoek aan 1) een rechtvaardige energietransitie centraal te stellen bij het overwegen van leefstijlveranderingen, 2) grotere systeem- en leefstijlveranderingen mee te nemen, 3) capaciteit op te bouwen in het gebruik van scenario's voor besluitvorming en 4) een holistische aanpak te hanteren.

8

Leefstijlverandering in de richting van duurzame ontwikkeling is afhankelijk van randvoorwaarden (bijv. infrastructuur) - die door overheden moeten worden gefaciliteerd. Dit onderzoek modelleerde de SLIM-scenario's hoofdzakelijk op basis van individualistische waarden. Met levensstijlveranderingen door gecentraliseerde ondersteuning (inclusief faciliterende voorwaarden zoals duurzaam infrastructuurontwerp) in Designed World zouden de emissies 39% lager zijn dan in het SSP2-referentiescenario voor de Global North en 27% voor de Global South. Met gedistribueerde steun, in Pocket Lifestyles, zou de reductie 15% bedragen voor de Global North en 23% voor de Global South. De andere (nog te modelleren) SLIM-scenario's worden voornamelijk gestuurd door collectieve waarden en zouden nog grotere emissiereducties kunnen laten zien. Het effect van veranderingen in levensstijl (in deze gemodelleerde scenario's) is aanzienlijk, maar er zijn ook grotere systeemveranderingen nodig om deze veranderingen in levensstijl mogelijk te maken en de klimaatdoelstellingen te bereiken. Daarom is facilitering door regeringen van vitaal belang en zijn ook bottom-up initiatieven nodig.

Bij de discussie over leefstijlverandering moet rechtvaardigheid een belangrijke overweging zijn. De resultaten van hoofdstuk 4 benadrukken de ongelijkheid van de CO2-emissies in de samenleving, tussen regio's en binnen regio's en doen de vraag naar rechtvaardigheid rijzen. Er is veel ruimte voor verbetering en emissiereductie wanneer de landen met een hoge uitstoot worden geanalyseerd. Lage uitstoters daarentegen hebben beperkte ruimte om hun CO2-uitstoot te verminderen. Als toekomstscenario's uitgaan van een rechtvaardige overgang om onze klimaatdoelstellingen te bereiken, moeten zij rechtvaardigheid integreren in de aannames en oplossingen die zij onthullen. Deze inzichten kunnen als leidraad dienen voor beleid, infrastructurele en ondersteunende culturele ingrepen om deze emissiearme consumptiepatronen mogelijk te maken.

Gebruik deze scenario's en emissiepaden effectief door een verbeelding te vormen van duurzame toekomsten en de gevolgen daarvan voor beleid en klimaatactie. De scenario verhaallijnen (hoofdstuk 5) en emissiepaden (hoofdstuk 6) zijn nuttig om duurzame toekomsten voor te stellen om volledig te begrijpen hoe het beleid wereldwijde gemeenschappen en het dagelijks leven van mensen zou kunnen beïnvloeden. In deze scenario's worden 'vraagverantwoordelijken' en veranderingen in levensstijl als belangrijke katalysatoren voor verandering aangewezen, waarbij het belang van individuele en gemeenschapsactoren en de vele duurzame richtingen die vraagverantwoordelijken kunnen inslaan, worden benadrukt. Deze scenario's kunnen de strategische dialoog en de beslissingen en maatregelen ter beperking van de wereldwijde klimaatverandering helpen sturen.

Beschouw verandering van levensstijl in de context van grotere systeemveranderingen. Zoals uit alle hoofdstukken blijkt, kunnen verandering van grotere systemen en verandering van levensstijl worden beschouwd als twee zijden van dezelfde medaille (Capstick et al., 2020). Vaak worden deze echter apart beschouwd, wat leidt tot *'consumer scapegoatism'* (Akenji, 2014), waarbij de verantwoordelijkheid bij consumenten wordt gelegd om hun leefstijl te veranderen, terwijl veel buiten hun macht ligt. Daarom zijn er beperkingen in mitigatie van klimaatverandering met alleen leefstijlverandering (zoals blijkt uit de Pocket Lifestyles van de SLIM-scenario's). Er is een bredere mitigatiestrategie nodig die zowel duurzame leefstijlen als grotere systeemveranderingen omvat. De multidisciplinaire aard van dit onderzoek maakt een geïntegreerde systeembenadering mogelijk en bevordert het inzicht dat onze context een belangrijke vorm van levensstijlen is.


P
M
BL A UWE

SUPPLEMENTARY INFORMATION

S2. IMPROVED MODELLING OF LIFESTYLE CHANGES IN INTEGRATED ASSESSMENT MODELS: CROSS-DISCIPLINARY INSIGHTS FROM METHODOLOGIES AND THEORIES

S2.1. Definitions and relevant quotes of behavioural change or lifestyle across disciplines

Disciplines	Definitions
Sustainable lifestyles	"A sustainable lifestyle is a cluster of habits and patterns of behaviour embedded in a society and facilitated by institutions, norms and infrastructures that frame individual choice, in order to minimize the use of natural resources and generation of wastes, while supporting fairness and prosperity for all." (Akenji & Chen, 2016)
	"A sustainable lifestyle minimizes ecological impacts while enabling a flourishing life for individuals, residential, communities, and beyond. It is the product of individual and collective decisions about aspirations and about satisfying needs and adopting practices, which are in turn conditioned, facilitated, and constrained by societal norms, political institutions, public policies, infrastructures, markets, and culture." (P. Vergragt et al., 2016)
Energy modelling	"Changes in lifestyle can be expressed in changes in energy demand either through more physical efficiency boosting actions or curtailment measures … as energy efficiency improvement measures overlap with technological improvements already included in the [IMAGE] model, we exclude these measures here" (van Sluisveld et al., 2016)
	Behavioural change is the "change in the quantity or quality of energy services consumed by end-users; micro-level (end-users)"
Innovation studies	"Changes in lifestyles and consumer behaviour are often defined as social innovations"(Scherhorn et al., 1997).
	"…Social innovations are manifested in changes in attitudes, behaviours, or perceptions, resulting in new social practices … social innovation is about social change … we are not only talking about changes in the way social agents act and interact with each other, but also changes in the social contexts in which these actions take place through the creation of new institutions and new social systems"(Cajaiba-Santana, 2014).
Industrial ecology	"From an industrial ecology perspective, the disaggregation of [different types of] behaviours into specific mitigation strategies helps to structure consumer practices and can serve as a starting point for calculating the emission-saving potential of different strategies in order to gain more insight into the effectiveness of specific measures." (Schanes et al., 2016)
Built environment	"…the design of the buildings (offices and homes) and urban spaces offers valuable avenues for influencing behaviour through spatial layouts, physical formations, technical systems and accessibility to and contact with the natural environment, all of which can encourage energy savings that carry over into other elements of daily life."(Fink, 2011)
Geography	"Increasingly, researchers consider how broader landscape factors – homes' structural characteristics, the morphology of their immediate neighbourhoods, and the broader development patterns in which they are embedded – drive household energy use (e.g., Sanne, 2002; Shove, 2003)." (Knuth, 2010)

Disciplines	Definitions
Sociology	"Some recent work in sociology suggests that the conspicuous and status-seeking aspects of consumer behaviour have been overemphasised. According to this view, a great deal of consumption in fact takes place inconspicuously as a part of the ordinary, everyday decision-making of millions of individual consumers … [which] is not oriented particularly towards individual display. Rather it is about convenience, habit, practice, and individual responses to social norms and institutional contexts. And far from being willing partners in the process of consumerism, consumers are seen as being 'locked-in' to a process of unsustainable consumption over which they have very little individual control." (Jackson, 2005).
Behavioural economics	"Not only does behavioural economics reveal that we are not rational, it also notes that we recognise this fact ourselves. We know that we aren't good at resisting temptation, and this can cause guilt and anxiety. In these cases, behaviour change can be seen, to augment individual freedom, helping us do what we want to but can't do, rather than constrain it."(Dolan et al., 2010) "[...] any aspect of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid. Nudges are not mandates. Putting the fruit at eye level counts as a nudge. Banning junk food does not." (Thaler & Sunstein, 1999).
Psychology	"Climate-relevant individual decisions are at the heart of climate change. Given that people often have difficulty identifying the causes of their behaviour, the task falls to researchers to reveal the factors that most influence their decisions. Of course, climate change-relevant behaviour is not solely dependent on individuals. Collective psychological processes also come into play. Collective guilt, for example, is experienced when people perceive that their in-group is responsible for doing harm. In terms of the present issue, collective guilt about GHG emissions mediates the effect of climate change beliefs on willingness to engage in mitigation behaviours. Collective or group decision making is also important that groups have a voice in the decision can affect, for example, which mitigation strategy is supported. These findings suggest that collective emotions and collective decision-making must be considered in order to fully encourage mitigative behavior." (Gifford et al., 2011)
Health and nutrition	"[Positive health effects] are important not only because they can provide an additional rationale to pursue mitigation strategies, but also because progress has been slow to address international health priorities such as the UN Millennium Development Goals (MDGs) and reductions in health inequities. Mitigation measures offer an opportunity not only to reduce the risks of climate change but also, if well-chosen and implemented, to deliver [substantial] improvements in health almost immediately."(Haines et al., 2009) "[There is a] need for improved nutrition, healthy cities, and lower pollution, among other factors, in order to obtain health goals, including combating the ever-increasing global obesity epidemic. Importantly, there are opportunities to improve both greenhouse gas emissions (GHGE) and health outcomes through climate change mitigation action. This collateral beneficial relationship is termed *co-benefits* … As individuals and communities strive to design and participate in healthier more sustainable lifestyles, increased research scrutiny is needed to inform decision making lifestyle-related mitigation strategies, [for example] increased active transport (i.e., cycling and walking) and climate-conscious diet modification (i.e., consuming foodstuffs with relatively low GHGE)" (Quam et al., 2017)
Philosophy	"Individual citizens can perform a variety of actions towards climate change mitigation on different levels of cooperative action, including engaging in political activism, establishing or joining local initiatives to promote sustainable energy use, joining established political parties to work towards political solutions to the mitigation problem. Yet, the question [from a philosophy perspective] … [could be] slightly different, taking up a frequently uttered demand to bid farewell to an energy-intensive lifestyle. It is: are individual citizens in high emission countries morally required to reduce their day-to-day GHG emissions?" (Schwenkenbecher, 2014)

S2.2. Search terms and criteria for relevant article selection for NVivo systematic review

Search terms:	
1	"climate and (mitigation or mitigate) and (lifestyle or behaviour or behavior) AND ("greenhouse gas" or emissions)"
Selection criteria:	
1.	Explicitly stating or modelling lifestyle or behaviour in as mitigation measures for climate change
2.	Explicitly consider behavioural change and not technological change based on cost efficiency

S2.3. Impact-oriented transport lifestyle changes

Categories	Measures	Details	Model	Sources
Less CO_2-intensive transport modes	Reduce vehicle use	Changing Travel Money Budget (TMB)	Energy modelling (IAM) - IMAGE	(Girod et al., 2013)
		TMB capped to current modal split in Japan (lowest reported value for a developed region)	Energy modelling (IAM) – IMAGE	(van Sluisveld et al., 2016)
		Changing surface passenger travel patterns: mode shift comes with a decrease in the average length of trips, due to a shift in destination resulting from localisation, and a decrease in a number of trips per capita, as some journeys will be replaced with 'virtual' trips.	(Transport) energy modelling (MARKAL)	(Anable et al., 2012)
		The assumption that passenger rides the bus 20 miles per week	EIO-LCA model	(Jones & Kammen, 2011)
	Shift to public transport	Changing future Travel Time Budget (TTB): continuous increase in income leads to a preference for faster transport modes, differentiating non-monetary preferences per transport mode influences model split	Energy modelling (IAM) – IMAGE	(Girod et al., 2013)
		Allow an additional 0.5 min per year on TTB	Energy modelling (IAM) - IMAGE	(van Sluisveld et al., 2016)
		All mobility demand related to commuting will be made by bus and rail transport	Energy modelling (IAM) - GCAM	(van de Ven et al., 2017)
		Replace all daily standard gasoline vehicle travel by bus transport	Input-output analysis	(Bjelle et al., 2018)
		Replace all daily standard gasoline vehicle travel with train transport	Input-output analysis	(Bjelle et al., 2018)
	Carpooling	Carpooling	Energy modelling (IAM) – IMAGE	(Girod et al., 2013)
		Work travel carpooling with a hybrid electric vehicle under 10 km trips	Input-output analysis	(Bjelle et al., 2018)
		Increased passenger load, translated into numbers with a load factor of 2 (the minimum definition) for every commute trip	Energy modelling (IAM) - GCAM	(van de Ven et al., 2017)

Categories	Measures	Details	Model	Sources
Less CO_2-intensive transport modes	Car sharing / car clubs	It is assumed that the same pkm is driven by cars with car sharing compared to car owners, although users tend to drive less in this behavioural option, this allows to solely focus on environmental benefits for sharing a car and not on the impact of reduced km's driven.	Energy modelling (IAM) - GCAM	(van de Ven et al., 2017)
	(Urban) cycling	This value is heavily dependent on the steepness of streets and the distance of the trip. For the urban cycling potential, the urban cycling rate of the Netherlands is used.	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
		The assumption that passenger rides a bicycle 20 miles per week	EIO-LCA model	(Jones & Kammen, 2011)
	Walking	Walk instead of taking the train (4.7 km each way)	Input-output analysis	(Bjelle et al., 2018)
	No trips by car under 3 km	Switch from the use of standard gasoline vehicle to walking or cycling for trips under 3 km	Input-output analysis	(Bjelle et al., 2018)
Reduced travel demand	Teleworking	Work one day a week from home – deduct demand for passenger commuting by 1/5 (assumed that citizens typically work five days a week away from home)	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
		Reduced one business flight (short flight) per month, replaced by video conference	Input-output analysis	(Bjelle et al., 2018)
		Telecommute to work once per week	EIO-LCA model	(Jones & Kammen, 2011)
	Avoid flights	The assumption that whenever there is a realistic alternative for a flight (under 10 hours), this option is taken.	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
		One less long-distant flight (e.g. Bangkok, Thailand from Norway)	Input-output analysis	(Bjelle et al., 2018)
		Domestic flight growth assumed to decelerate and eventually saturate, as it becomes increasingly uncompetitive on oil price rise, rail improvement and increasingly unacceptable.	(Transport) energy modelling (MARKAL)	(Anable et al., 2012)
	Closer holidays	Intercontinental leisure flights - assumed intra-EU trips (1000 km per trip average distance) replaces 50% of all intercontinental leisure trips (5000 km per trip average distance)	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
Use of vehicles	Eco-driving	Assumed to be behavioural, as drivers can opt to adopt this driving style, and in this behavioural option, is applied to all car-driven km	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
		The assumption that driver reaches a top speed 50% of the time, reducing rapid braking and acceleration	EIO-LCA model	(Jones & Kammen, 2011)
	Maintain vehicles	Assumption fuel efficiency increase with a more efficient vehicle, in addition to keeping tires properly inflated and changes air filters regularly	EIO-LCA model	(Jones & Kammen, 2011)

Categories	Measures	Details	Model	Sources
Choice of vehicles	Budget electric vehicle	Switch from purchasing a standard gasoline vehicle to budget electric vehicle (Renault Zoe)	Input-output analysis	(Bjelle et al., 2018)
	Top of the line electric vehicle	Switch from purchasing standard gasoline vehicle to high-end electric vehicle	Input-output analysis	(Bjelle et al., 2018)
	Changing luxury levels		Energy modelling (IAM) – IMAGE	(Girod et al., 2013)

S2.4. Impact-oriented household lifestyle changes

Categories	Measures	Details	Model	Sources
Heating and cooling	Adjustment of temperature	Change of 1-deg C in reference levels	Energy modelling (IAM) – IMAGE	(van Vuuren et al., 2018)
		Thermostat set-back assumed, from 21- to 20-deg C with more clothing worn indoors; Reduced use of air-conditioner in summer assumed, increased target temperature from 25.5- to 26.5-deg C	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
		Reduce indoor temperature by 1-deg C (heating)	Input-output analysis	(Bjelle et al., 2018)
		Turn down thermostat in winter in the U.S., assumption that 8-deg C decrease for 8 hours at night and 2-deg C for 10 hours during the day	EIO-LCA model	(Jones & Kammen, 2011)
		Turn up thermostat in summer in the U.S., assumption that 2-deg C is turned up for 10 hours during the day and 4-deg C for 8 hours at night	EIO-LCA model	(Jones & Kammen, 2011)
		User accepts a change in desired temperature by reducing the base temperature of 18-deg C by 1-deg C (for heating) and increasing by 1-deg C (for cooling)	Energy modelling (IAM) – IMAGE	(van Sluisveld et al., 2016)
Reduced heating of water		Assumed 2 minutes reduced shower time (based on a correction factor in total energy demand for heating water calculated from literature)	Energy modelling (IAM) – IMAGE	(van Sluisveld et al., 2016)
		Space and water heating reduction based on a 65% reduction potential	Input-output analysis	(Bjelle et al., 2018)

Categories	Measures	Details	Model	Sources
Reduced use of appliances	Switch off standby mode	Assumed appliance standby energy use (as listed by LBNL) per appliance category and deduct this value from total average energy consumption	Energy modelling (IAM) – IMAGE	(van Sluisveld et al., 2016)
	Reduction in use of several domestic appliances	Assumed reduction of appliance ownership rate per household, limited to present maximum ownership rates	Energy modelling (IAM) – IMAGE	(van Sluisveld et al., 2016)
		Line-dry clothing	EIO-LCA model	(Jones & Kammen, 2011)
		Use tumble dryer less	Input-output analysis	(Bjelle et al., 2018)
More efficient or smarter use of appliances		Increase the size of washing and drying loads	Input-output analysis	(Bjelle et al., 2018)
		Assumed that different wash temperatures are chosen, maximize on washing loads per cycle, placement of 'cold' appliances (e.g. fridges) wisely, etc.	Energy modelling (IAM) – IMAGE	(van Sluisveld et al., 2016)
		Reduced energy use from appliances based on a 30% reduction potential	Input-output analysis	(Bjelle et al., 2018)
Buying more efficient appliances		Replace 5 lightbulbs with CFLs	EIO-LCA model	(Jones & Kammen, 2011)
		Choosing Energy Star refrigerator: assumed that household is ready to purchase a new refrigerator, and chooses Energy Star over non-Energy Star model	EIO-LCA model	(Jones & Kammen, 2011)
Waste management	Organic waste		Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
	Paper waste	All paper waste by the consumer will be recycled for the production of new paper. For EU there will limited gains from recycling, compared to other regions	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
	Plastic/metal/glass waste	Plastic waste recycling and reduced demand for consumer plastic	Energy modelling (IAM) – IMAGE	(van Sluisveld et al., 2016)
		All plastic, metal and glass waste will be recycled (proportions assumed to be consistent over time)	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
Household dimensions	Reduce per capita floor space	Assumed that with increasing wealth, the increase of per capita floor space is limited to levels of 2010 of the EU (a representative developed region)	Energy modelling (IAM) – IMAGE	(van Sluisveld et al., 2016)
Decentralised service provision (e.g. mini-grids)		From end users to energy producers, traders, co-designers, citizens and community members all involved in the energy-service provision	Energy modelling (IAM) – MESSAGEix-GLOBIOM	(Grubler et al., 2018)

S2.5. Impact-oriented food lifestyle changes

Categories	Measures	Details	Model	Sources
Healthier, less meat-intensive diet	Willet diet	Conforming to health recommendations	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
			Energy modelling (IAM) – IMAGE	(van Vuuren et al., 2018)
		"Healthy eating" recommendations, transitioning from 2010-2030	Energy modelling (IAM) – IMAGE	(Stehfest et al., 2009)
		Based on the relative kg CO_2-eq savings from Willet diet	Input-output analysis	(Bjelle et al., 2018)
		Based on the relative kg CO_2-eq savings from Willet diet in addition to organic farming	Input-output analysis	(Bjelle et al., 2018)
		Compares carbon footprint of user's diet with lower carbon, and lower calorie diet	EIO-LCA model	(Jones & Kammen, 2011)
	Reduced ruminant meat	Complete protein substitution of cattle, sheep, goats and buffaloes, by plant-proteins, transitioning from 2010-2030	Energy modelling (IAM) – IMAGE	(Stehfest et al., 2009)
		Beef consumption reduction, substitute beef with pork and poultry	Energy modelling (IAM) – TIMES-Canada	(Frenette et al., 2017)
		Dairy and Poultry scenario – ruminants still used for dairy product supply, with culled calves and cows entering the meat chain, with a reduced ruminant meat consumed. It is assumed that animal production efficiencies increase to the North-western European (i.e. Swedish) levels of highly intensive systems.	Energy modelling - spreadsheet model	(Röös et al., 2016)
	Vegetarian diet	Complete protein substitution of pork and poultry by plant-proteins, transition from 2010-2030	Energy modelling (IAM) – IMAGE	(Stehfest et al., 2009)
		No meat, but includes dairy products and possibly fish products	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
		Beef, poultry and pork reductions, substitute with an increase in food grains, fruit, vegetables, eggs and dairy	Energy modelling (IAM) – TIMES-Canada	(Frenette et al., 2017)
		Dairy and Aquaculture scenario – it is assumed that demand for animal protein continues rapidly, but health consciousness increases combined with high efficiencies by intensive aquaculture systems, by 2050 all animal meat consumed are from aquatic products (20% of aquaculture products are oysters, mussels and other filter feeding and 80% are low trophic-level finfish).	Energy modelling - spreadsheet model	(Röös et al., 2016)
		Artificial Meat and Dairy scenario – consumer acceptance of in vitro meat matched with production technological breakthroughs (meat and dairy replaced by these novel proteins and those produced from insects and algae), essentially protein production in this scenario is landless.	Energy modelling - spreadsheet model	(Röös et al., 2016)

Categories	Measures	Details	Model	Sources
Healthier, less meat-intensive diet	Vegan diet	No animal products, additional protein substitution of eggs and milk by plant-proteins, transition from 2010-2030	Energy modelling (IAM) – IMAGE	(Stehfest et al., 2009)
		No animal products (no meat, dairy or fish)	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
		Progressively reduce animal products until 2030 (substitute by grain and vegetable consumption)	Energy modelling (IAM) – TIMES-Canada	(Frenette et al., 2017)
		Plant-Based Eating scenario – animal-free (with the exception of a small amount of wild stock seafood). Policy actions discourage the consumption of animal products, in addition to growing environmental concern from the public, and technological developments of plant-based novel proteins, vegan diets are most common. Assumed that grazing land are used for other activities, and the cropland is used production of foods directly for human consumption	Energy modelling - spreadsheet model	(Röös et al., 2016)
Food waste reduction and composting		Assumed excess food used for animal feed as food waste, due to a reduction in final calories for humans	Energy modelling (IAM) – GCAM	(van de Ven et al., 2017)
		Eliminate food waste and composting	Input-output analysis	(Bjelle et al., 2018)
Organic and local foods		Organic and local foods	Input-output analysis	(Bjelle et al., 2018)

S2.6. Impact-oriented lifestyle changes of consumer goods and services

Categories	Measures	Details	Model	Sources
Purchasing sustainable goods	Eco-efficiency	A choice for eco-efficiency across supply chain	Input-output analysis	(Bjelle et al., 2018)
	Design	A choice of design for durability	Input-output analysis	(Bjelle et al., 2018)
	Synthetic fibres	Market shift towards a higher proportion of synthetic fibres	Input-output analysis	(Bjelle et al., 2018)
	Goods from recycled materials	Buy furniture with 20% recycled MDF (medium-density fibreboard)	Input-output analysis	(Bjelle et al., 2018)
Sustainable use of goods	Maintain goods	Wash at lower temperature	Input-output analysis	(Bjelle et al., 2018)
		Clean clothing less	Input-output analysis	(Bjelle et al., 2018)
	Circular economy	Dispose less, reuse/recycle more	Input-output analysis	(Bjelle et al., 2018)
		Start closed loop recycling of synthetic fibres	Input-output analysis	(Bjelle et al., 2018)
		Value derived from useful services, flexible and varied day-to-day service consumption, agile or destabilised routines	Energy modelling (IAM) – MESSAGEix-GLOBIOM	(Grubler et al., 2018)
		Eliminate unsolicited mail	Input-output analysis	(Bjelle et al., 2018)
		Reducing plastic waste by 30%	Input-output analysis	(Bjelle et al., 2018)
		Reduce printing	Input-output analysis	(Bjelle et al., 2018)
Buy less / increase lifetime	Reduce purchasing of goods	clothing purchases by 20%	Input-output analysis	(Bjelle et al., 2018)
	Infrequent replacement of goods	Average of changing 6 pieces of furniture	Input-output analysis	(Bjelle et al., 2018)
	Increase lifetime of all goods by 20%	e.g. through reselling or longer lifetime	Input-output analysis	(Bjelle et al., 2018)
	Trade in for reduced price	Trade in vehicles	EIO-LCA model	(Jones & Kammen, 2011)
Digitalize goods	Granularity	Widespread adoption and equitable distribution of user-centred energy technologies with low unit costs	Energy modelling (IAM) – MESSAGEix-GLOBIOM	(Grubler et al., 2018)
	Digitalisation of daily life	Ubiquitous use of mobile devices to access & manage services, digital mediation of daily routines, mixture of taking and yielding control	Energy modelling (IAM) – MESSAGEix-GLOBIOM	(Grubler et al., 2018)

S2.7. Impact-oriented lifestyle changes in other domains

Category	Measures	Details	Model	Sources
Rapid transformation	Drastic social change movement	Strong end-use demand for change, social inertia reduced by clearly observable benefits of improved energy services	Energy modelling (IAM) – MESSAGEix-GLOBIOM	(Grubler et al., 2018)
Time	Working time reduction	All residential (or initiators and followers illustrating leisure shocks with heterogeneity) choose to work less, towards leisure such that in 2016 working time in the market is 25% reduced (at old wages) and time spent on energy-consuming household activities are reduced as well	Economic modelling	(GLAMURS, 2016)
	Shift from energy-intensive to time-intensive activities		Economic modelling	(GLAMURS, 2016)

S2.8. Intent-oriented lifestyle changes across domains

Categories	Measures	Model/methodology	Sources
Food	Environmentally rational diets	Narrative-based backcasting analysis	(Neuvonen et al., 2014)
	Better sustainability choices		
	Local foods and energy		
	Optimal eating patterns by eating out		
Residential	Smaller, denser dwelling spaces		
	Shared space and equipment		
	Functionality and flexibility in interior design of buildings		
	Local partnerships empower neighbourhoods for self-sufficiency		
	Do-it-yourself (DIY)		
	Urbanity	Input-output analysis	(Ala-Mantila et al., 2014)
	Household size		
Consumer goods and services	Upcycled consumer goods	Narrative-based backcasting analysis	(Neuvonen et al., 2014)
	Virtual reality and communities		

Categories	Measures	Model/methodology	Sources
Transport	Local travel and community focus	Narrative-based backcasting analysis	(Neuvonen et al., 2014)
	Living in close proximity to peers		
	Settlement pattern	Energy modelling (MESSAGE)	(McCollum et al., 2017)
	Attitude towards technology adoption		
	Vehicle usage intensity		
	Range anxiety		
	Refuelling station availability		
	Risk premium		
	Model availability		
	Availability of EV charger		
	Smart mobility services	Narrative-based backcasting analysis	(Neuvonen et al., 2014)
Digitalize goods	Ubiquitous technology and smart appliances		
	3D printing changes self-actualisation		
Facilitators	Policy-driven nudges and bans		
	5 levers of change	Unilever	(Unilever, 2013)
	Default-setting and labels	Energy modelling (IAM) – IMAGE	(Girod et al., 2014)
Circular economy	Service-based goods	Narrative-based backcasting analysis	(Neuvonen et al., 2014)
Awareness	Social learning	Energy modelling (IAM) – IMAGE	(Edelenbosch et al., 2018)
	Improved information and education for better decision-making	Narrative-based backcasting analysis	(Neuvonen et al., 2014)
	Online networks on lifestyle issue interests		
Health	Health becomes a communal issue		
Demographics	Per-capita expenditure	Input-output analysis	(Ala-Mantila et al., 2014)
	Life stage transitions	Agent-based model	(GLAMURS, 2016)
Cross-cutting frameworks	Social-Ecological Infrastructural Systems		(Ramaswami et al., 2012)

Categories	Measures	Model/methodology	Sources
Heterogeneity	Free market economists	Agent-based climate-economic model	(Geisendorf & Klippert, 2017)
	Scientifically-informed		
	Environmentalists		
	Cost-optimal decisions, with social discounting	Energy modelling (BLUE)	(Li, 2017)
	Heterogeneous decisions, social discounting		
	Heterogeneous decisions, individual discounting		
	Convenient profile	Energy modelling (GCAM)	(van de Ven et al., 2017)
	Conscious profile		
	Enthusiastic profile		
	Early adopters	Energy modelling (MESSAGE)	(McCollum et al., 2017)
	Early majority		
	Late majority		
	Laggards		
	Enthusiast	UK Transport Carbon Model	(Brand et al., 2017)
	Aspirer		
	Mass		
	Resistor		
	User chooser		
	Honestly disengaged	Public segmentation model	(Defra, 2008)
	Stalled starters		
	Waste watchers		
	Cautious participants		
	Sideline supporters		
	Concerned consumers		
	Positive greens		

S3. DECOMPOSITION ANALYSIS OF PER CAPITA EMISSIONS: A TOOL FOR ASSESSING CONSUMPTION CHANGES AND TECHNOLOGY CHANGES WITHIN SCENARIOS

S3.1. Selection of IMAGE regions in developing and developed clusters

Regional clusters	Regions
World	All regions
Developing regions	Western Africa
	Eastern Africa
	India
	South-Eastern Asia (excl. Indonesia)
	South Asia
	Southern Africa (excl. South Africa)
Developed regions	Canada
	USA
	Western Europe
	Central Europe
	Japan
	Oceania

S3.2. Equations for each energy service decomposition analysis

$$E_{transport,r,m}(2050) = E_{r,m}(2015) + \Delta E_{\text{pkms\_pc},r} + \Delta E_{\text{mode\%},r,m} + \Delta E_{\text{intensity},r,m} + \Delta E_{\text{fuel mix},r,m}.$$

$$E_{fuel\ mix,r,m}(t) =$$

$$E_{fuel\ mix,r,m}(t) = \sum_{m=1}^{7} \%_{\text{fuel type},r,m} + E_{\text{fuel type},r,m}.$$

$$E_{spaceheating,r}(2050) = E_r(2015) + \Delta E_{floorspace\_pc,r} + \Delta E_{\text{HDD},r} + \Delta E_{\text{intensity},r} + \Delta E_{\text{fuel mix},r}.$$

$$E_{spacecooling,r}(2050) = E_r(2015) + \Delta E_{AC\_pc,r} + \Delta E_{\text{CDD},r} + \Delta E_{\text{intensity},r} + \Delta E_{\text{fuel mix},r}.$$

$$E_{appliances,r}(2050) = E_r(2015) + \Delta E_{ownership\_pc,a,r} + \Delta E_{\text{CDD,a},r} + \Delta E_{\text{intensity},r} + \Delta E_{\text{fuel mix},r}.$$

$$E_{appliances,r}(2050) = E_r(2015) + \sum_{a=1}^{11} \Delta E_{ownership\_pc,a,r} + \Delta E_{\text{CDD,a},r} + \Delta E_{\text{intensity},a,r} + \Delta E_{\text{fuel mix},a,r}.$$

$$E_{waterheating,r}(2050) = E_r(2015) + \Delta E_{w.heatingdemand,r} + \Delta E_{\text{intensity},r} + \Delta E_{\text{fuel mix},r}.$$

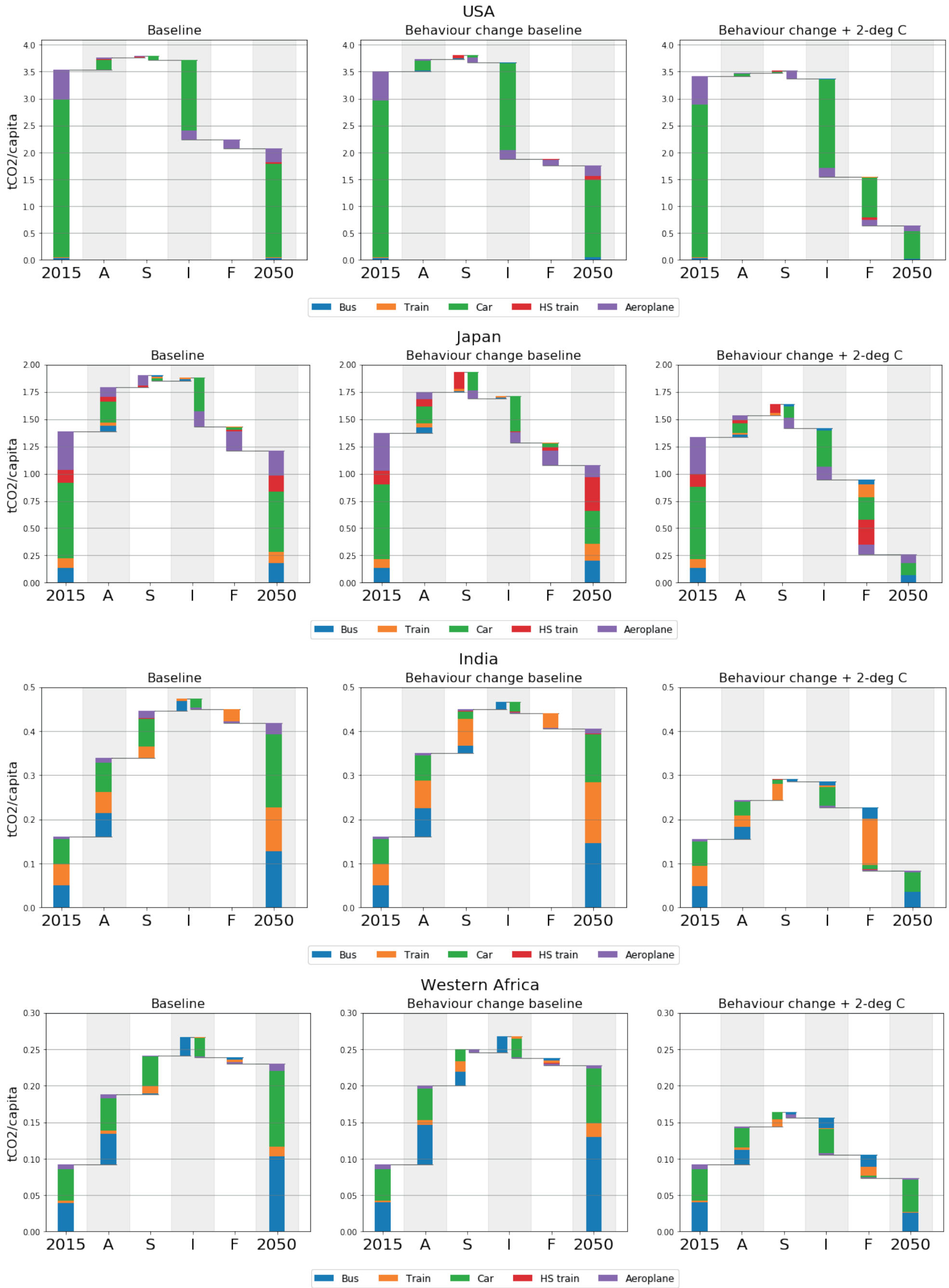
$$E_{cooking,r}(2050) = E_r(2015) + \Delta E_{cookingdemand,r} + \Delta E_{\text{fuel mix},r}.$$

9

S3.3. Details of contributing factors of the decomposition analysis by sector and energy service

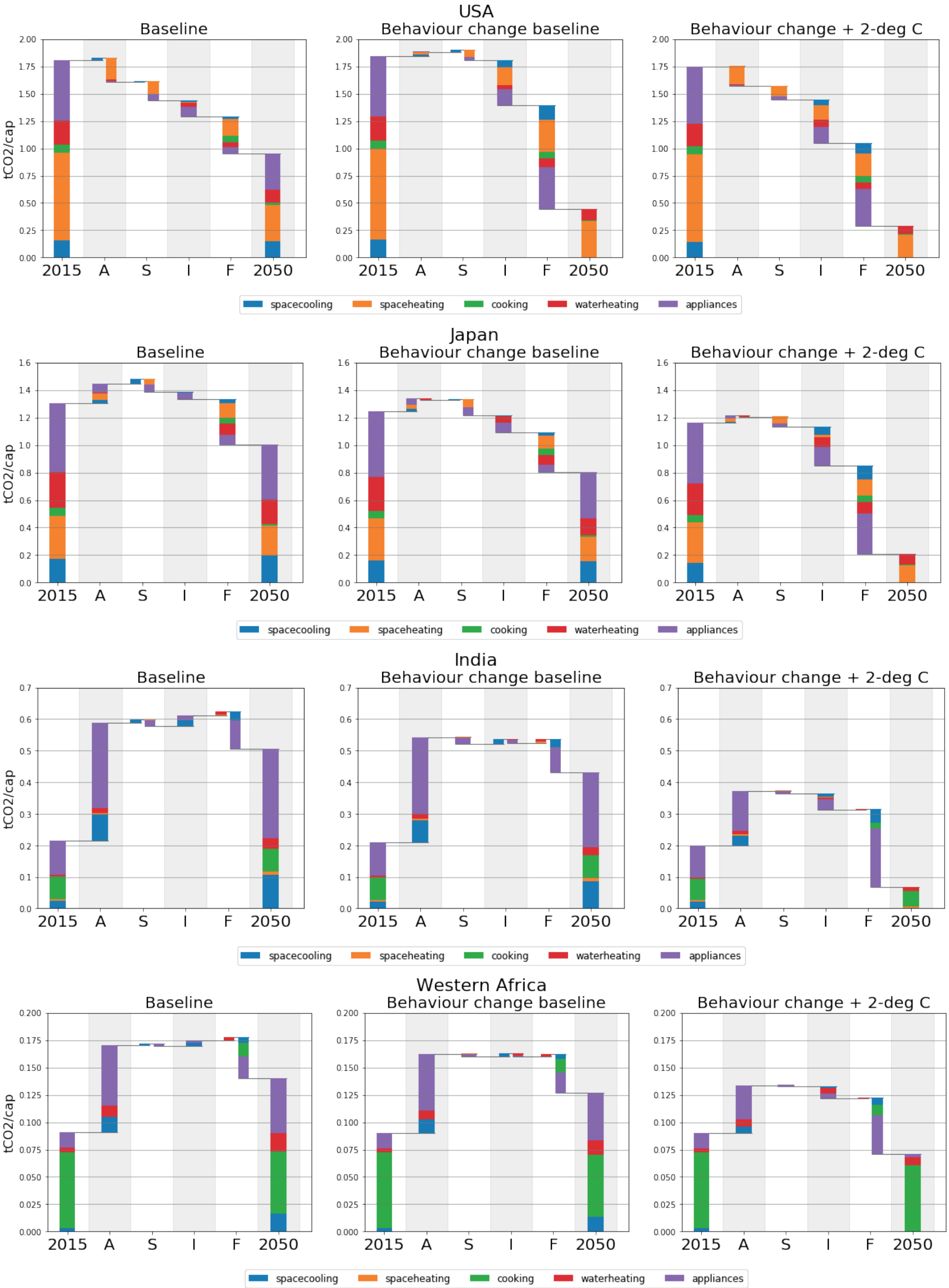
Contributing factors	**Sectors**	**Energy services**	**Details**
Activity	Transport		Average distance travelled in pkm per capita
	Residential	Cooking	Energy for cooking in GJ_{UE} per capita
		Space heating	Heated floor space in m^2 per capita
		Space cooling	Air conditioner ownership in units
		Water heating	Maximum useful energy in GJ per capita
Shift	Transport		Share of transport mode that contributes to the travel demand in pkm of each mode *m* over the total pkm
	Residential	Space heating	Shifts in space heating energy demand in HDD
		Space cooling	Shifts in space cooling energy demand in CDD
Intensity	Transport		Energy consumed per pkm for each mode *m* in MJ per pkm
	Residential	Space heating	Energy consumed per GJ per HDD and m^2
		Space cooling Water heating	Energy consumed per GJ per CDD and AC unit
Fuel mix	Transport		CO_2 emissions emitted per unit of energy used in g CO_2 per GJ of each fuel type *f* in each mode *m*
	Residential		CO_2 emissions emitted per unit of energy used in g CO_2/GJ of each fuel type *f* in each energy service
	The *fuel mix* is calculated from the aggregation of emission factor (g CO_2 per GJ) of each fuel *f* multiplied by a fuel use share (%) of each fuel *f*		

S3.4.1. Regional specific decomposed transport emissions for USA, Japan, India and Western Africa. The categories A (Activity changes), S (Structural changes), I (Intensity changes) and F (Fuel mix changes) represents the contribution of these factors to the change in emissions between 2015 and 2050 for various regions (see S3.1)

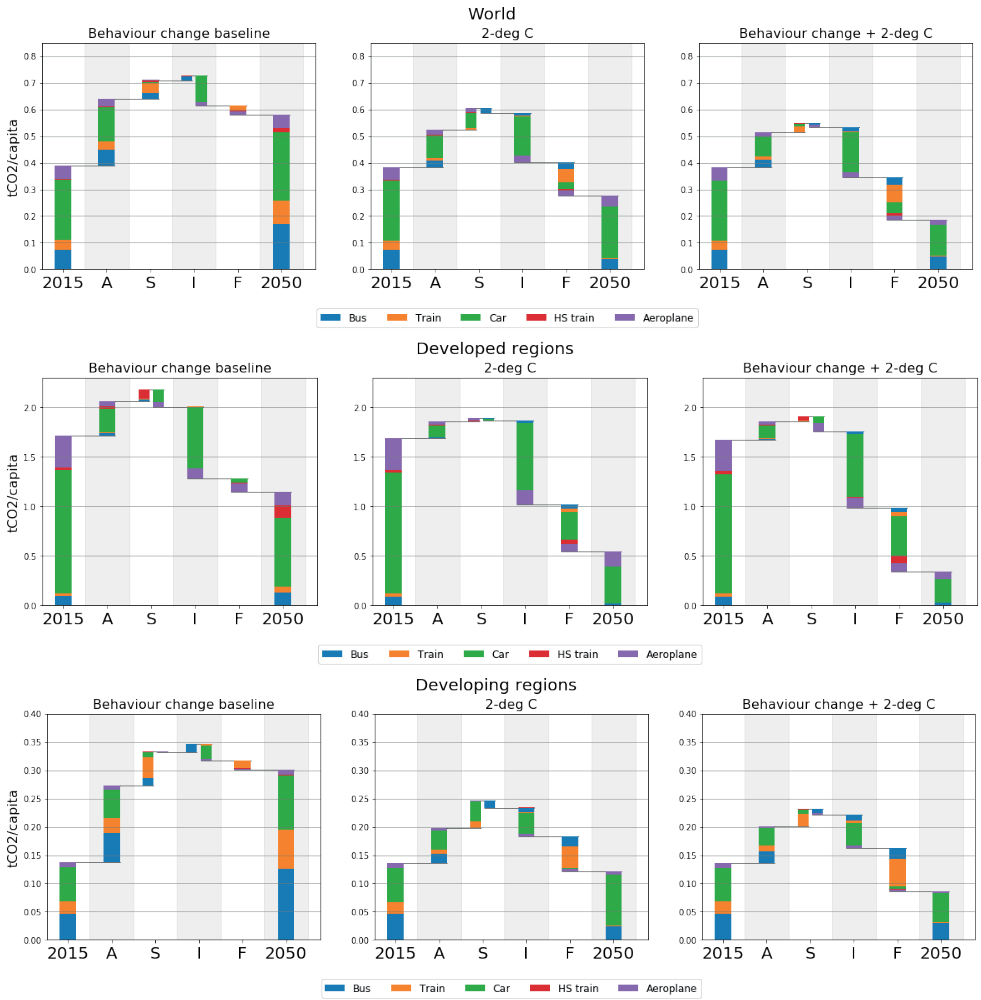


9

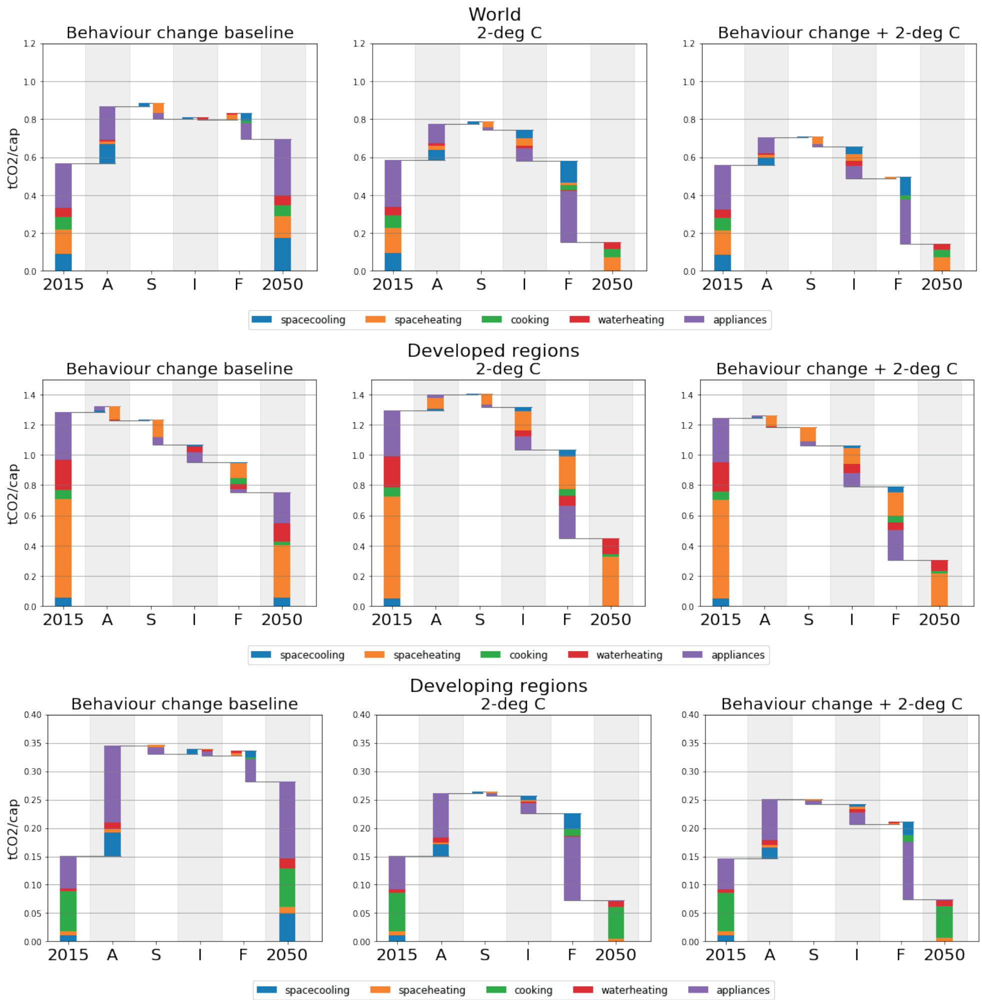
S3.4.2. Regional specific decomposed residential emissions for USA, Japan, India and Western Africa. The categories A (Activity changes), S (Service changes), I (Intensity changes) and F (Fuel mix changes) represents the contribution of these factors to the change in emissions between 2015 and 2050 for various regions (see S3.1)



S3.4.3. Decomposition of per capita transport emissions for a baseline scenario including behavioural measures (Behaviour change baseline), a scenario that only includes climate policy (2-deg C) and a combination of both behavioural measures and climate policy (Behaviour change + 2-deg C). The factors A (Activity changes), S (Structural changes), I (Intensity changes) and F (Fuel mix changes) contribute to the change in emissions between 2015 and 2050 for various regions.

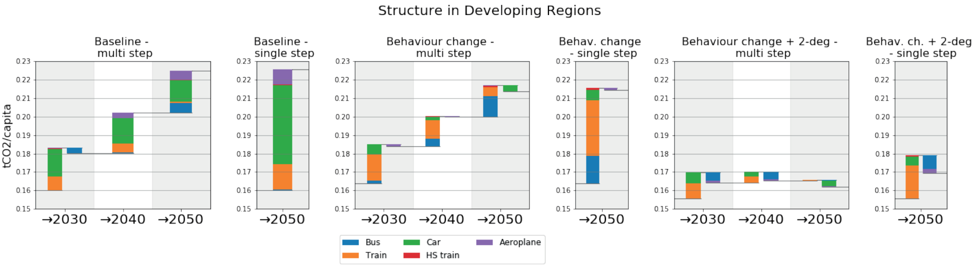


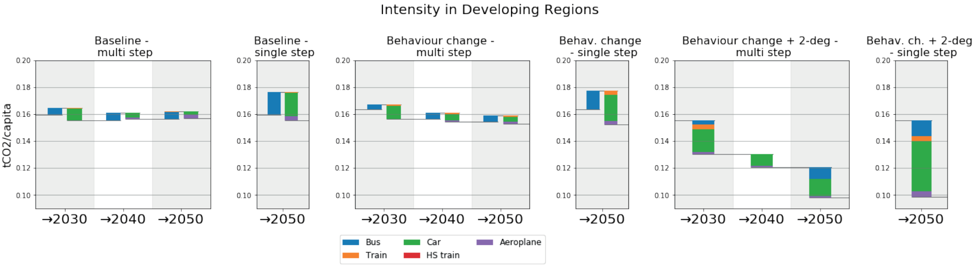
S3.4.4. Decomposition of per capita residential emissions for a baseline scenario including behavioural measures (Behaviour change baseline), a scenario that only includes climate policy (2-deg C) and a combination of both behavioural measures and climate policy (Behaviour change + 2-deg C). The factors A (Activity changes), S (Service changes), I (Intensity changes) and F (Fuel mix changes) contribute to the change in emissions between 2015 and 2050 for various regions

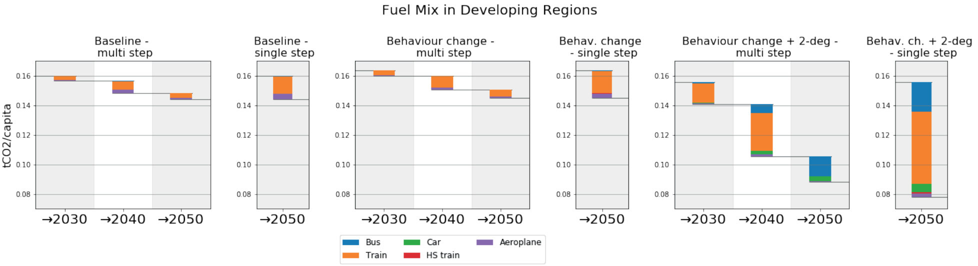


S3.4.5. Multi step verses single step results: decomposition of per capita transport global emissions from activity, structure, intensity and fuel mix. The subplots compare a baseline scenario including behavioural measures (Behaviour change baseline), a scenario that only includes climate policy (2-deg C) and a combination of both behavioural measures and climate policy (Behaviour change + 2-deg C) for both multi-step (2020-2030, 2030-2040, 2040-2050) and single-step (2020-2050) time periods.

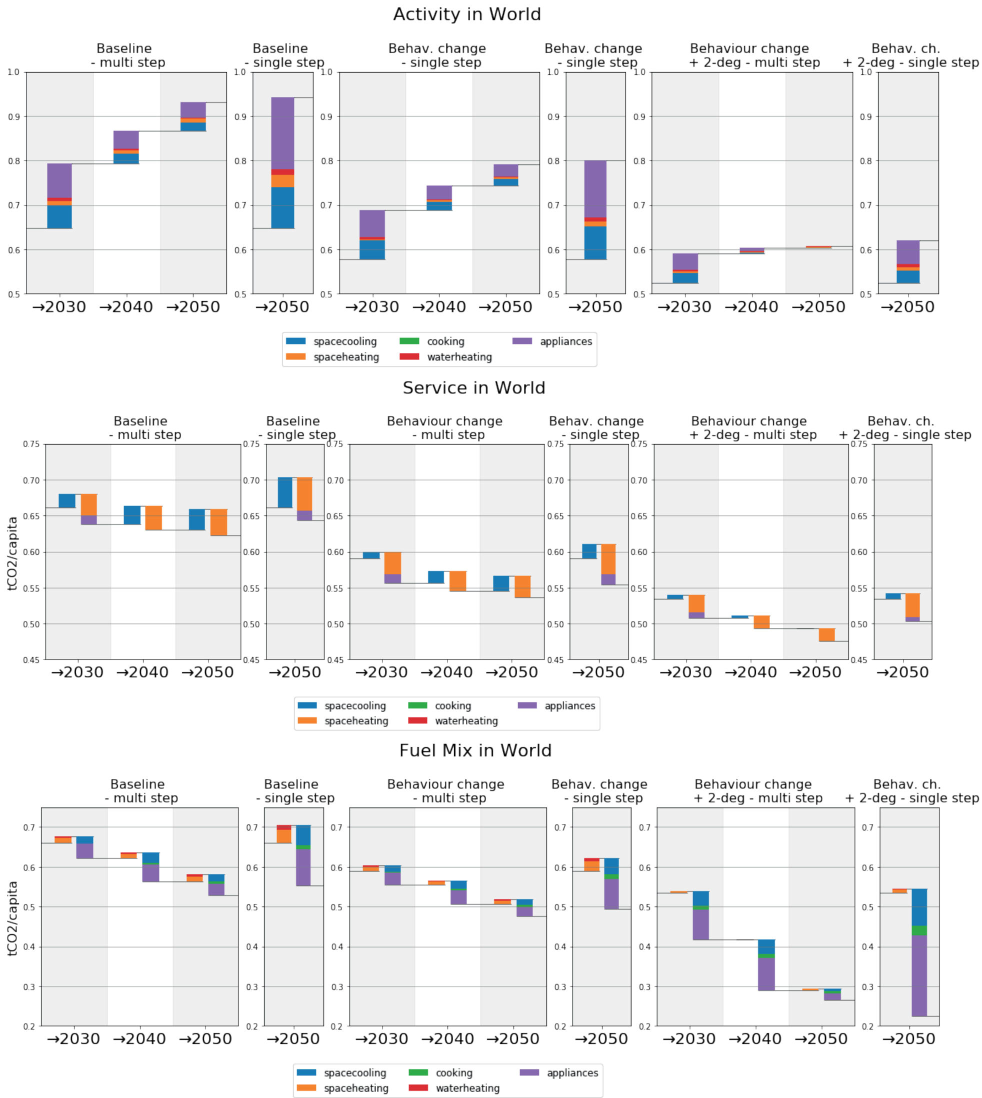

Activity in Developed Regions
Structure in Developed Regions
Intensity in Developed Regions
Fuel Mix in Developed Regions
Activity in Developing Regions
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030
→2040
→2050
Bus
Train
Car
HS train
Aeroplane

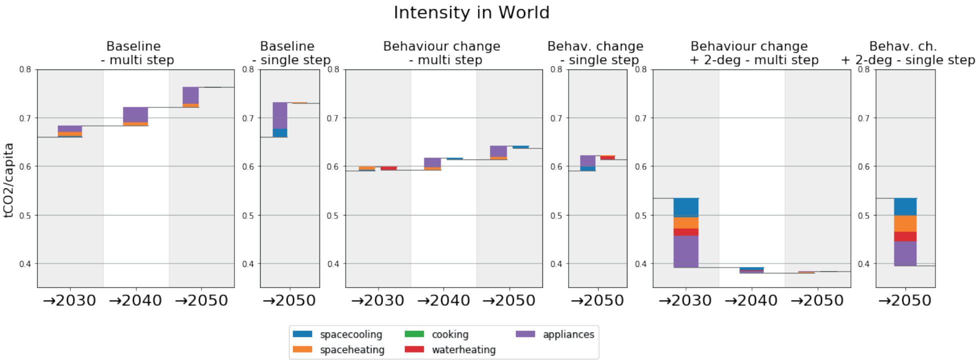

Structure in Developing Regions
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030 →2040 →2050
Bus
Train
Car
HS train
Aeroplane

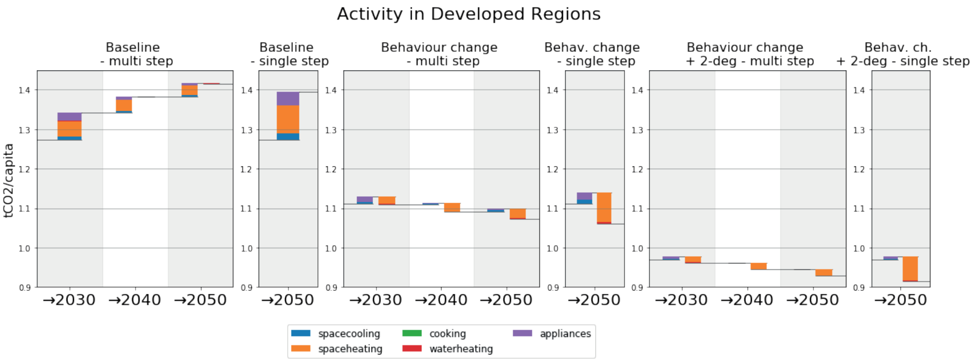

Intensity in Developing Regions
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030 →2040 →2050
Bus
Train
Car
HS train
Aeroplane

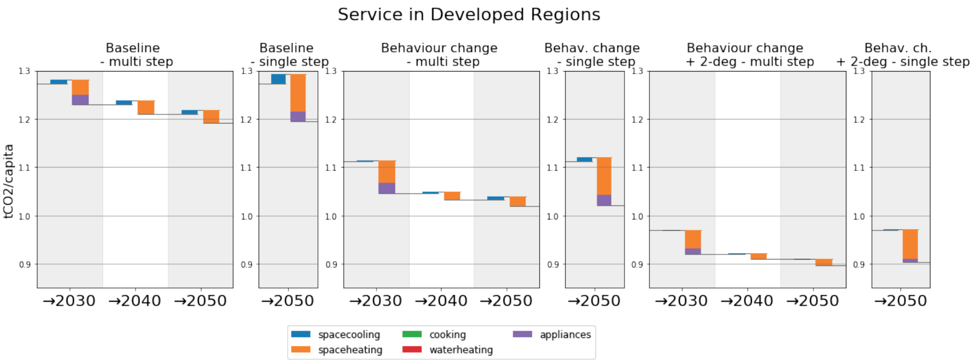

Fuel Mix in Developing Regions
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030 →2040 →2050
Bus
Train
Car
HS train
Aeroplane

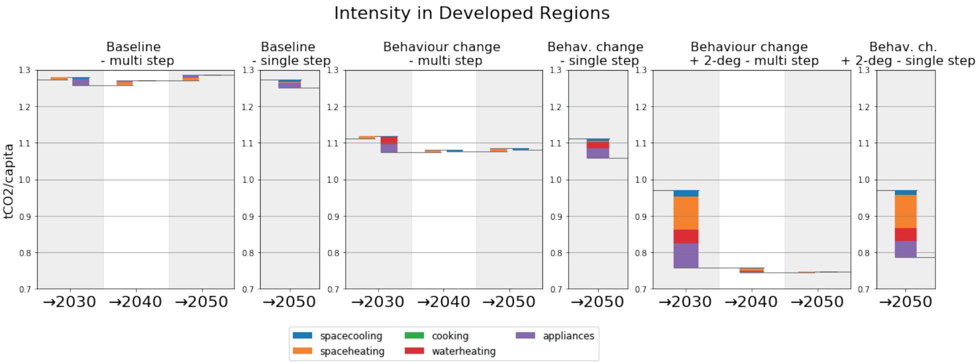
S3.4.6. Multi step verses single step results: decomposition of per capita residential global emissions from activity, structure, intensity and fuel mix. The subplots compare a baseline scenario including behavioural measures (Behaviour change baseline), a scenario that only includes climate policy (2-deg C) and a combination of both behavioural measures and climate policy (Behaviour change + 2-deg C) for both multi-step (2020-2030, 2030-2040, 2040-2050) and single-step (2020-2050) time periods.

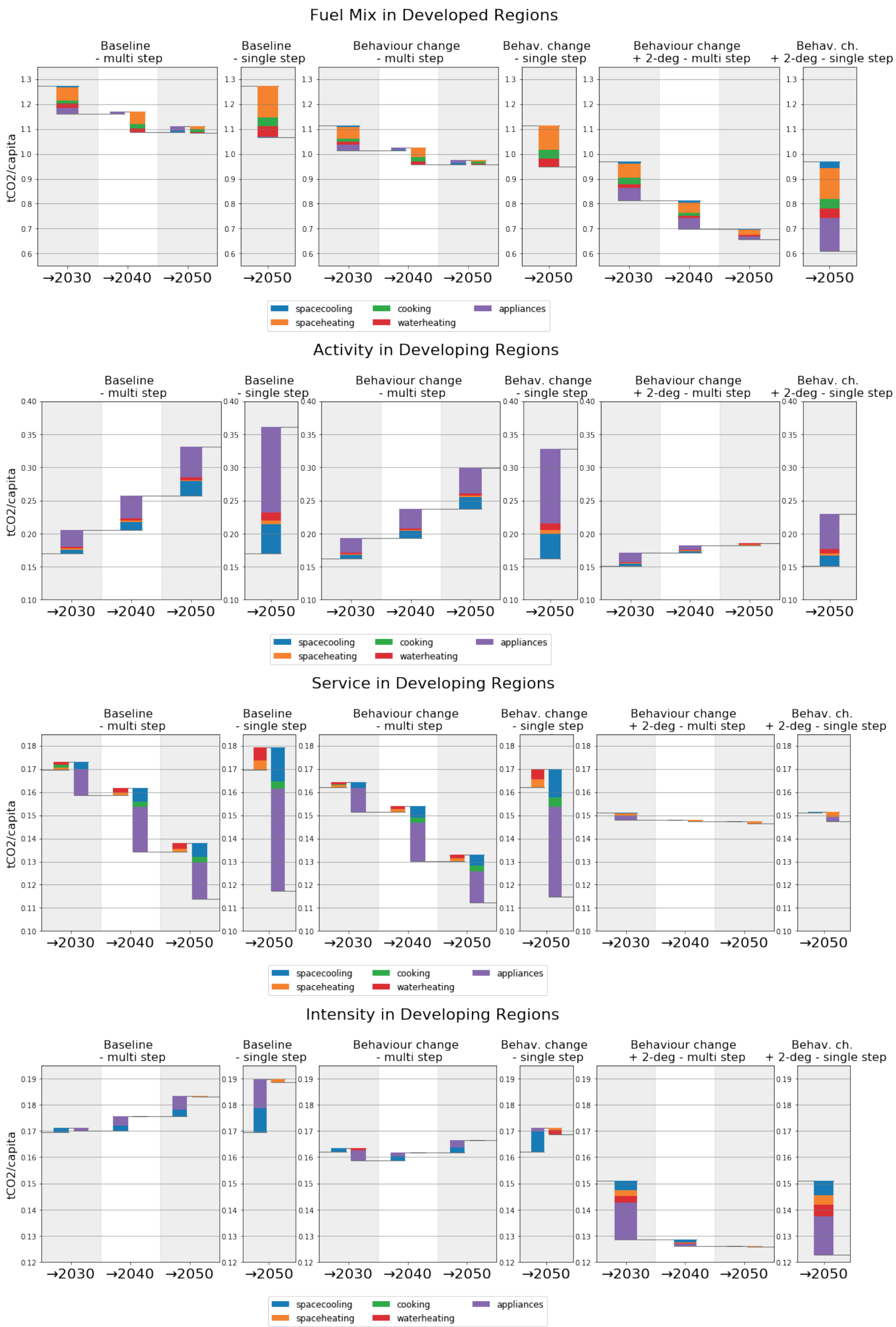



Intensity in World
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030 →2040 →2050
→2050
spacecooling
spaceheating
cooking
waterheating
appliances

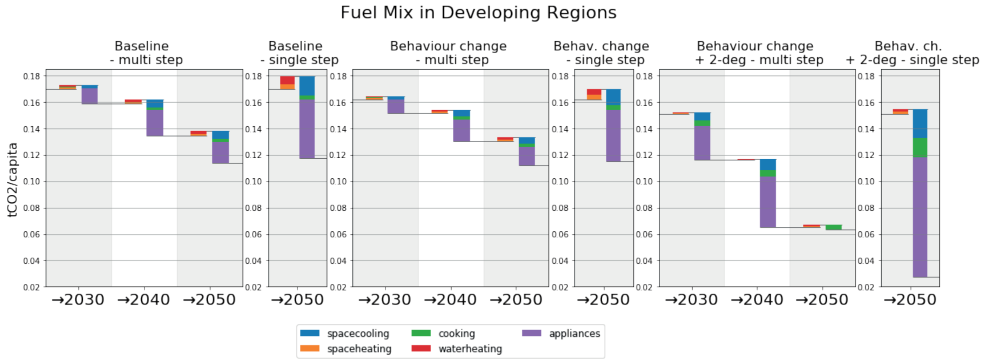

Activity in Developed Regions
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030 →2040 →2050
→2050
spacecooling
spaceheating
cooking
waterheating
appliances


Service in Developed Regions
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030 →2040 →2050
→2050
spacecooling
spaceheating
cooking
waterheating
appliances

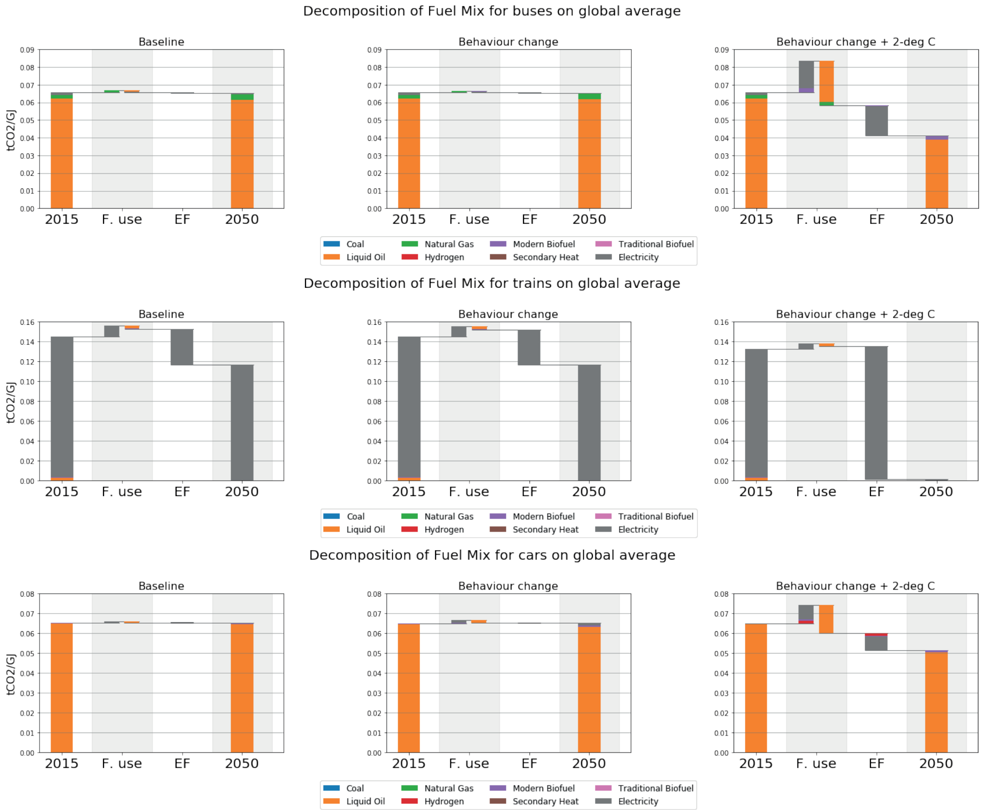

Intensity in Developed Regions
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030 →2040 →2050
→2050
spacecooling
spaceheating
cooking
waterheating
appliances



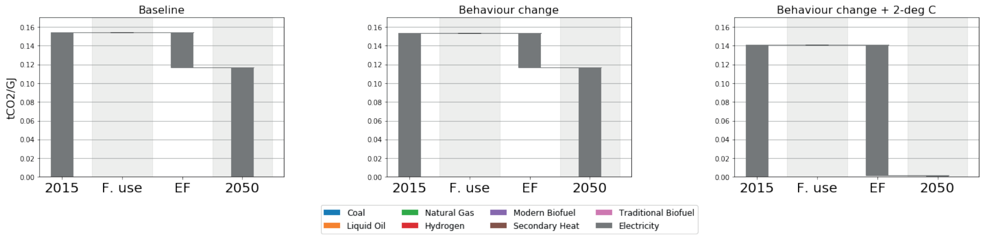
Fuel Mix in Developed Regions
Baseline - multi step
Baseline - single step
Behaviour change - multi step
Behav. change - single step
Behaviour change + 2-deg - multi step
Behav. ch. + 2-deg - single step
tCO2/capita
→2030 →2040 →2050
spacecooling
spaceheating
cooking
waterheating
appliances
Activity in Developing Regions
Service in Developing Regions
Intensity in Developing Regions



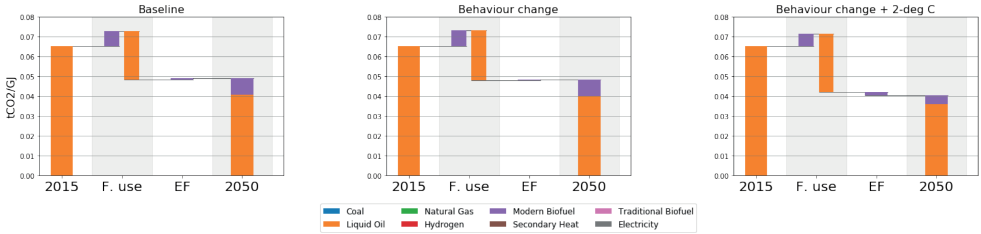
S3.4.7. Decomposition analysis of fuel mix changes (i.e. fuel use and emission factors) for transport modes in different regions from 2015 to 2050. The subplots show a baseline scenario including behavioural measures (Behaviour change baseline), a scenario that only includes climate policy (2-deg C) and a combination of both behavioural measures and climate policy (Behaviour change + 2-deg C). The legend shows the different fuel types. On the y-axis is the fuel mix changes (in tCO2/GJ).



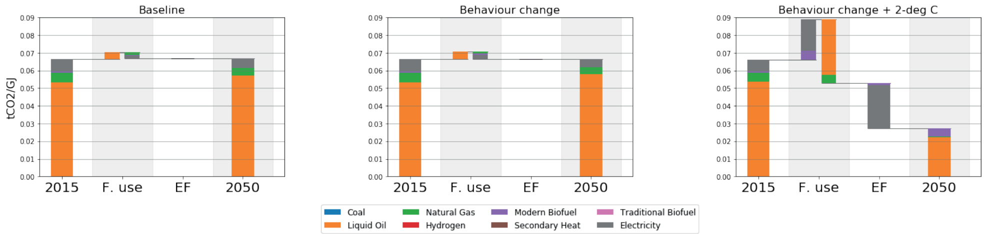
Decomposition of Fuel Mix for hispeed trains on global average



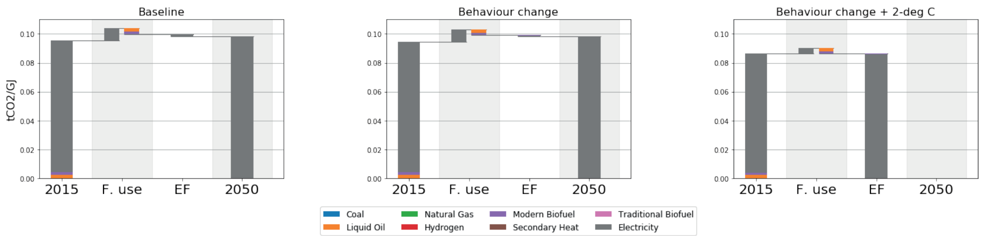
Decomposition of Fuel Mix for aeroplanes on global average



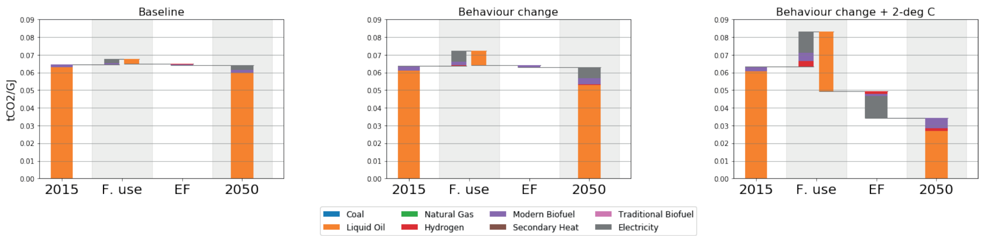
Decomposition of Fuel Mix for buses in Developed Regions



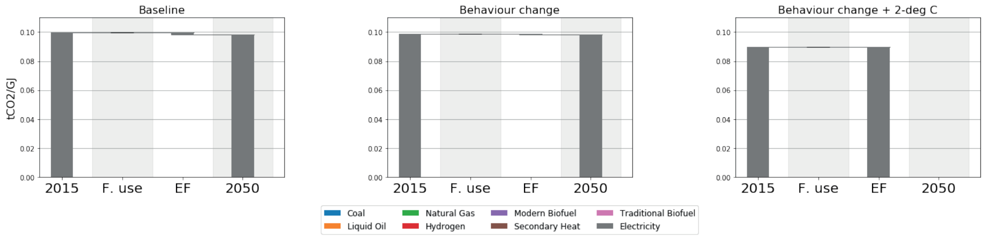
Decomposition of Fuel Mix for Trains in Developed Regions



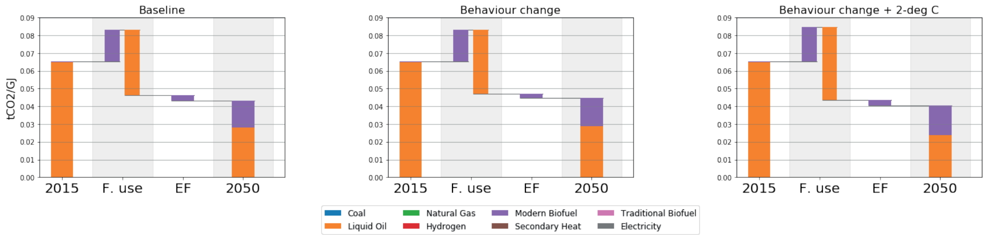
Decomposition of Fuel Mix for Cars in Developed Regions



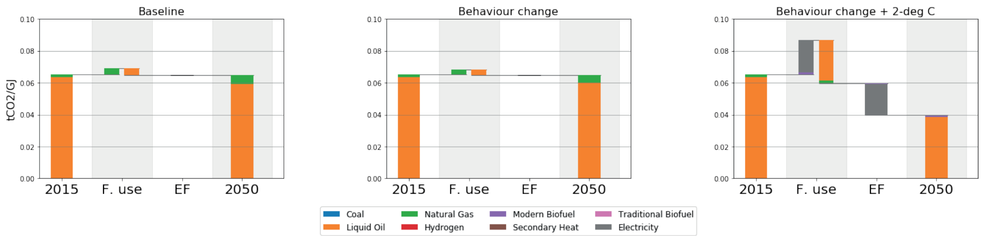
Decomposition of Fuel Mix for High-speed Trains in Developed Regions



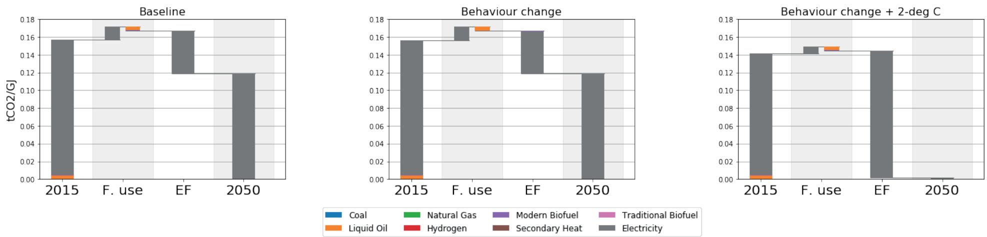
Decomposition of Fuel Mix for Aeroplanes in Developed Regions



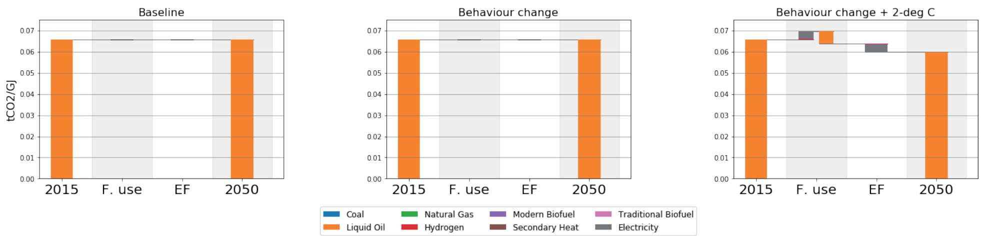
Decomposition of Fuel Mix for Buses in Developing Regions



Decomposition of Fuel Mix for Trains in Developing Regions

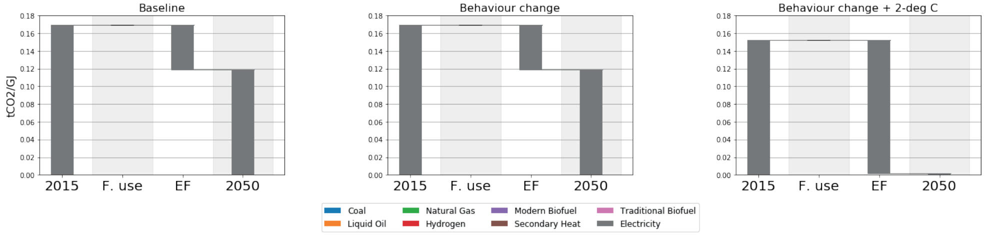


Decomposition of Fuel Mix for Cars in Developing Regions

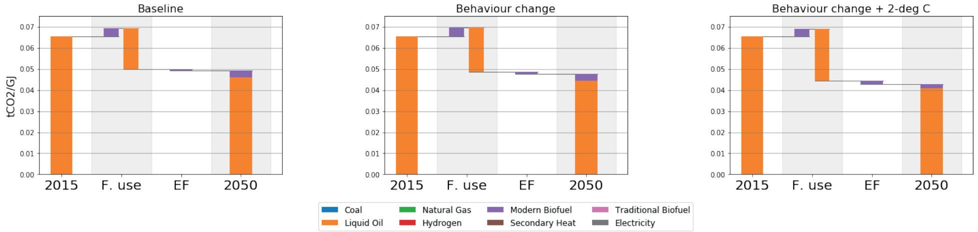


9

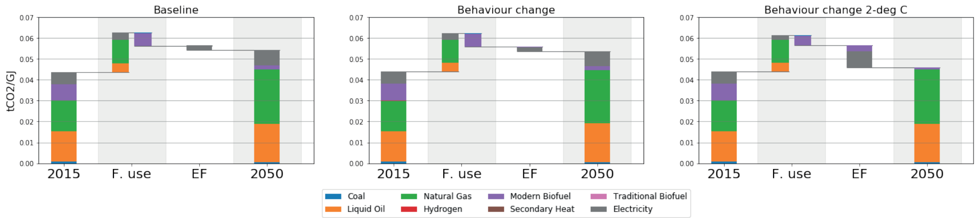
Decomposition of Fuel Mix for High-speed Trains in Developing Regions



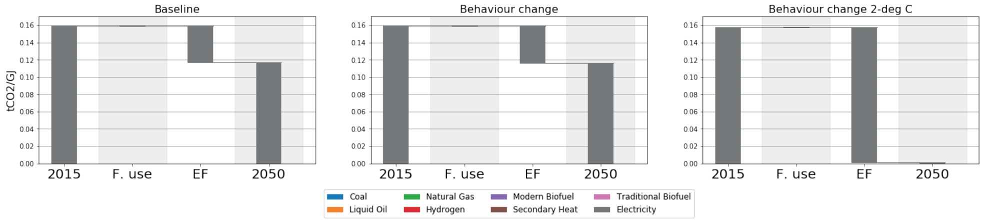
Decomposition of Fuel Mix for Aeroplanes in Developing Regions



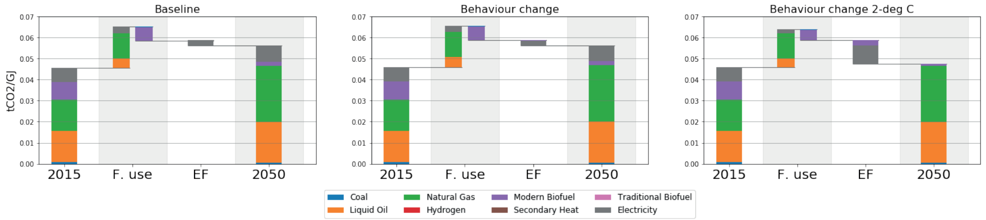
Decomposition of Fuel Mix for space heating on global average



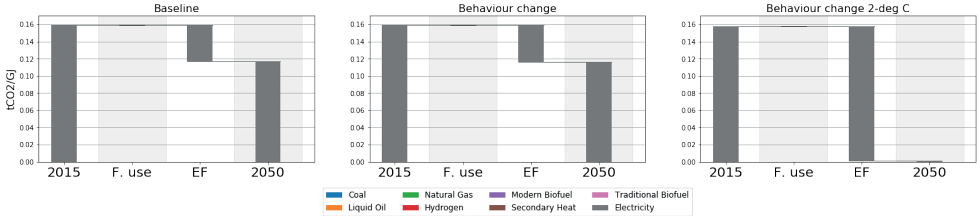
Decomposition of Fuel Mix for space cooling on global average



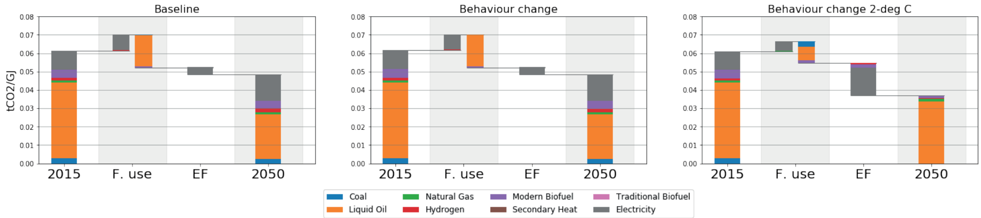
Decomposition of Fuel Mix for water heating on global average



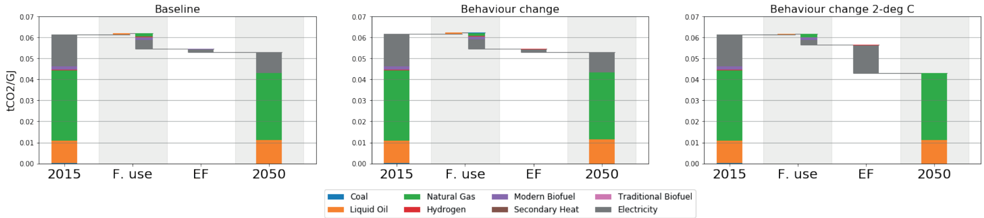
Decomposition of Fuel Mix for appliances on global average



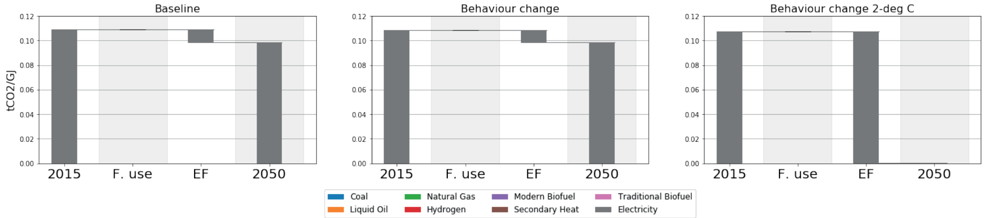
Decomposition of Fuel Mix for cooking on global average



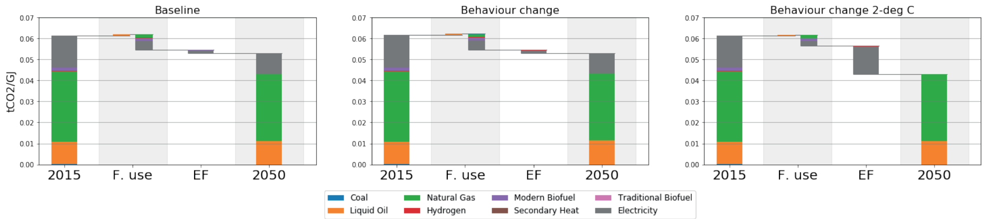
Decomposition of Fuel Mix for space heating in Developed Regions



Decomposition of Fuel Mix for spacecooling in Developed Regions

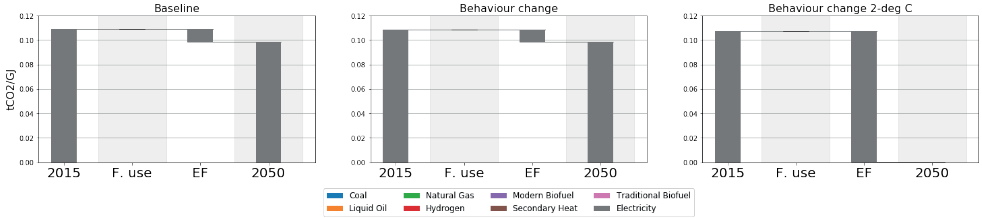


Decomposition of Fuel Mix for water heating in Developed Regions

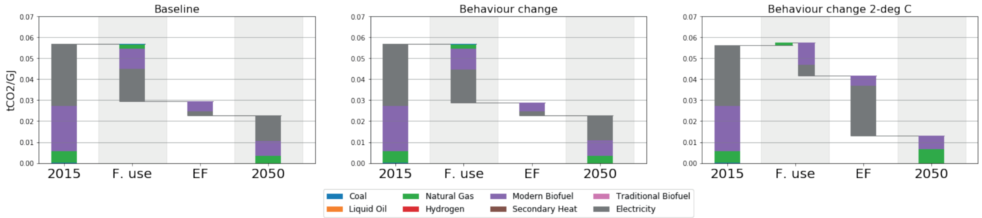


9

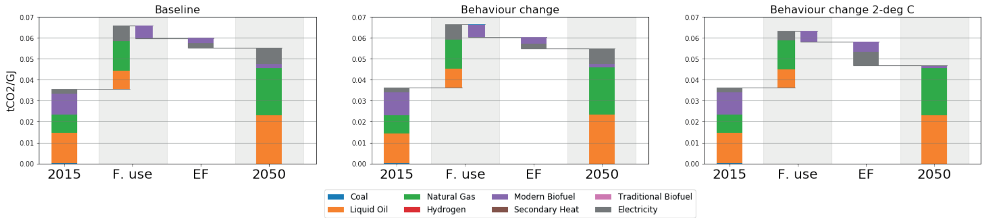
Decomposition of Fuel Mix for appliances in Developed Regions



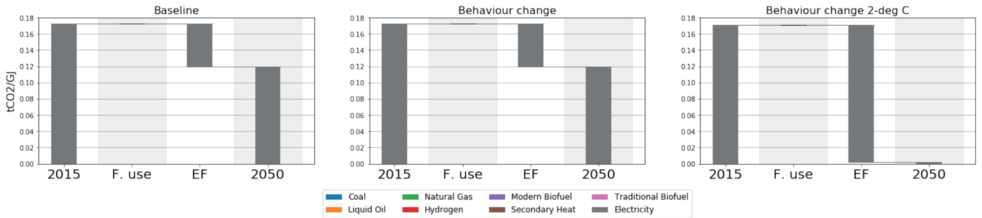
Decomposition of Fuel Mix for cooking in Developed Regions



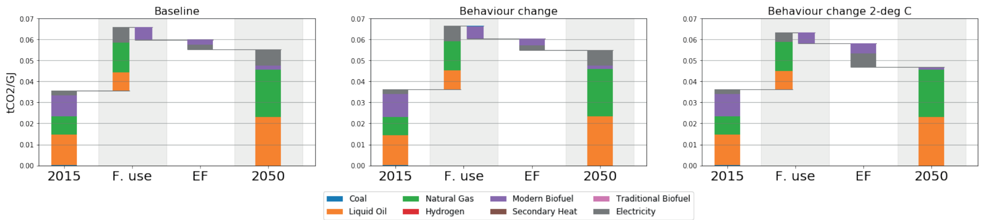
Decomposition of Fuel Mix for space heating in Developing Regions

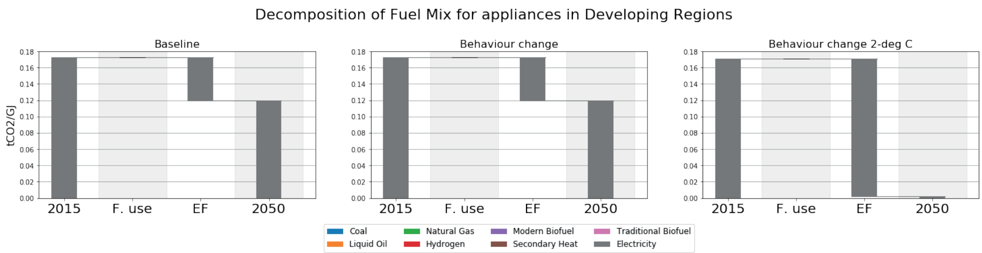


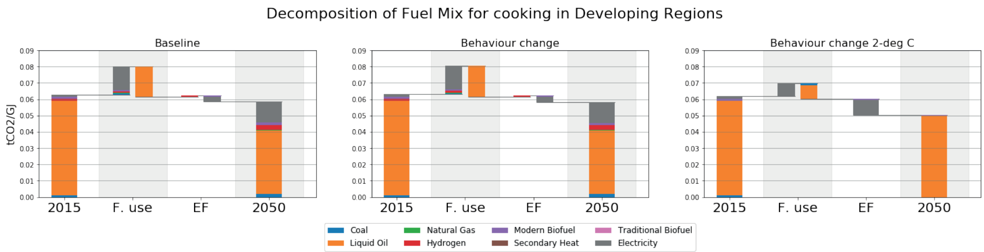
Decomposition of Fuel Mix for spacecooling in Developing Regions



Decomposition of Fuel Mix for water heating in Developing Regions







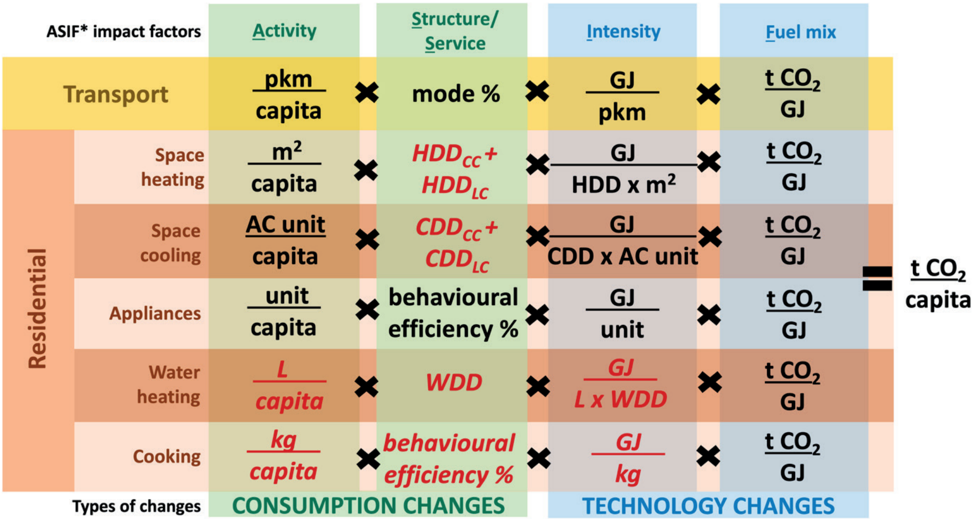
S3.5. Final energy demand per energy service and sector (Grubler et al., 2018)

Table 2 | Impact of the LED scenario on final energy demand in 2050

		Region	% change in activity levels (2020–2050)	% change in energy demand (2020–2050)	Activity levels in 2050	Energy demand in 2050 (EJ)	Total energy demand in 2050 (EJ) (GJ capita^{-1})
End-use services	Thermal comfort	North	6	−74	47×10^9 m^2	8	16 (1.8)
		South	63	−79	218×10^9 m^2	8	
	Consumer goods	North	79	−25	67×10^9 units	13	41 (4.5)
		South	175	54	186×10^9 units	28	
	Mobility	North	29	−60	25×10^{12} passenger km	16	27 (3.0)
		South	122	−59	73×10^{12} passenger km	12	
	Contingency reserve						8
Upstream	Public and commercial buildings	North	49	−64	35×10^9 m^2	5	8 (0.9)
		South	77	−82	68×10^9 m^2	3	
	Industry	North	−42	−57	1.0×10^9 t	26	107 (11.7)
		South	−12	−23	5.4×10^9 t	82	
	Freight transport	North	109	−28	31×10^{12} tkm	11	27 (3.0)
		South	75	−12	51×10^{12} tkm	17	
	International aviation and shipping (bunker fuels)						10
Total		North[a]		−53		82	245
		South[a]		−32		153	

All sub-totals and totals are rounded (lower integer at numerical values <0.5, to upper integer ≥ 0.5). [a]Contingency reserve of 8 EJ is allocated equally to the global North and global South. Bunker fuels are reported at the global level only, consistent with current energy balances and emission accounting frameworks.

S3.6.1. Suggested changes of ASIF* variables (WDD = Water Degree Days; HDD_{cc}= Heating Degree Days from Climate Change; HDD_{LS}= Heating Degree Days from Lifestyle changes; CDD_{cc}= Cooling Degree Days from Climate Change; CDD_{LS}= Cooling Degree Days from Lifestyle changes)



S3.6.2. Details of suggested changes (from current) of ASIF* variables for decomposition tool

<table>
<tr><th rowspan="2">Energy service</th><th colspan="2">Activity</th><th colspan="2">Shift</th><th colspan="2">Intensity</th><th colspan="2">Fuel mix</th></tr>
<tr><th>Current</th><th>Suggested</th><th>Current</th><th>Suggested</th><th>Current</th><th>Suggested</th><th>Current</th><th>Suggested</th></tr>
<tr><td>Transport</td><td colspan="2">pkms per capita</td><td colspan="2">mode %</td><td colspan="2">GJ per pkm</td><td colspan="2" rowspan="10">tCO_2 per GJ</td></tr>
<tr><td rowspan="2">Space heating</td><td colspan="2" rowspan="2">m² per capita</td><td rowspan="2">HDD</td><td>HDD_{cc}</td><td colspan="2" rowspan="2">GJ per HDD and m²</td></tr>
<tr><td>HDD_{LC}</td></tr>
<tr><td rowspan="2">Space cooling</td><td colspan="2">AC units per capita</td><td rowspan="2">CDD</td><td>CDD_{cc}</td><td colspan="2" rowspan="2">GJ per AC unit and CDD and m²</td></tr>
<tr><td></td><td>m_2 per capita</td><td>CDD_{LS}</td></tr>
<tr><td>Appliances</td><td colspan="2">Appliance units per capita</td><td colspan="2">behavioural efficiency %</td><td colspan="2">GJ per appliance unit</td></tr>
<tr><td>Water heating</td><td>GJ per capita</td><td>L per capita</td><td></td><td>WDD</td><td>Efficiency %</td><td>GJ per L and WDH</td></tr>
<tr><td>Cooking</td><td>GJ per capita</td><td>Kg per capita</td><td></td><td>behavioural efficiency %</td><td></td><td>GJ per kg</td></tr>
</table>

S4. CURRENT LIFESTYLES IN THE CONTEXT OF FUTURE CLIMATE TARGETS: AN ANALYSIS OF LONG-TERM SCENARIOS AND CONSUMER SEGMENTS FOR RESIDENTIAL AND TRANSPORT

S4.1. Details of ASIF* factors contributing to per capita emissions

ASIF* contributing factors	Details	
	Transport	Residential
Activity	Effects of Changes in transportation demand (i.e. passenger-kilometres (pkm) per capita)	Effects of changes in residential energy demand (e.g. floor space per capita).
Structure/service	Effects of Changes in modes of transportation (i.e. pkm per capita in a particular transport mode)	Effects of changes in *service* demand in residential energy services (e.g. Heating Degree Days, or HDD).
Intensity	Effects of Changes in energy *intensity* within transport modes and fuel type (i.e. energy usage per pkm of a particular transport mode and fuel type)	Effects of changes in energy *intensity* within residential energy services (e.g. energy usage per HDD of floor space).
Fuel mix	Effects of changes in transport fuel types	Effects of changes in residential fuel types

The contributing ASIF* factors to emissions among the sectors transport, residential cooking, residential space heating, space cooling, water heating and appliances are shown below. In this ASIF* framework, the CO_2 emissions per capita at time t are calculated using an extended version of the Kaya-identity, for each energy service es and region r:

9

$$E_{es,r}(t) = \text{CO}_2 \text{ emissions per capita}_{es,r}(t)$$
$$= \text{Activity}_{es,r}(t) \times \text{Structure/service}_{es,r}(t) \times \text{Intensity}_{es,r}(t) \times \text{Fuel mix}_{es,r}(t),$$

where the fuel mix is calculated by summing over each fuel type f:

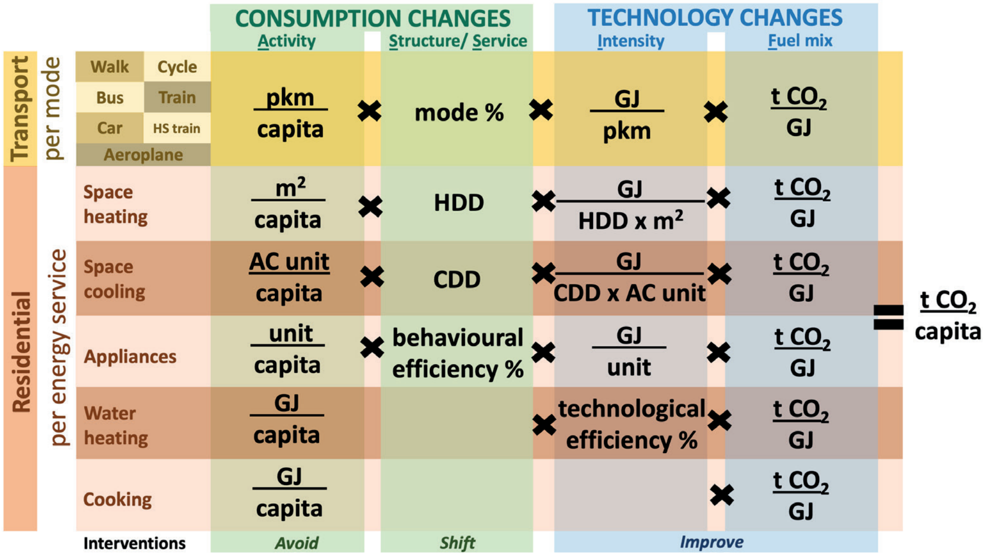
$$\text{Fuel mix}_{es,r}(t) = \sum_f \left(\text{emission factor}_{es,r,f}(t) \times \text{fuel use share}_{es,r,f}(t)\right).$$

The decomposition method used here splits the difference between the per capita CO_2 emissions in two years (in our case, 2050 and 2015) in differences attributable to each component:

$$E_{es,r}(2050) = E_{es,r}(2015) + \Delta E_{\text{activity},es,r} + \Delta E_{\text{structure/service},es,r} + \Delta E_{\text{intensity.},es,r} + \Delta E_{\text{fuel mix},es,r}.$$

The exact formulations of each factor of the decomposition are described in S4.2.

S4.2. Breakdown of variables and units for decomposition analysis in transport modes and residential energy services in terms of the Activity, Structure/Service, Intensity and Fuel Mix (ASIF*) impact factors



S4.3. IMAGE regions

Regions	Countries
USA	St. Pierre and Miquelon (666), United States (840)
Brazil	Brazil (76)
South Africa	South Africa (710)
Western Europe	Andorra (20), Austria (40), Belgium (56), Denmark (208), Faeroe Islands (234), Finland (246), France (250), Germany (276), Gibraltar (292), Greece (300), Iceland (352), Ireland (372), Italy (380), Liechtenstein (438), Luxembourg (442), Malta (470), Monaco (492), Netherlands (528), Norway (578), Portugal (620), San Marino (674), Spain (724), Sweden (752), Switzerland (756), United Kingdom (826), Vatican City State (336)
Russia region	Armenia (51), Azerbaijan (31), Georgia (268), Russian Federation (643)
India	India (356)
China region	China (156), Hong Kong, China (344), Macao, China (446), Mongolia (496), Taiwan (158)
Indonesia region	East Timor (626), Indonesia (360), Papua New Guinea (598)
Japan	Japan (392)

S4.4. Emission factors used in the IMAGE scenarios

Emission factors (tCO_2/GJ)												
Fuel type	Scenarios	Years	USA	Brazil	S. Africa	W. Europe	Russia	India	China	Indonesia	Japan
Coal	all	all	0.09								
Oil Light Liquid Fuels	all	all	0.07								
Natural Gas	all	all	0.06								
Traditional biomass	all	all	0.04								
Modern biomass	SSSP2 baseline	2015	0.04	0.05	0.00	0.04	0.03	0.01	0.01	0.03	0.03
		2050	0.03	0.05	0.01	0.02	0.10	0.00	0.05	0.02	0.01
	SSP2 2-degree C	2015	0.04	0.05	0.00	0.04	0.03	0.01	0.01	0.03	0.03
		2050	0.04	-0.01	0.01	0.02	0.00	0.01	0.02	0.03	0.02
	Behaviour change 2-degree C	2015	0.04	0.05	0.00	0.04	0.03	0.01	0.01	0.03	0.03
		2050	0.04	-0.01	0.00	0.02	0.00	0.01	0.02	0.03	0.01
Electricity	SSSP2 baseline	2015	0.14	0.04	0.26	0.07	0.09	0.25	0.20	0.22	0.14
		2050	0.12	0.04	0.17	0.07	0.09	0.17	0.16	0.13	0.12
	SSP2 2-degree C	2015	0.14	0.04	0.26	0.07	0.09	0.25	0.20	0.22	0.14
		2050	0.12	0.04	0.17	0.07	0.09	0.17	0.16	0.13	0.12
	Behaviour change 2-degree C	2015	0.14	0.04	0.26	0.07	0.09	0.25	0.20	0.22	0.13
		2050	-0.04	0.01	-0.04	-0.02	-0.02	-0.03	-0.01	-0.02	-0.01
Hydrogen	SSSP2 baseline	2015	0.08	0.00	0.15	0.11	0.03	0.11	0.10	0.08	0.12
		2050	0.05	0.05	0.08	0.05	0.05	0.10	0.06	0.10	0.05
	SSP2 2-degree C	2015	0.08	0.00	0.15	0.09	0.03	0.00	0.10	0.08	0.12
		2050	0.03	-0.02	0.00	0.02	0.05	-0.03	-0.03	-0.01	0.03
	Behaviour change 2-degree C	2015	0.08	0.09	0.15	0.09	0.03	0.00	0.10	0.08	0.12
		2050	0.03	-0.03	0.00	0.01	0.04	-0.04	-0.04	-0.02	0.02

S4.5. Consumer segments and underlying data (Koide et al., 2019)

Segment No.	Segment Name	WeightedSize (IndividualWeight)	(Share in %)	Housing GHG Footprints (kgCO2e/cap/year)	Mobility GHG Footprints (kgCO2e/cap/year)
1	1: Small Families with Very Frequent Driving and Materialistic Hobbies	115164,6	0,4%	4626,780132	10049,30917
2	2: Small Families Enjoying Material Consumption and Long-Distance Leisure	143338,3	0,5%	4390,520796	1780,316769
3	3. Rural Small Families Living in Large Houses with High Fuel Consumption	171788,5	0,6%	7876,010765	1346,721676
4	4: Meat and Fish Lovers Enjoying Leisure Living in Large Houses with High Electricity Consumption	422767,2	1,4%	5248,166548	1597,247375
5	5: Middle-Sized Families with Frequent Driving and Materialistic Hobbies	865419,6	2,8%	4032,243326	4017,856354
6	6: Single Residents in Metropolitan Apartments Enjoying Long-Distance Leisure and Outings	562243,1	1,8%	3066,007377	3115,070649
7	7: All-Round Consumers Living in Metropolitan Small Housing	1260220	4,1%	3601,327204	1415,780846
8	8: Single Residents in Apartments Enjoying Beverages and Snacks at Home	757151,9	2,5%	3657,607162	1772,733975
9	9: Rural Residents with High Fuel Consumption	1486816	4,9%	3875,945153	1209,836903
10	10: Residents Living in Inefficient Housing with High Electricity and Water Consumption	1364131	4,5%	4442,177227	830,7786566
11	11: Meat-Loving Large Families with Moderate Material Consumption	2190866	7,1%	3262,094289	1148,34218
12	12: Large Families Living in Efficient Houses Enjoying Leisure with Driving	2948680	9,6%	2915,895853	1979,549553
13	13: All-Round Consumers Living in Small-Sized Housing	2999771	9,8%	2567,164639	1192,306264
14	14: Large Families with Limited Material Consumption	6711649	21,9%	2249,072832	847,041331
15	15: Large Families with Efficient Housing and Limited Material Consumption	8648497	28,2%	1894,043742	835,4188693

S5. A DIVERSITY OF SUSTAINABLE LIFESTYLES IN 2050: FUTURE SCENARIO NARRATIVES FOR CLIMATE CHANGE MITIGATION

S5.1. Detailed narratives for the SLIM scenarios

In this section, we take a deeper dive by exploring the specifics of each scenario, cross cutting the dominant domains of food, mobility, goods, housing, and leisure; how they might develop and why.

Designed World

As natural resources reach their tipping points, governments respond to growing environmental and social values held by the public, moving towards enabling sustainable consumer and lifestyles options and adapting to leaner and cleaner production methods in the *Designed World* (see Figure 3). Money is shifted towards low-carbon solutions, and innovations have financial incentives to focus on ease and efficiency within climate-conscious restrictions. Governments move away from fossil fuel funding and towards circular technologies and systems. Sustainability is made simple dfor citizens through governmental sufficiency implementations. For example, the United Nations Environment Programme (UNEP) elects a Chief Planetary Health Officer, and global pacts are reassessed and amended. These changes spur innovations and allow further capital to go towards environmental conservation and policies. People are motivated by the ease, convenience, and cost-effectiveness of high structural support, and many are amenable to the public sector and private sector setting top-down directives through large scale policy interventions.

The movement toward phasing out fossil fuel production and natural resource extraction leads to sufficiency policies in business, and resource efficiency, sustainable limits, and reduced consumption becomes part of corporate social responsibility and environmental, social and corporate governance (ESG). Efforts to increase efficiency of goods and services – doing more with less – are complemented with a focus on sufficiency – ‘enoughness’ and adequate levels to achieve quality of life. Products, services, and systems are optimized in response to sufficiency policies leading to low personal vehicle ownership rates, high adoption rates of electric power for remaining vehicles, progression in peer-to-peer zero-emission taxis and shuttles, urban agriculture lab-grown meat, and net-zero building codes. The efficiency of automation is adopted rapidly. Value shifts are incremental at first but progress as policies change cultural context. Prices regulate with resource privatization and global carbon taxes, and it becomes desirable to live in smaller dwellings with larger shared amenity access. As cooperation between governments and corporations becomes stronger, a consolidation of sustainable lifestyle options and consumer choices emerges.

Some challenges in this world include a high risk of oligarchy and authoritarianism, resource distribution issues, homogenous consumer choice, and cultural erasure. As the individual agency is lower in exchange for convenient sustainability, democratic rights may become easily infringed on as elite classes invest in governments. Enforcement of policies may lead to the ubiquity of surveillance capitalism and increased privately funded policing. As resources become privatized, problems arise around resource-extraction regions. Less emphasis on context-specific or tailored goods and services leads to homogeneity in consumer options and leaves divergent individuals without choice. Historically cultural stewardship of land and resources is not represented and considered in opposition to new values of the controlled distribution. This leads to massive backlash as community stakeholders are neglected and deep cultural change is not nurtured.

Global Commons

Universal values shape a global governance structure in *Global Commons*, where governments have given up part of their sovereignty and Global South leadership becomes prominent. There is a focus on enabling slower and more flexible lifestyles while promoting the widespread distribution of shared facilities and services. A massive shift in global governance leads to nation-states moving to interdependence and relinquishing independent sovereignty. Global commons and resources become part of the global governance system; global impacts of climate change and resource limits are recognized. Resources are governed and allocated outside of the competitive marketplace. Resource competition is restricted to areas that are not impactful to planetary systems or detrimental to global commons but within economic spaces that give additional value to the states. Motivations in this world are closely tied to global social cohesion, planetary fate, human-centred wellbeing, and environmentally conscious convenience.

The shift towards global interdependence leads to a networked and connected governance system. The rule of law becomes key in intergovernmental compliance. Large scale public sectors invest heavily in infrastructure, shared provisioning systems and strong universal basic services such as education, transportation, and health (see fig. 3). Internet coverage becomes universal but quickly falls into regulation due to increased security threats. Money creation comes under public control and maximum wage policies are implemented. Wealth hoarding decreases. Affordable housing is classified as a public utility in places such as Vienna and Amsterdam. Commons and solidarity are society's organizational references, led by state intervention. As the level of technology and infrastructure required for global energy systems increase, energy remains privatized, and corporations remain influential while operating under government regulations. Global South leadership strengthens, and new global institutions emerge. These institutions give way for new global leadership roles, and potential institutions such as the Ministry for Climate Change, Ombudsman for Future Societies, and the International Resource Governance emerge. There is an increase of women and gender non-conforming persons in leadership positions. Resource allocation is contingent on planetary boundaries, and massive rewilding projects are initiated in multiple resource-depleted sites, such as the Amazon rainforest and the Cerro Matoso mine site. Inter-regional trade has become dominant rather than global trade. Democratic processes are securely streamlined and reinvigorated by increased consultation and engagement with communities. Mindsets and institutions lean towards decolonization in practice by combining a renewed global democracy, global governance, and care for communal wellbeing.

Wellbeing risks involved in this scenario are global governments becoming too powerful, some people being left behind the sharp curve of change, mass migration issues, cyber-terrorism and other attempts of governmental subversion, divisive identity politics, and potentially unfair labour distribution. The amalgamation of nation-states and governments may lead to decreased individual representation. The turn towards *Global Commons* requires social revolution on a large scale, and it may be a difficult and debilitating transition for many groups of people. As climate emergencies raze liveable land, mass migration leads to conflicts of land ownership, cultural assimilation, and racism. Diverse cultural groups may be forced by environmental change or by the government to cohabitate in the name of decolonization, which may lead to cultural clashes and identity polarisation. As wages are regulated and capped globally and progressive taxes climb, labour workloads are difficult to assess fairly, and many people are paid inequitably. Ultra-wealthy individual investors no longer exist, as such, all major government projects and technological advancements are funded through taxes.

Big Village

Big Village has people band together in community and nurture skills in self-sufficiency, care, collaboration and bridging divides. Community is central to this scenario, with simpler living and social cohesion being key motivators in daily life. Urban and rural planning shift towards community-accommodating neighbourhoods, and eco-villages and community living are commonplace. Social norms shift as nation states lose legitimacy and power decentralizes to local governments. There is a revival of the importance of civic duties, and participatory self-governance such as citizen assemblies and local councils gain decision-making power. This leads to practical and radical alternative practices at all levels of society, economy, politics, and law. Housing shortages lead to inclusive regulations allowing unconventional households and shared communal amenities. Shorter workweeks lead to better work/life balance, and rural-urban migration slows as environmentally- and socially sustainable communities rise in popularity.

Strong communities lead to collective action with high impact. The importance of shared experiences is recognized above wealth gain, which leads to lower GDP growth and discretionary income.

Neighbourhood planning allows for families to live closer to one another and in multigenerational households; this affords more time together through part-time work and basic income support. Economies are localized with hyper-local energy and food production, shared use of appliances, communal spaces, equipment, and services (see fig. 3). There is a spiritual revival and value shift towards reverence for nature, other species, seasons, regionalism, local culture, and diversity. Indigenous ways of knowing are valued and respected. People have stronger skills for self-provisioning and DIY, trades, and crafts. Many people participate in mutual learning opportunities in their communities, schools, and organizations. There is an increased provisioning of sharing systems and local production. Part-time shared work frees up time for volunteer work, community service, skill-sharing and timebanks. People focus on maintaining social relationships rather than monetary accomplishments.

Potential challenges of the *Big Village* scenario include isolation from other communities resulting in a lack of collaboration and conflicting actions, unequal access to resources and structural support, vulnerabilities around libertarian mindsets and guerilla mercenary groups, considerable social sacrifices, and difficulties with the integration of mass migration. As communities segregate and become self-sufficient, isolation may result in a lack of resources and distrust of neighbouring communities. Actions may be taken in multiple communities that conflict with one another and cause redundancies, unnecessary structural complexities, or environmental backpedalling. Municipalities may refuse to share resources and goods with other communities, ensuring unequal access and potential waste of resources. As nation-states lose legitimacy, security concerns arise, and guerrilla mercenary groups deal in protection and retribution. Local governments are not equipped to prosecute systemic corruption. Defence is provided by the local militia. Radical shifts are required to move towards this scenario, and many people must sacrifice, at times unwillingly, to communal living. Migration becomes difficult to govern as local governments have varied policies on immigration. There is no global directory for climate refugees, and affected persons must directly negotiate their own means of immigration with local governments.

Pocket Lifestyles

People adopt ambitious sustainable lifestyle behaviours and practices and rapidly spread them through peer-to-peer interaction and digital technology in *Pocket Lifestyles*. Influencers and innovators strengthen social media exchange and contribute to the design and adoption of sustainable goods and services. In the absence of governmental leadership regarding climate change, people and households' rebel against materialistic lifestyles. Global digitalization allows for the distribution of peer-to-peer apps, where contributors are motivated by social interaction, long-distance learning, trends, and technological aptitude. People take it upon themselves to engage in sustainable lifestyle practices. Practices are normalized through digital social interaction and contribute to massive uptake, inspiring changes in institutions and infrastructure.

Millennials and Gen Z become the dominant political force by 2040. This shifts dominant values towards sustainable and socio-political trends. Peer-to-peer exchange and communication boost the spread of sustainable traditional, informal, and indigenous modes of living. Sustainable lifestyles become aligned with social status, being eco-conscious is encouraged and trendy. Influencers and corporate brands play a pivotal role in spreading sustainable lifestyle practices. Firms submit to huge demands to offer ethically produced and sustainable goods and services. Governments are not driving change, although politics becomes heavily influenced by sustainable practices. Governments continue collecting and redistributing taxes for services. Do-It-Yourself (DIY) production and repairs become normalized. This is ubiquitous from smaller products such as clothing and dishware to larger infrastructure such as self-built housing. Builders pride themselves on technology-enabled self-sufficient builds, incorporating onsite production of energy, food, and water. Smart technologies are used to facilitate efficient mobility and transportation (see Figure 3). Plant-based diets are increasingly adopted and recognized as being both healthy and environmentally friendly. Social and mental health improves as people feel self-efficacy and purpose, shift offline and focus on producing for themselves and their friends. There is increased desire for meaningful social exchanges through social eating, living, and carpooling. Time is a symbol of affluence as self-sufficiencies lead to more leisure time.

Risks in this scenario include the spread of superficial and greenwashed goods and services, access to sustainable lifestyles may not be equitable, the carbon footprint of continued and expanded social media and cell phone use grows, political cleavages and group divisions widen, lack of coordination at the government level can breed growing disillusionment, larger structural transformations are difficult, deep changes in social aspects may not emerge, and overall carbon footprints may be subject to rebound effects in which emission gains in one aspect of life (e.g., income saved from reduced food waste or energy savings) transfers to another high impact behaviour (e.g., savings used to purchase a vacation flight). It becomes difficult to discern between fake consumer products over social media and monetary and greenwash scams becoming common. The increased use of social media and digital platforms leads to further energy use from server farms, and shadow carbon footprints grow. As technology continues under capitalism consumerism, paywalls and products increase in price and become less accessible to lower-income populations. Polarisation increases through sensationalized media sharing and unsupported government regulations. Trends shared on social media often contradict or oppose government policies. As governments operate outside of trends, it is difficult for systemic changes in time use, work-life balance, and public infrastructure. These changes fall into a crisis in incrementality where large value shifts are not encouraged in public government.

S5.2. Cross-cutting actions in the SLIM scenarios affected by motivations and enabling factors

Scenarios	Cross-cutting actions	People Motivations	Enabling factors
Designed World	Money is shifted to invest in low-carbon solutions	Cost savings; status; convenience	financial incentives and expenditures; infrastructure; availability & options
	Innovating to support fast and efficient lifestyles	Convenience	Infrastructure
Global Commons	Focus on enabling slower & more flexible lifestyles	Environmentally-conscious; convenience;	Social norm changes
	Widespread shared facilities and services	Social cohesion	Subsidies for poorer households; collective infrastructure in neighbourhoods
Big Village	Shorter workweek and more work-life balance	Simpler living	Social norm changes
	Community living (e.g. multi-generational homes)	Social cohesion; community is central	Redesigned neighbourhoods to accommodate community
Pocket Lifestyles	Digitalisation	Social interaction; long-distance learning; trendy; tech-savvy	Peer-to-peer apps
	Strong social media presence and exchange	Social interaction; long-distance learning; trendy; tech-savvy	Influencers / innovators; design of sustainable goods and services

S5.3. Transport, residential and food actions, the adoption rates and speed of transition affected by motivations and enabling factors in the SLIM scenarios

Scenarios	Transport Actions	People Motivations	Enabling factors	Adoption rates Global North	Adoption rates Global South	Speed of transition
Designed World	Electric vehicles	EVs are cheaper in use; status	financial incentives; EV charging infrastructure (e.g. charging lanes)	High	Med	Moderately slow
	Peer-to-peer taxi services	Convenience of being driven	availability and options (e.g. Uber, Lift)	Low	Med	Fast
Global Commons	Bus & rail transport	Environmentally-conscious; choice for one long-term holiday per year over multiple holidays per year	Subsidies for public transport; frequent flyer levy; higher road taxes	High	Med	Moderately fast
	Fewer long-distance trips (e.g. international travel)		Frequent flyer levy; social norms change to slower travel	Med	Med	Fast
	Commercial car-sharing		Social norm changes away from ownership; more firms enter the market to provide sharing options (e.g. Sixt Share)	Med	Med	Moderately fast
Big Village	Staycations	simpler living; slower living; social cohesion; more time for community; environmentally-friendly	Social norms towards simpler holidays; focus on family/friends rather than destination; strong community and local governance	Med	Med	Fast
	Live closer to work, friends and family		Strong community & local governance; social & cultural norms change; local road infrastructure designed for walking and cycling;	Med	Med	Moderately fast
	Shorter workweek		Social norms change towards less focus on work and replace with time in community	Med	Low	Fast
	Carpooling		Carpooling platforms become more prominent (e.g. Bla Bla Car); carpool-lanes	Med	High	Fast
Pocket Lifestyles	Telecommuting	trendy; tech-savvy; cost-effective; social	Strong tech innovation for improved telecommuting	Med	Low	Fast
	Peer-to-peer car sharing		Platforms for shared car ownership or renting out own car (e.g. Snapp-car)	Med	Low	Moderately fast
	Active transport		Influencers; social media; marketing to encourage active transport & sustainable vehicles	Low	Low	Fast
	Efficient vehicles			Med	Med	Fast

9

Scenarios	RESIDENTIAL Actions	People Motivations	Enabling factors	Adoption rates		Speed of transition
				Global North	Global South	
Designed World	Insulation	Cost-savings; comfort; improved indoor air quality	Prepaid subsidies; extra incentives for housing associations & landlords (large-scale), stricter regulation for new buildings	Med	Low	Fast
	Heat pumps		Financial incentives for choosing green energy providers	Med	Low	Moderately fast
	Smart meters		Prepaid subsidies; extra incentives for housing associations & landlords (large-scale); stricter regulation for new buildings	High	Med	Fast
	Rooftop solar	Cost-savings on energy bills	Subsidies; stricter regulation for new buildings	Med	Med	Moderately fast
	Green energy providers	Convenience & ease to switch	Energy companies to provide smart meters and inform consumers about optimising energy use	High	Low	Fast
	Quookers / shower heat recovery	Comfort; cost-savings	Subsidies for heat recovery; stricter regulation for new buildings	High	Med	Moderately fast
	Leasing efficient appliances	Convenience; initially cheaper	More leasing firms with affordable options	Med	Med	Fast
Global Commons	Collective heat pumps	environmentally-conscious; convenience; social cohesion;	Large-scale infrastructure of ground heat pumps for neighbourhoods; subsidies & cheaper credit for poorer households	High	Med	Moderately fast
	Smaller living space, larger public space		Designed apartment buildings and neighbourhoods with small living space and large public space	High	High	Slow
	Collective appliance ownership		Infrastructural changes for design of collective areas for shared ownership & space	High	High	Fast
	Collective green roofs / gardens			Med	Med	Moderately fast

Scenarios	Residential Actions	People Motivations	Enabling factors	Adoption rates: Global North	Adoption rates: Global South	Speed of transition
Big Village	Communal living areas & multi-generation homes	Community is central; environmentally-conscious; back-to-basics	Social norms towards simpler living; strong community and local governance	High	High	Moderately fast
	Repair, renovate & flexible/ modular homes		Product designers / architects design with repair and renovation in mind	Med	High	Moderately fast
	Fewer showers		Social norms towards simpler living	Med	High	Fast
	Natural ventilation			High	Med	Fast
Pocket Lifestyles	Minimalist apartments & tiny houses	Trendy, social, tech-savvy, cost-effective	Regulation adjusted to accommodate for smaller living; social norm changes	High	High	Slow
	Adjust thermostat		Social norm changes; influencers	High	High	Fast
	Lower-heat showers			High	High	Fast
	Rent out room/house/couch		house/room sharing platforms become more prominent with proper regulation (e.g. couch surfing, Airbnb); influencers	Low	Med	Moderately fast
	Hang dry on clothing lines		Social norm changes; influencers	Med	High	Fast
	Meal prepping (i.e. reduced cooking energy demand)		Marketing; social media; influencers	High	High	Fast

Scenarios	Food Actions	People Motivations	Enabling factors	Adoption rates		Speed of transition
				Global North	Global South	
Designed World	Lab-grown meat	Still able to eat meat	Invest in R&D to speed up commercial lab-grown meat to make it affordable; meat tax	High	Low	Slow
	Dining out at eco-friendly restaurants	Convenience	Incentivise restaurant owners to focus on sustainability via subsidies and regulations	Med	Low	Fast
Global Commons	Flexitarian diets with conscious meat purchase	Environmentally-conscious; convenience	Supermarkets stock more plant-based options, discounts on vegetables and not meat; meat tax; social norm changes	High	High	Fast
	Vegetable gardening		Subsidies for vegetable gardening	Low	Med	Moderately fast
	Local & seasonal food		More supermarkets prioritising local and seasonal food; subsidised	Med	High	Fast
Big Village	Vegan & sufficient diets	Environmentally-friendly; social cohesion; more time for community; simple & slower lifestyles	Social norm changes around animal-product consumption and overconsumption	Low	Low	Fast
	Communal dining		Social norm changes	Med	High	Moderately fast
	Community gardens		Neighbourhood redesigned to facilitate urban gardening	Low	Med	Slow
Pocket Lifestyles	Vegetarian diets	Trendy; healthy	Marketing; social media; influencers; apps for recipes	Med	Med	Fast
	Meal / leftovers sharing via peer-to-peer apps	Tech-savvy; cost-savings	Marketing; social media; influencers; more peer-to-peer apps to facilitate sharing	High	High	Moderately fast
	Conscious grocery shopping about quantity	Cost-savings; trendy; minimalism	Marketing; social media; influencers; supermarkets incentivise buying amounts you need.	High	High	Fast
	Meal prepping	Cost-savings; convenience; trendy	Marketing; social media; influencers.	High	High	Fast

S6. (PATH)WAYS TO SUSTAINABLE LIVING: THE IMPACT OF THE SLIM SCENARIOS ON LONG-TERM EMISSIONS

S6.1. Quantitative assumptions for lifestyle scenarios

Domains	Scenarios	Behaviour actions or lifestyles	ASI	Motivations	Contextual factors	Assumption by 2050	How many in 2050 in Global North?	How many in 2050 in Global South?	Market shares / saturation year of adopter group				
Passenger transport	Designed World	Electric vehicles	I	in-use cost savings, status	financial incentives, EV charging infrastructure (e.g. charging lanes)	Replace petrol vehicle with electric vehicle	80%	50%	2023	2028	2035	2043	2050
		(Peer-to-peer) taxi services	A/I	convenience	availability and options (e.g. Uber, Lift)	20% less kms per person in car travel; replace private car travel with taxi rides	30%	60%	2025	2035	2040	2045	2050
	Pocket Lifestyles	Telecommuting	A	Trendy, tech-savvy	Strong tech innovation for improved telecommuting	Work from home 2 days a week and 40% less business trips, thus less travel but more residential	42%	21%	2023	2028	2035	2043	2050
		Peer-to-peer car sharing	A	Trendy, tech-savvy	Platforms for shared car ownership or renting out own car (e.g. Snapp-car)	Replace car ownership with car sharing	53%	26%	2025	2035	2040	2045	2050
		Active passenger transport	S	Trendy, cost-effective	Influencers; social media; marketing to encourage active passenger transport	car, bus --> walk & cycle (short distance)	30%	20%	2023	2028	2035	2043	2050
		Smaller vehicles	I	Trendy, cost-effective	Influencers; social media; marketing to encourage sustainable driving habits	Shift from bigger to smaller vehicles	53%	53%	2023	2028	2035	2043	2050

9

Residential	Designed World	Insulation	I	cost-savings energy bills, comfort, indoor air quality	Prepaid subsidies; extra incentives for housing associations & landlords (large-scale), stricter regulation for new buildings	Insulation at new building regulation levels	68%	34%	2025	2035	2040	2045 2050
		Heat pump	I	cost-savings on energy bills, comfort, indoor air quality	Prepaid subsidies; extra incentives for housing associations & landlords (large-scale); stricter regulation for new buildings	Install heat pump	40%	20%	2025	2035	2040	2045 2050
		Rooftop solar	I	cost-savings on energy bills	Subsidies; stricter regulation for new buildings	Roof fully covered with PV	60%	40%	2023	2028	2035	2043 2050
		Quookers / shower heat recovery	I	comfort, convenience, cost-savings energy bills	Subsidies for heat recovery; stricter regulation for new buildings	Installed quooker; shower heat recovery	70%	40%	2025	2035	2040	2045 2050
	Pocket Lifestyles	Minimalist apartments & tiny houses	A	Trendy (less-is-more), tech-savvy, cost-effective	Regulation adjusted to accommodate for smaller living; social norm changes	36 m2 (urban) / 43 m2 (rural) per capita or less	70%	90%	2028	2038	2043	2048 2050
		Adjust thermostat	S	Trendy (health), cost-effective	Social norm changes; influencers	2°C less for heating and more for cooling	70%	90%	2023	2028	2035	2043 2050
		Lower-heat showers	S	Trendy (health), cost-effective	Social norm changes; influencers	36°C showers	70%	90%	2023	2028	2035	2043 2050
		Rent out room	A	Trendy, cost-effective, social	house/room sharing platforms become more prominent with proper regulation (e.g. couchsurfing, Airbnb); influencers	20 m2 per capita for 2 months of the year	26%	40%	2025	2035	2040	2045 2050
		Hang dry on clothing lines	A	Trendy, cost-effective	Social norm changes; influencers	Hand-dry clothing	40%	80%	2023	2028	2035	2043 2050
		Meal prepping	S	Trendy, cost-effective	Marketing; social media; influencers.	Meal prep for 7 days	70%	70%	2023	2028	2035	2043 2050

S6.2: References for quantitative assumptions based on literature and advisors

Domains	Scenarios	Behaviour actions or lifestyles	Literature sources	Advisors’ comments
Passenger transport	Designed World			“I’d be interested to see how manufacturing transport fits/changes in each of the scenarios.” “Ripple effects on car ownership could deal with material demand implications.” “I am a bit astonished that quite a lot of individuals (car) mobility is part of the scenarios. As well I am wondering how the aspects of lower temperature and less showering would bring us very close to the 1.5-degree lifestyles. I seriously doubt that a scenario based on individual mobility and expanded e-cars will lead to the necessary reduction in emissions, not to talk about the resources needed for building the cars and the so much larger infrastructure to provide the electricity.”
		Electric vehicles	Replacing typic car with electric/hybrid (27% based on Swedish ranking for highest emission reduction of individual living in richer countries, IPSOS)	“We have to make the high polluting choice harder and the low polluting choice easier. We have to design in cycling infrastructure; design out expanded roads. We have to design out individual car ownership - once people own cars, they use them. What about integrated mobility apps - so mobility is a service, not a commodity. (That might be in pocket lifestyles) We thought electric vehicles could go faster (but maybe they shouldn’t as we don’t want cities with bumper-to-bumper electric vehicles. Actions could include no car ownership - but rather have mobility as a service - no more hassles with buying and maintaining a car; paying for insurance, and dealing with parking. That’s a designed world with cars designed out. (perhaps also design out new road building). but other options for the door-to-door service have to be readily available - but expensive so active travel has a chance - create infrastructure for cycling which provides independence and convenience. This would be moderately slow to adopt because it depends on the infrastructure being set up. Electric vehicles are further ahead.” “The need for mixed-mode transport in the designed world, and particularly the need to design infrastructure (i.e. bike lanes) to avoid lock-in into complete dependence on private vehicles.”
		(Peer-to-peer) taxi services	Not having a car (30% based on Swedish ranking for highest emission reduction of individual living in richer countries, IPSOS)	“Uber/Lyft need to be improved.”

Passenger transport	Pocket Lifestyles	Telecommuting	Avoiding one long-distance flight (lasting 6 hours or more) (42% based on Swedish ranking for highest emission reduction of individual living in richer countries, IPSOS)	
		Peer-to-peer car sharing	Not having a car (30% based on Swedish ranking for highest emission reduction of individual living in richer countries, IPSOS) Carpooling/sharing (53% based on Swedish categorisation of top ways of reducing personal climate change impact, IPSOS)	
		Active passenger transport	Not having a car (30% based on Swedish ranking for highest emission reduction of individual living in richer countries, IPSOS)	
		Smaller vehicles	Fuel efficient driving practices (e.g. using the correct gear, and driving more slowly) (53% based on Saudi Arabians categorisation of top ways of reducing personal climate change impact, IPSOS)	
Residential	Designed World	Insulation	Refurbishing and renovating housing for efficiency (68% based on Hungarian categorisation of top ways of reducing personal climate change impact, IPSOS)	
		Heat pump	More energy-efficient cooking equipment, using cleaner fuel or renewable energy (69% based on Turkish categorisation of top ways of reducing personal climate change impact, IPSOS)	“We also discussed the difficulties of rapidly adopting heat-pumps everywhere, particularly in apartment and historic/protected buildings. More thought is needed on the feasibility and speed of the required retrofits.” “Actions make sense - but heat humps difficult for apartment living. Adoption rate and speed of transition look good”
		Rooftop solar		
		Quookers / shower heat recovery		

Residential	Pocket Lifestyles	Minimalist apartments & tiny houses	Having smaller living spaces / or co-housing to fill empty rooms (26% based on Turkish categorisation of top ways of reducing personal climate change impact, IPSOS) Average floor space per capita in EU28 is 42,56 (European Commission, 2011)	"There is one aspect I think very unlikely -the very significant reduction in floor space/capita in the Global North across 3 of the scenarios. Floor space/capita is something I thought about a lot in my work, and I could see how important it was in the modelling. Trends, not only in the Global North but also very strongly in China (there's been a huge jump in the last 2 decades) have been for increasing space per person to around the 40-50m2/capita mark. Covid has strengthened people's desire for space at home, a trend I think will be hard to reverse, and certainly not to reduce floor space by up to 40% as shown in the scenarios. I'm saying this as someone who used to live on my own in a 98m2 flat and (mainly for climate reasons) have downsized to 66m2. I look around at friends and family – prosperous, middle-aged and elderly – quite a few of whom have more than 100m2/capita. Also, what I know about the aspirations of younger people growing up in less prosperous, more cramped circumstances is that they aspire to spacious homes and will move to these whenever they get the chance. There's also the question of the huge amount of wealth (and debt) tied up in exiting housing stock -again China is catching up with Europe on this one – that would create resistance to changes in housing configuration. Most of the homes in 2050 in the UK have already been built and some are >100 years old, it's hard to see how the existing construction and mortgage industries would cope with the major modifications needed to convert to micro or communal housing." "Not sure that minimalist apartments and tiny houses will have high adoption rate in Global North"
		Adjust thermostat		
		Lower-heat showers		
		Rent out room	Having smaller living spaces / or co-housing to fill empty rooms (26% based on Turkish categorisation of top ways of reducing personal climate change impact, IPSOS) Average floor space per capita in EU28 is 42,56 (European Commission, 2011)	
		Hang dry on clothing lines	Hang-drying their clothes, instead of using an electric or gas dryer (40% based on French ranking for highest emission reduction of individual living in richer countries, IPSOS)	
		Meal prepping		This I don't quite understand, how do you deal with meal conservation? Many in the global south externalize the fridge/freezer.

S6.3. Parameters and implementation of behaviour actions of lifestyle scenarios in IMAGE

Domains	Scenarios	Behaviour actions	Parameters	Implementation
Passenger transport	Designed World	Electric vehicles	Additional passenger technology costs	Optimistic cost development for electric cars till the point of 80% shares for Global North
		Replace private cars with peer-to-peer taxis	Correction factor passenger-kilometres	Adjust passenger-kilometres of cars based on the adoption rates, adopter groups and saturation years (see assumptions in previous tables)
			Mode preferences	Adjust preferences to shift from car mode to walking, cycling, bus and train modes
	Pocket Lifestyles	Telecommuting	Correction factor passenger-kilometres	Adjusted passenger-kilometres according to assumption on the adoption rates, adopter groups and saturation years (see assumptions in previous tables)
		Peer-to-peer car sharing	Correction factor passenger-kilometres	Adjusted passenger-kilometres according to assumption on the adoption rates, adopter groups and saturation years (see assumptions in previous tables)
			Additional passenger technology costs	Technology costs more expensive, less incentive to take the car
			Mode preferences	Calibrated mode preferences to shift from cars to bus and train according to narrative quantification
		Active passenger transport	Mode preferences	Calibrated mode preferences to shift from cars to walking and cycling according to narrative quantification
		Smaller vehicles	Luxury factor elasticity	Adjusted the elasticity towards a preference for smaller and more efficient vehicles according to narrative quantification

Domains	Scenarios	Behaviour actions	Parameters	Implementation
Residential	Designed World	Insulation	Premium factor on different building insulation levels	Adjust premium to facilitate insulation with the rate corresponding to the adoption rates, adopter groups and saturation years (see assumptions in previous tables)
		Heat pump	Heatpump premium	Adjust premium to facilitate heat pump adoption with the rate corresponding to the adoption rates, adopter groups and saturation years (see assumptions in previous tables)
		Rooftop solar	Rooftop PV area	Increased the area for rooftop PV potential
		Quookers / shower heat recovery	Water demand correction factor	Lower the water demand by 28% for the corresponding adoption rates, adopter groups and saturation years (see assumptions in previous tables)
	Pocket Lifestyles	Minimalist apartments & tiny houses	Cap on floorspace per capita	Introduced a cap on floorspace per capita that ends up at 36 m2 (urban) / 43 m2 (rural) in 2050 based on the adoption rates, adopter groups and saturation years (see assumptions in previous tables)
		Adjust thermostat	Correction factor for HDD and CDD	Adjusted these parameters based on the adoption rates, adopter groups and saturation years (see assumptions in previous tables)
		Lower-heat showers	Water demand correction factor	Lower the water demand by 10% for the corresponding adoption rates, adopter groups and saturation years (see assumptions in previous tables)
		Rent out room/house/couch	Household size	Technology costs more expensive, less incentive to take the car
		Hang dry on clothing lines	Mode preferences	Adjust preferences to shift from cars to walking and cycling
		Meal prepping (i.e. reduced cooking energy demand)	Luxury factor elasticity	Adjusted the elasticity towards a preference for smaller and more efficient vehicles.

S6.4. Absolute and relative emissions change for the various scenarios on per capita emissions for 2015 and 2050, and relative change from 2050 to 2015, colours representing decreasing (in green) or increasing emissions (in red) and the dark orange shading represents the scenario comparisons in 2050.

Scenarios	Region	Comparisons	Transport		Residential	
			Absolute change (tCO2/capita)	**Percentage change (%)**	**Absolute change (tCO2/capita)**	**Percentage change (%)**
SSP2 reference	Global North	2015	3.88		1.83	
		2050	2.25		1.45	
		2050 – 2015	-1.63	-42%	-0.38	-21%
	Global South	2015	0.51		0.56	
		2050	1.07		0.61	
		2050 – 2015	0.56	110%	0.05	9%
Designed World reference	Global North	2050	1.11		1.14	
		2050 – 2015	-2.77	-71%	-0.69	-38%
		DW – SSP2	**-1.14**	**-51%**	**-0.31**	**-21%**
	Global South	2050	0.65		0.58	
		2050 – 2015	0.14	28%	0.02	4%
		DW – SSP2	**-0.42**	**-39%**	**-0.03**	**-5%**
Pocket Lifestyles reference	Global North	2050	1.90		1.25	
		2050 – 2015	-1.98	-51%	-0.58	-32%
		PL – SSP2	**-0.35**	**-16%**	**-0.20**	**-14%**
	Global South	2050	0.73		0.56	
		2050 – 2015	0.22	43%	0.01	1%
		PL – SSP2	**-0.34**	**-32%**	**-0.04**	**-7%**
SSP2 2C	Global North	2050	0.64		0.38	
		2050 - 2015	-2.49	-64%	-1.45	-79%
		SSP2 2C - SSP2	**-1.61**	**-71%**	**-1.07**	**-74%**
		SSP2 2C - DW	**-0.46**	**-42%**	**-0.76**	**-67%**
		SSP2 2C - PL	**-1.25**	**-66%**	**-0.87**	**-70%**
	Global South	2050	0.64		0.25	
		2050 - 2015	0.14	27%	-0.31	-56%
		SSP2 2C - SSP2	**-0.43**	**-40%**	**-0.36**	**-60%**
		SSP2 2C - DW	**0.00**	**0%**	**-0.33**	**-29%**
		SSP2 2C - PL	**-0.08**	**-11%**	**-0.32**	**-57%**

S6.5.1. Global North – passenger transport results of decomposition analysis

Global North		Emissions change (Gt CO2)					Percentage change (%)				
Scenarios	Factors	Total	Bus	Train	Car	Air	Total	Bus	Train	Car	Air
SSP2	2015	2.19	0.13	0.00	1.89	0.17					
	P	0.18	0.01	0.00	0.15	0.02	8.0%	0.4%	0.0%	6.7%	0.9%
	A	0.49	0.03	0.00	0.41	0.06	22.5%	1.2%	0.0%	18.7%	2.6%
	M	0.01	-0.01	0.00	-0.02	0.04	0.6%	-0.2%	0.0%	-1.1%	2.0%
	E	-0.98	-0.05	0.00	-0.90	-0.03	-44.9%	-2.2%	0.0%	-41.2%	-1.5%
	I	-0.49	-0.05	0.00	-0.45	0.01	-22.3%	-2.1%	-0.1%	-20.4%	0.3%
	2050	1.40	0.06	0.00	1.08	0.26	-36.0%	-3.1%	-0.1%	-37.2%	4.4%
Designed World	SSP2 2050	1.40	0.06	0.00	1.08	0.26					
	P	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%
	A	-0.01	0.00	0.00	-0.01	0.00	-0.9%	-0.1%	0.0%	-0.6%	-0.2%
	M	0.00	0.00	0.00	0.00	0.00	0.1%	-0.1%	0.0%	0.3%	-0.2%
	E	-0.34	0.00	0.00	-0.34	0.00	-24.2%	0.0%	0.0%	-24.3%	0.0%
	I	-0.36	0.00	0.00	-0.36	0.00	-25.6%	0.0%	0.0%	-25.7%	0.0%
	DW 2050	0.69	0.06	0.00	0.37	0.26	-50.6%	-0.1%	0.0%	-50.3%	-0.3%
Pocket Lifestyles	SSP2 2050	1.40	0.06	0.00	1.08	0.26					
	P	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%
	A	-0.12	-0.01	0.00	-0.09	-0.02	-8.3%	-0.4%	0.0%	-6.3%	-1.6%
	M	-0.11	0.03	0.00	-0.11	-0.03	-7.8%	2.1%	0.1%	-7.8%	-2.2%
	E	0.03	0.00	0.00	0.03	0.01	2.1%	-0.1%	0.0%	1.8%	0.4%
	I	0.02	0.00	0.00	0.01	0.01	1.6%	-0.1%	0.0%	1.0%	0.6%
	PL 2050	1.23	0.08	0.00	0.92	0.23	-12.5%	1.6%	0.1%	-11.3%	-2.8%

S6.5.2. Global South – passenger transport results of decomposition analysis

Global South		Emissions change (Gt CO2)					Percentage change (%)				
Scenarios	Factors	Total	Bus	Train	Car	Air	Total	Bus	Train	Car	Air
SSP2	2015	1.58	0.32	0.01	1.16	0.09					
	P	0.73	0.15	0.00	0.52	0.05	46.1%	9.7%	0.2%	33.1%	3.2%
	A	1.41	0.30	0.00	1.01	0.10	89.1%	18.7%	0.3%	63.9%	6.2%
	M	0.92	-0.10	0.00	0.93	0.09	58.0%	-6.5%	-0.1%	58.9%	5.6%
	E	-0.64	0.07	0.00	-0.71	0.00	-40.6%	4.4%	-0.1%	-45.0%	0.1%
	I	0.35	0.21	-0.01	0.13	0.02	21.9%	13.4%	-0.7%	8.1%	1.1%
	2050	4.34	0.95	0.01	3.04	0.35	174.5%	39.8%	-0.3%	118.9%	16.2%
Designed World	SSP2 2050	4.34	0.95	0.01	3.04	0.35					
	P	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%
	A	-0.11	-0.03	0.00	-0.07	-0.01	-2.5%	-0.7%	0.0%	-1.5%	-0.2%
	M	-0.01	0.02	0.00	-0.03	0.00	-0.2%	0.5%	0.0%	-0.6%	0.0%
	E	-0.97	0.00	0.00	-0.97	0.00	-22.3%	0.0%	0.0%	-22.4%	0.1%
	I	-0.63	0.00	0.00	-0.63	0.00	-14.6%	0.0%	0.0%	-14.5%	-0.1%
	DW 2050	2.63	0.94	0.01	1.34	0.33	-39.5%	-0.2%	0.0%	-39.0%	-0.3%
Pocket Lifestyles	SSP2 2050	4.34	0.95	0.01	3.04	0.35					
	P	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%
	A	-0.21	-0.06	0.00	-0.13	-0.02	-4.8%	-1.4%	0.0%	-3.1%	-0.4%
	M	-0.98	0.28	0.01	-1.15	-0.11	-22.6%	6.4%	0.2%	-26.6%	-2.6%
	E	0.09	0.00	0.00	0.03	0.07	2.2%	0.0%	0.0%	0.6%	1.5%
	I	-0.06	0.00	0.00	0.01	-0.08	-1.4%	0.0%	0.1%	0.3%	-1.8%
	PL 2050	3.19	1.17	0.02	1.79	0.21	-26.6%	4.9%	0.3%	-28.7%	-3.2%

S6.5.3. Global North - residential results of decomposition analysis

Global North		Emissions change (Gt CO2)							Percentage change (%)						
Scenarios	Factors	Total	Appliances	Lighting	Cooking	Water heating	Space heating	Space cooling	Total	Appliances	Lighting	Cooking	Water heating	Space heating	Space cooling
SSP2	2015	2.07	0.49	0.10	0.14	0.37	0.85	0.12							
	P	0.19	0.05	0.01	0.01	0.03	0.07	0.01	9.1%	2.5%	0.3%	0.6%	1.6%	3.6%	0.5%
	A	0.17	0.01	0.00	0.00	0.01	0.11	0.04	8.2%	0.6%	0.1%	0.2%	0.4%	5.1%	1.8%
	S	0.08	0.15	-0.05	0.00	0.01	-0.04	0.01	4.0%	7.2%	-2.6%	-0.1%	0.6%	-1.8%	0.7%
	E	-0.32	0.00	0.00	0.01	-0.04	-0.22	-0.07	-15.3%	0.0%	0.0%	0.5%	-1.9%	-10.5%	-3.3%
	I	-0.38	-0.15	-0.02	-0.05	-0.05	-0.08	-0.04	-18.5%	-7.3%	-0.8%	-2.4%	-2.4%	-3.9%	-1.8%
	2050	1.81	0.55	0.04	0.11	0.33	0.69	0.08	-12.5%	3.0%	-3.0%	-1.2%	-1.6%	-7.5%	-2.1%
Designed World	SSP2 2050	1.81	0.55	0.04	0.11	0.33	0.69	0.08							
	P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	A	-0.03	-0.02	0.00	0.00	-0.01	0.00	0.00	-1.8%	-1.0%	-0.1%	-0.2%	-0.5%	0.0%	0.0%
	S	0.01	0.01	0.00	0.00	-0.01	0.00	0.00	0.6%	0.7%	0.1%	0.2%	-0.4%	0.0%	0.0%
	E	-0.37	0.00	0.00	0.00	-0.11	-0.26	0.00	-20.4%	0.0%	0.0%	0.0%	-6.0%	-14.2%	-0.2%
	I	0.00	-0.05	0.00	0.00	0.02	0.04	-0.01	0.0%	-2.6%	-0.2%	-0.2%	1.3%	2.0%	-0.3%
	DW 2050	1.42	0.50	0.03	0.11	0.23	0.47	0.07	-21.5%	-2.8%	-0.2%	-0.2%	-5.6%	-12.2%	-0.5%
Pocket Lifestyles	SSP2 2050	1.81	0.55	0.04	0.11	0.33	0.69	0.08							
	P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	A	-0.22	-0.05	0.00	-0.01	-0.03	-0.11	-0.01	-12.0%	-2.9%	-0.2%	-0.6%	-1.7%	-6.2%	-0.5%
	S	0.04	0.05	0.00	0.01	0.01	-0.01	-0.01	2.3%	2.5%	-0.3%	0.6%	0.6%	-0.5%	-0.7%
	E	0.00	0.00	0.00	-0.01	0.00	0.01	0.00	0.3%	0.0%	0.0%	-0.4%	0.0%	0.5%	0.2%
	I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1%	-0.1%	0.0%	0.0%	0.0%	0.1%	0.0%
	PL 2050	1.64	0.55	0.03	0.11	0.31	0.58	0.06	-9.4%	-0.4%	-0.4%	-0.4%	-1.1%	-6.1%	-1.0%

S6.5.4. Global South - residential results of decomposition analysis

Global South		Emissions change (Gt CO2)							Percentage change (%)						
Scenarios	Factors	Total	Appliances	Lighting	Cooking	Water heating	Space heating	Space cooling	Total	Appliances	Lighting	Cooking	Water heating	Space heating	Space cooling
SSP2	2015	3.48	0.39	0.20	1.21	0.47	0.95	0.25							
	P	1.12	0.17	0.07	0.33	0.16	0.25	0.13	32.1%	5.0%	1.9%	9.6%	4.6%	7.1%	3.8%
	A	1.98	0.26	0.10	0.50	0.24	0.31	0.57	56.8%	7.4%	2.8%	14.4%	6.9%	8.9%	16.4%
	S	0.06	0.43	0.03	-0.51	0.10	-0.06	0.08	1.9%	12.3%	0.8%	-14.7%	2.8%	-1.7%	2.3%
	E	-0.98	0.00	0.00	-0.24	-0.21	-0.46	-0.07	-28.2%	0.0%	0.0%	-6.8%	-6.1%	-13.2%	-2.0%
	I	-0.67	-0.26	-0.10	-0.01	0.02	-0.11	-0.21	-19.3%	-7.6%	-2.7%	-0.3%	0.5%	-3.1%	-6.1%
	2050	4.98	0.99	0.30	1.29	0.77	0.88	0.75	43.2%	17.2%	2.8%	2.2%	8.6%	-2.0%	14.4%
Designed World	SSP2 2050	4.98	0.99	0.30	1.29	0.77	0.88	0.75							
	P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	A	-0.20	-0.06	-0.02	-0.08	-0.04	0.00	0.00	-3.9%	-1.2%	-0.4%	-1.6%	-0.8%	0.0%	0.0%
	S	0.05	0.04	0.02	0.08	-0.08	0.00	0.00	1.0%	0.8%	0.4%	1.6%	-1.7%	0.0%	0.0%
	E	-0.16	0.00	0.00	0.00	-0.02	-0.10	-0.04	-3.2%	0.0%	0.0%	0.0%	-0.4%	-2.0%	-0.9%
	I	0.00	-0.02	0.00	0.00	0.00	0.03	-0.01	0.0%	-0.3%	-0.1%	-0.1%	0.1%	0.7%	-0.3%
	DW 2050	4.68	0.95	0.30	1.28	0.63	0.82	0.69	-6.2%	-0.7%	-0.1%	-0.1%	-2.8%	-1.3%	-1.2%
Pocket Lifestyles	SSP2 2050	4.98	0.99	0.30	1.29	0.77	0.88	0.75							
	P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	A	-0.25	-0.07	-0.02	-0.09	-0.05	0.00	-0.03	-5.1%	-1.3%	-0.4%	-1.7%	-1.0%	-0.1%	-0.6%
	S	-0.12	0.02	0.02	0.09	-0.08	-0.02	-0.15	-2.5%	0.3%	0.4%	1.7%	-1.6%	-0.3%	-3.1%
	E	-0.02	0.00	0.00	-0.09	0.00	-0.01	0.08	-0.3%	0.0%	0.0%	-1.8%	0.0%	-0.2%	1.7%
	I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	PL 2050	4.59	0.94	0.30	1.20	0.64	0.85	0.66	-7.9%	-1.0%	0.0%	-1.8%	-2.6%	-0.6%	-1.9%

S6.6. Food actions, the adoption rates and speed of transition affected by motivations and enabling factors in the SLIM scenarios, Designed World and Pocket Lifestyles

Scenarios	Food Actions	People Motivations	Enabling factors	Adoption rates		Speed of transition
				Global North	Global South	
Designed World	Lab-grown meat	Still able to eat meat	Invest in R&D to speed up commercial lab-grown meat to make it affordable; meat tax	High	Low	Slow
	Dining out at eco-friendly restaurants	Convenience	Incentivise restaurant owners to focus on sustainability via subsidies and regulations	Med	Low	Fast
Pocket Lifestyles	Vegetarian diets	Trendy; healthy	Marketing; social media; influencers; apps for recipes	Med	Med	Fast
	Meal / leftovers sharing via peer-to-peer apps	Tech-savvy; cost-savings	Marketing; social media; influencers; more peer-to-peer apps to facilitate sharing	High	High	Moderately fast
	Conscious grocery shopping about quantity	Cost-savings; trendy; minimalism	Marketing; social media; influencers; supermarkets incentivise buying amounts you need.	High	High	Fast
	Meal prepping	Cost-savings; convenience; trendy	Marketing; social media; influencers.	High	High	Fast

9

REFERENCES

Adelt, F., Weyer, J., Hoffmann, S., & Ihrig, A. (2018). Simulation of the governance of complex systems (SimCo): basic concepts and experiments on urban transportation. *Journal of Artificial Societies and Social Simulation*, *21*(2).

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179-211. https://doi.org/https://doi.org/10.1016/0749-5978(91)90020-T

Akenji, L. (2014). Consumer scapegoatism and limits to green consumerism. *Journal of Cleaner Production*, *63*, 13-23.

Akenji, L., Bengtsson, F., Chiu, A., Briggs, E., Daconto, G., Fadeeva, Z., Fotiou, S., Gandhi, R., Mohanty, B., Salem, J., Sang-Arun, J., Schandl, H., & Tabucanon, M. (2012). *Sustainable Consumption and Production: A Handbook for Policy Makers*.

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

Akenji, L., & Chen, H. (2016). *A framework for shaping sustainable lifestyles: determinants and strategies*. U. N. E. Programme.

Ala-Mantila, S., Heinonen, J., & Junnila, S. (2014). Relationship between urbanization, direct and indirect greenhouse gas emissions, and expenditures: A multivariate analysis [Article]. *Ecological Economics*, *104*, 129-139. https://doi.org/10.1016/j.ecolecon.2014.04.019

Ala-Mantila, S., Ottelin, J., Heinonen, J., & Junnila, S. (2016). To each their own? The greenhouse gas impacts of intra-household sharing in different urban zones [Article]. *Journal of Cleaner Production*, *135*, 356-367. https://doi.org/10.1016/j.jclepro.2016.05.156

Alonso-Betanzos, A., Sánchez-Maroño, N., Fontenla-Romero, O., Polhill, J. G., Craig, T., Bajo, J., & Corchado, J. M. (2017). *Agent-based modeling of sustainable behaviors*. Springer.

Amer, M., Daim, T. U., & Jetter, A. (2013). A review of scenario planning. *Futures*, *46*, 23-40.

Anable, J., Brand, C., Tran, M., & Eyre, N. (2012). Modelling transport energy demand: A socio-technical approach. *Energy Policy*, *41*, 125-138. https://doi.org/10.1016/j.enpol.2010.08.020

Ang, B. W. (2004). Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Policy*, *32*(9), 1131-1139.

Ang, B. W., Liu, F., & Chew, E. P. (2003). Perfect decomposition techniques in energy and environmental analysis. *Energy Policy*, *31*(14), 1561-1566.

Babutsidze, Z., & Chai, A. (2018). Look at me Saving the Planet! The Imitation of Visible Green Behavior and its Impact on the Climate Value-Action Gap [Article]. *Ecological Economics*, *146*, 290-303. https://doi.org/10.1016/j.ecolecon.2017.10.017

Backhaus, J., Breukers, S., Mont, O., Paukovic, M., & Mourik, R. (2012). *Sustainable Lifestyles: Today's Facts & Tomorrow's Trends*.

Baiocchi, G., Creutzig, F., Minx, J., & Pichler, P. P. (2015). A spatial typology of human settlements and their CO<inf>2</inf> emissions in England [Article]. *Global Environmental Change*, *34*, 13-21. https://doi.org/10.1016/j.gloenvcha.2015.06.001

Bauer, N., Calvin, K., Emmerling, J., Fricko, O., Fujimori, S., Hilaire, J., Eom, J., Krey, V., Kriegler, E., Mouratiadou, I., Sytze de Boer, H., van den Berg, M., Carrara, S., Daioglou, V., Drouet, L., Edmonds, J. E., Gernaat, D., Havlik, P., Johnson, N., . . . van Vuuren, D. P. (2017). Shared Socio-Economic Pathways of the Energy Sector – Quantifying the Narratives [Article]. *Global Environmental Change*, *42*, 316-330. https://doi.org/10.1016/j.gloenvcha.2016.07.006

Beck, S., & Mahony, M. (2018). The politics of anticipation: the IPCC and the negative emissions technologies experience. *Global Sustainability*, *1*.

Bijl, D. L., Bogaart, P. W., Dekker, S. C., Stehfest, E., de Vries, B. J. M., & van Vuuren, D. P. (2017). A physically-based model of long-term food demand. *Global Environmental Change*, *45*, 47-62. https://doi.org/10.1016/j.gloenvcha.2017.04.003

Bjelle, E., Steen-Olsen, K., & Wood, R. (2018). Climate change mitigation potential of Norwegian households and the rebound effect [Article]. *Journal of Cleaner Production*, *172*, 208-217. https://doi.org/10.1016/j.jclepro.2017.10.089

Brand, C., Cluzel, C., & Anable, J. (2017). Modeling the uptake of plug-in vehicles in a heterogeneous car market using a consumer segmentation approach [Article]. *Transportation Research Part A: Policy and Practice*, *97*, 121-136. https://doi.org/10.1016/j.tra.2017.01.017

Bravo, G., Vallino, E., Cerutti, A. K., & Pairotti, M. B. (2013). Alternative scenarios of green consumption in Italy: An empirically grounded model. *Environmental modelling & software*, *47*, 225-234.

Brizga, J., Feng, K., & Hubacek, K. (2017). Household carbon footprints in the Baltic States: a global multi-regional input–output analysis from 1995 to 2011. *Applied Energy*, *189*, 780-788.

Busch, J., Roelich, K., Bale, C. S., & Knoeri, C. (2017). Scaling up local energy infrastructure; An agent-based model of the emergence of district heating networks. *Energy Policy*, *100*, 170-180.

Cairns, G., & Wright, G. (2017). *Scenario thinking: Preparing your organization for the future in an unpredictable world*. Springer.

Cajaiba-Santana, G. (2014). Social innovation: Moving the field forward. A conceptual framework. *Technological Forecasting and Social Change*, *82*, 42-51. https://doi.org/https://doi.org/10.1016/j.techfore.2013.05.008

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

Chaturvedi, V., & Sharma, M. (2015). Modelling long-term HFC emissions from India's residential air-conditioning sector: exploring implications of alternative refrigerants, best practices, and a sustainable lifestyle within an integrated assessment modelling framework. *Climate Policy*, *16*(7), 877-893. https://doi.org/10.1080/14693062.2015.1052954

Chen, H.-H., Hof, A. F., Daioglou, V., de Boer, H. S., Edelenbosch, O. Y., van den Berg, M., van der Wijst, K.-I., & van Vuuren, D. P. (2021). Using decomposition analysis to determine the main contributing factors to carbon neutrality across sectors. *Energies*, *15*(1), 132.

Chermack, T. J. (2011). *Scenario planning in organizations: how to create, use, and assess scenarios*. Berrett-Koehler Publishers.

Clarke, L., Jiang, K., Akimoto, K., Babiker, M., Blanford, G., Fisher-Vanden, K., Hourcade, J.-C., Krey, V., Kriegler, E., Loschel, A., McCollum, D., Paltsev, S., Rose, S., Shukla, P. R., Tavoni, M., Zwaan, B. C. C. v. d., & Vuuren, D. P. v. (2014). *Assessing transformation pathways* (Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Issue.

Cornelius, M., Armel, K. C., Hoffman, K., Allen, L., Bryson, S. W., Desai, M., & Robinson, T. N. (2014). Increasing energy- and greenhouse gas-saving behaviors among adolescents: A school-based cluster-randomized controlled trial [Article]. *Energy Efficiency*, *7*(2), 217-242. https://doi.org/10.1007/s12053-013-9219-5

Costa, L., Moreau, V., Thurm, B., Yu, W., Clora, F., Baudry, G., Warmuth, H., Hezel, B., Seydewitz, T., & Ranković, A. (2021). The decarbonisation of Europe powered by lifestyle changes. *Environmental Research Letters*, *16*(4), 044057.

Creutzig, F., Callaghan, M., Ramakrishnan, A., Javaid, A., Niamir, L., Minx, J., Müller-Hansen, F., Sovacool, B., Afroz, Z., & Andor, M. (2021). Reviewing the scope and thematic focus of 100 000 publications on energy consumption, services and social aspects of climate change: a big data approach to demand-side mitigation. *Environmental Research Letters*, *16*(3), 033001.

Creutzig, F., Fernandez, B., Haberl, H., Khosla, R., Mulugetta, Y., & Seto, K. C. (2016). Beyond Technology: Demand-Side Solutions for Climate Change Mitigation. In *Annual Review of Environment and Resources* (Vol. 41, pp. 173-198).

Creutzig, F., Roy, J., Devine-Wright, P., Díaz-José, J., Geels, F. W., Grubler, A., Maïzi, N., Masanet, E., Mulugetta, Y., Onyige, C. D., Perkins, P. E., Sanches-Pereira, A., & Weber, E. U. (2022). *Demand, services and social aspects of mitigation. In IPCC, 2022* (Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Issue. doi: 10.1017/9781009157926.007

Creutzig, F., Roy, J., Lamb, W. F., Azevedo, I. M. L., Bruine de Bruin, W., Dalkmann, H., Edelenbosch, O. Y., Geels, F. W., Grubler, A., Hepburn, C., Hertwich, E. G., Khosla, R., Mattauch, L., Minx, J. C., Ramakrishnan, A., Rao, N. D., Steinberger, J. K., Tavoni, M., Ürge-Vorsatz, D., & Weber, E. U. (2018). Towards demand-side solutions for mitigating climate change. *Nature Climate Change*, *8*(4), 260-263. https://doi.org/10.1038/s41558-018-0121-1

Czepkiewicz, M., Heinonen, J., & Ottelin, J. (2018). Why do urbanites travel more than do others? A review of associations between urban form and long-distance leisure travel. *Environmental Research Letters*, *13*(7), 073001.

Daioglou, V., Van Ruijven, B. J., & Van Vuuren, D. P. (2012). Model projections for household energy use in developing countries. *Energy*, *37*(1), 601-615.

De Cian, E., Dasgupta, S., Hof, A. F., van Sluisveld, M. A., Köhler, J., Pfluger, B., & van Vuuren, D. P. (2020). Actors, decision-making, and institutions in quantitative system modelling. *Technological Forecasting and Social Change*, *151*, 119480.

Deetman, S., de Boer, H. S., Van Engelenburg, M., van der Voet, E., & van Vuuren, D. P. (2021). Projected material requirements for the global electricity infrastructure–generation, transmission and storage. *Resources, Conservation and Recycling*, *164*, 105200.

Defra. (2008). *A framework for pro-environmental behaviours*.

Dolan, P., Hallsworth, M., Halpern, M., King, D., & Vlaev, I. (2010). *MINDSPACE: influencing behaviour through public policy*.

Dubois, G., & Ceron, J. P. (2015). Consumption and lifestyles: An alternative perspective on climate change mitigation policies [Article]. *Natures Sciences Societes*, *23*, S76-S90. https://doi.org/10.1051/nss/2015020

Echegaray, F. (2021). What POST-COVID-19 lifestyles may look like? Identifying scenarios and their implications for sustainability. *Sustainable Production and Consumption*, *27*, 567-574.

Edelenbosch, O. Y., McCollum, D., van Vuuren, D., Bertram, C., Carrara, S., Daly, H., Fujimori, S., Kitous, A., Kyle, P., & Broin, E. Ó. (2017). Decomposing passenger transport futures: Comparing results of global integrated assessment models. *Transportation Research Part D: Transport and Environment*, *55*, 281-293.

Edelenbosch, O. Y., McCollum, D. L., Pettifor, H., Wilson, C., & Van Vuuren, D. P. (2018). Interactions between social learning and technological learning in electric vehicle futures. *Environmental Research Letters*, *13*(12), 124004.

Edelenbosch, O. Y., Van Vuuren, D. P., Blok, K., Calvin, K., & Fujimori, S. (2020). Mitigating energy demand sector emissions: The integrated modelling perspective. *Applied Energy*, *261*, 114347.

Ernst, A., & Briegel, R. (2017). A dynamic and spatially explicit psychological model of the diffusion of green electricity across Germany. *Journal of Environmental Psychology*, *52*, 183-193.

Ernst, A. M. (1999). Resource dilemmas, computer simulated actors and climate change? A methodology to investigate human behavior in a complex domain. *Complex problem solving: Cognitive psychological issues and environmental policy applications*, 95-105.

Faber, J., Schroten, A., Bles, M., Sevenster, M., Markowska, A., Smit, M., Rohde, C., Dütschke, E., Köhler, J., & Gigli, M. (2012). Behavioural climate change mitigation options and their appropriate inclusion in quantitative longer term policy scenarios. *Delft: CE Delft*.

Fink, H. S. (2011). Promoting behavioral change towards lower energy consumption in the building sector [Review]. *Innovation*, *24*(1-2), 7-26. https://doi.org/10.1080/13511610.2011.586494

Frenette, E., Bahn, O., & Vaillancourt, K. (2017). Meat, Dairy and Climate Change: Assessing the Long-Term Mitigation Potential of Alternative Agri-Food Consumption Patterns in Canada [Article]. *Environmental Modeling and Assessment*, *22*(1). https://doi.org/10.1007/s10666-016-9522-6

Friege, J., & Chappin, E. (2014). Modelling decisions on energy-efficient renovations: A review. *Renewable and Sustainable Energy Reviews*, *39*, 196-208.

Froemelt, A., Dürrenmatt, D. J., & Hellweg, S. (2018). Using data mining to assess environmental impacts of household consumption behaviors. *Environmental Science & Technology*, *52*(15), 8467-8478.

Geels, F. W., Berkhout, F., & Van Vuuren, D. P. (2016). Bridging analytical approaches for low-carbon transitions. *Nature climate change*, *6*(6), 576-583.

Geels, F. W., Hekkert, M. P., & Jacobsson, S. (2008). The dynamics of sustainable innovation journeys. In: Taylor & Francis.

Geisendorf, S., & Klippert, C. (2017). The Effect of Green Investments in an Agent-Based Climate-Economic Model [Article]. *Environmental Modeling and Assessment*, *22*(4), 323-343. https://doi.org/10.1007/s10666-017-9549-3

Giddens, A. (1984). *The constitution of society: Outline of the theory of structuration*. Univ of California Press.

Gifford, R., Kormos, C., & McIntyre, A. (2011). Behavioral dimensions of climate change: drivers, responses, barriers, and interventions. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(6), 801-827. https://doi.org/10.1002/wcc.143

Girod, B., van Vuuren, D. P., & de Vries, B. (2013). Influence of travel behavior on global CO<inf>2</inf>emissions [Article]. *Transportation Research Part A: Policy and Practice*, *50*, 183-197. https://doi.org/10.1016/j.tra.2013.01.046

Girod, B., van Vuuren, D. P., & Hertwich, E. G. (2014). Climate policy through changing consumption choices: Options and obstacles for reducing greenhouse gas emissions [Article]. *Global Environmental Change*, *25*(1), 5-15. https://doi.org/10.1016/j.gloenvcha.2014.01.004

GLAMURS. (2016). *Green Lifestyles, Alternative Models and Upscaling Regional Sustainability*. I. o. P. S. a. Research.

Goodall, C. (2010). *How to live a low-carbon life: the individual's guide to tackling climate change*. Routledge.

Gore, T. (2020). Confronting Carbon Inequality: Putting climate justice at the heart of the COVID-19 recovery.

Green, K., & Vergragt, P. (2002). Towards sustainable households: A methodology for developing sustainable technological and social innovations [Article]. *Futures*, *34*(5), 381-400. https://doi.org/10.1016/S0016-3287(01)00066-0

Grubler, A., Wilson, C., Bento, N., Boza-Kiss, B., Krey, V., McCollum, D. L., Rao, N. D., Riahi, K., Rogelj, J., De Stercke, S., Cullen, J., Frank, S., Fricko, O., Guo, F., Gidden, M., Havlík, P., Huppmann, D., Kiesewetter, G., Rafaj, P., . . . Valin, H. (2018). A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. *Nature Energy*, *3*(6), 515-527. https://doi.org/10.1038/s41560-018-0172-6

Guinée, J., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., Udo de Haes, H., Van der Voet, E., & Wrisberg, M. (2002). Life cycle assessment. *An operational guide to ISO standards, vols*, 1-3.

Haines, A., McMichael, A. J., Smith, K. R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B. G., Campbell-Lendrum, D., Dangour, A. D., Davies, M., Bruce, N., Tonne, C., Barrett, M., & Wilkinson, P. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. *The Lancet*, *374*(9707), 2104-2114. https://doi.org/10.1016/S0140-6736(09)61759-1

Hallström, E., Carlsson-Kanyama, A., & Börjesson, P. (2015). Environmental impact of dietary change: a systematic review. *Journal of Cleaner Production*, *91*, 1-11. https://doi.org/10.1016/j.jclepro.2014.12.008

Hanley, N., & Brennan, D. (2013). Economics of a low-carbon future [Article]. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, *103*(2), 149-156. https://doi.org/10.1017/S1755691013000042

Hanmer, C., Wilson, C., Edelenbosch, O. Y., & Van Vuuren, D. P. (2022). Translating Global Integrated Assessment Model Output into Lifestyle Change Pathways at the Country and Household Level. *Energies*, *15*(5), 1650.

Hargreaves, T. (2011). Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change. *Journal of consumer culture*, *11*(1), 79-99.

Heinonen, J., Jalas, M., Juntunen, J. K., Ala-Mantila, S., & Junnila, S. (2013a). Situated lifestyles: I. How lifestyles change along with the level of urbanization and what the greenhouse gas implications are—a study of Finland. *Environmental Research Letters*, *8*(2), 025003.

Heinonen, J., Jalas, M., Juntunen, J. K., Ala-Mantila, S., & Junnila, S. (2013b). Situated lifestyles: II. The impacts of urban density, housing type and motorization on the greenhouse gas emissions of the middle-income consumers in Finland. *Environmental Research Letters*, *8*(3), 035050.

Heinonen, J., Ottelin, J., Ala-Mantila, S., Wiedmann, T., Clarke, J., & Junnila, S. (2020). Spatial consumption-based carbon footprint assessments-A review of recent developments in the field. *Journal of Cleaner Production*, *256*, 120335.

Hesselink, L. X., & Chappin, E. J. (2019). Adoption of energy efficient technologies by households–Barriers, policies and agent-based modelling studies. *Renewable and Sustainable Energy Reviews*, *99*, 29-41.

Hicks, A. L., Theis, T. L., & Zellner, M. L. (2015). Emergent effects of residential lighting choices: prospects for energy savings. *Journal of Industrial Ecology*, *19*(2), 285-295.

Höhne, N., den Elzen, M., & Escalante, D. (2013). Regional GHG reduction targets based on effort sharing: a comparison of studies. *Climate Policy*, *14*(1), 122-147. https://doi.org/10.1080/14693062.2014.849452

Hölsgens, R., Lübke, S., & Hasselkuß, M. (2018). Social innovations in the German energy transition: an attempt to use the heuristics of the multi-level perspective of transitions to analyze the diffusion process of social innovations. *Energy, Sustainability and Society*, *8*(1), 1-13.

Howaldt, J., Kopp, R., & Schwarz, M. (2015). On the theory of social innovations: Tarde's neglected contribution to the development of a sociological innovation theory.

IEA. (2004). Oil crises and climate challenges: 30 years of energy use in IEA countries. Energy & Security in the Changing World, International Conference, 2004,

IPCC. (2014). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]*. C. U. Press.

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, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W.

Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. *In Press*.

IPCC. (2022). *Climate Change 2022: Mitigation of Climate Change. Contributions of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R.*

Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. C. U. Press.

Isaac, M., & Van Vuuren, D. P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy Policy*, *37*(2), 507-521.

Ivanova, D., Barrett, J., Wiedenhofer, D., Macura, B., Callaghan, M. W., & Creutzig, F. (2020). Quantifying the potential for climate change mitigation of consumption options. *Environmental Research Letters*.

Ivanova, D., & Wood, R. (2020). The unequal distribution of household carbon footprints in Europe and its link to sustainability. *Global Sustainability*, *3*.

Jackson, T. (2005). *Motivating Sustainable Consumption: a review of evidence on consumer behaviour and behavioural change*. S. D. R. Network.

Jager, W. (2021). Using agent-based modelling to explore behavioural dynamics affecting our climate. *Current Opinion in Psychology*, *42*, 133-139.

Jones, C., & Kammen, D. M. (2014). Spatial distribution of US household carbon footprints reveals suburbanization undermines greenhouse gas benefits of urban population density. *Environmental science & technology*, *48*(2), 895-902.

Jones, C. M., & Kammen, D. M. (2011). Quantifying carbon footprint reduction opportunities for U.S. households and communities [Article]. *Environmental Science and Technology*, *45*(9), 4088-4095. https://doi.org/10.1021/es102221h

Kangur, A., Jager, W., Verbrugge, R., & Bockarjova, M. (2017). An agent-based model for diffusion of electric vehicles. *Journal of Environmental Psychology*, *52*, 166-182.

Kaya, Y., & Yokobori, K. (1997). *Environment, energy, and economy: strategies for sustainability*. United Nations University Press Tokyo.

Knuth, S. E. (2010). Addressing place in climate change mitigation: Reducing emissions in a suburban landscape [Article]. *Applied Geography*, *30*(4), 518-531. https://doi.org/10.1016/j.apgeog.2010.01.001

Koide, R., Lettenmeier, M., Kojima, S., Toivio, V., Amellina, A., & Akenji, L. (2019). Carbon Footprints and Consumer Lifestyles: An Analysis of Lifestyle Factors and Gap Analysis by Consumer Segment in Japan. *Sustainability*, *11*(21), 5983.

Konno, N., Nonaka, I., & Ogilvy, J. (2014). Scenario planning: the basics. *World Futures*, *70*(1), 28-43.

Krumm, A., Süsser, D., & Blechinger, P. (2022). Modelling social aspects of the energy transition: What is the current representation of social factors in energy models? *Energy*, *239*, 121706.

Lacroix, K., & Richards, G. (2015). An alternative policy evaluation of the British Columbia carbon tax: Broadening the application of Elinor Ostrom's design principles for managing common-pool resources [Article]. *Ecology and Society*, *20*(2). https://doi.org/10.5751/ES-07519-200238

Lettenmeier, M., Koide, R., Toivio, V., Amellina, A., & Akenji, L. (2019). *1.5-Degree Lifestyles: Targets and Options for Reducing Lifestyle Carbon Footprints. Technical Report*.

Li, F. G. N. (2017). Actors behaving badly: Exploring the modelling of non-optimal behaviour in energy transitions [Article]. *Energy Strategy Reviews*, *15*, 57-71. https://doi.org/10.1016/j.esr.2017.01.002

Li, F. G. N., & Strachan, N. (2017). Modelling energy transitions for climate targets under landscape and actor inertia [Article]. *Environmental Innovation and Societal Transitions*, *24*, 106-129. https://doi.org/10.1016/j.eist.2016.08.002

Lin, S. P. (2013). The gap between global issues and personal behaviors: Pro-environmental behaviors of citizens toward climate change in Kaohsiung, Taiwan [Article]. *Mitigation and Adaptation Strategies for Global Change*, *18*(6), 773-783. https://doi.org/10.1007/s11027-012-9387-1

Löschel, A., Sturm, B., & Uehleke, R. (2017). Revealed preferences for voluntary climate change mitigation when the purely individual perspective is relaxed – evidence from a framed field experiment [Article]. *Journal of Behavioral and Experimental Economics*, *67*, 149-160. https://doi.org/10.1016/j.socec.2016.12.007

Mancuso, I., Natalicchio, A., Panniello, U., & Roma, P. (2021). Understanding the purchasing behavior of consumers in response to sustainable marketing practices: An empirical analysis in the food domain. *Sustainability*, *13*(11), 6169.

Manzini, E., & Jégou, F. (2003). Sustainable everyday. *Design Philosophy Papers*, *1*(4).

Mattauch, L., Ridgway, M., & Creutzig, F. (2014). Happy or liberal? Making sense of behavior in transport policy design [Article]. *Transportation Research Part D: Transport and Environment*, *45*, 64-83. https://doi.org/10.1016/j.trd.2015.08.006

McCollum, D. L., Wilson, C., Pettifor, H., Ramea, K., Krey, V., Riahi, K., Bertram, C., Lin, Z., Edelenbosch, O. Y., & Fujisawa, S. (2017). Improving the behavioral realism of global integrated assessment models: An application to consumers' vehicle choices [Article]. *Transportation Research Part D: Transport and Environment*, *55*, 322-342. https://doi.org/10.1016/j.trd.2016.04.003

Minx, J. C., Wiedmann, T., Wood, R., Peters, G. P., Lenzen, M., Owen, A., Scott, K., Barrett, J., Hubacek, K., & Baiocchi, G. (2009). Input–output analysis and carbon footprinting: an overview of applications. *Economic systems research*, *21*(3), 187-216.

Mittal, S., Dai, H., Fujimori, S., Hanaoka, T., & Zhang, R. (2017). Key factors influencing the global passenger transport dynamics using the AIM/transport model. *Transportation Research Part D: Transport and Environment*, *55*, 373-388.

Mont, O., Neuvonen, A., & Lähteenoja, S. (2014). Sustainable lifestyles 2050: Stakeholder visions, emerging practices and future research [Article]. *Journal of Cleaner Production*, *63*, 24-32. https://doi.org/10.1016/j.jclepro.2013.09.007

Moreau, V., Rankovic, A., & Costa, L. (2017). *EU Calculator: trade-offs and pathways towards sustainable and low-carbon European Societies - EUCalc*.

Morris, J., Marzano, M., Dandy, N., & O'Brien, L. (2012). *Theories and models of behaviour and behaviour change*.

Mosler, H.-J., & Martens, T. (2008). Designing environmental campaigns by using agent-based simulations: Strategies for changing environmental attitudes. *Journal of Environmental Management*, *88*(4), 805-816.

Muelder, H., & Filatova, T. (2018). One theory-many formalizations: Testing different code implementations of the theory of planned behaviour in energy agent-based models. *JASSS*.

Nakata, T., Silva, D., & Rodionov, M. (2011). Application of energy system models for designing a low-carbon society. *Progress in Energy and Combustion Science*, *37*(4), 462-502. https://doi.org/10.1016/j.pecs.2010.08.001

Neuvonen, A., Kaskinen, T., Leppänen, J., Lähteenoja, S., Mokka, R., & Ritola, M. (2014). Low-carbon futures and sustainable lifestyles: A backcasting scenario approach [Article]. *Futures*, *58*, 66-76. https://doi.org/10.1016/j.futures.2014.01.004

Nielsen, K. S., Nicholas, K. A., Creutzig, F., Dietz, T., & Stern, P. C. (2021). The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions. *Nature Energy*, *6*(11), 1011-1016. https://doi.org/10.1038/s41560-021-00900-y

Nissinen, A., & 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., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century [Article]. *Global Environmental Change*, *42*, 169-180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

Obradovich, N., & Guenther, S. M. (2016). Collective responsibility amplifies mitigation behaviors [Article]. *Climatic Change*, *137*(1-2), 307-319. https://doi.org/10.1007/s10584-016-1670-9

Ottelin, J., Heinonen, J., Nässén, J., & Junnila, S. (2019). Household carbon footprint patterns by the degree of urbanisation in Europe. *Environmental Research Letters*, *14*(11), 114016.

Pauliuk, S., Arvesen, A., Stadler, K., & Hertwich, E. G. (2017). Industrial ecology in integrated assessment models. *Nature Climate Change*, *7*(1), 13.

Petty, R. E., & Cacioppo, J. T. (1986). The elaboration likelihood model of persuasion. In *Communication and persuasion* (pp. 1-24). Springer.

Pietzcker, R. C., Longden, T., Chen, W., Fu, S., Kriegler, E., Kyle, P., & Luderer, G. (2014). Long-term transport energy demand and climate policy: Alternative visions on transport decarbonization in energy-economy models. *Energy*, *64*, 95-108.

Poortinga, W., Spence, A., Demski, C., & Pidgeon, N. F. (2012). Individual-motivational factors in the acceptability of demand-side and supply-side measures to reduce carbon emissions [Article]. *Energy Policy*, *48*, 812-819. https://doi.org/10.1016/j.enpol.2012.06.029

Quam, V. G. M., Rocklöv, J., Quam, M. B. M., & Lucas, R. A. I. (2017). Assessing greenhouse gas emissions and health co-benefits: A structured review of lifestyle-related climate change mitigation strategies [Review]. *International Journal of Environmental Research and Public Health*, *14*(5), Article 468. https://doi.org/10.3390/ijerph14050468

Quinet, E., & Vickerman, R. (2004). Principles of transport economics. *Books*.

Quist, J., Knot, M., Young, W., Green, K., & Vergragt, P. (2001). Strategies towards sustainable households using stakeholder workshops and scenarios. *International Journal of sustainable development*, *4*(1), 75-89.

Quist, J., & Leising, E. (2016). Green Lifestyles Alternative Models and Up-scaling Regional Sustainability/GLAMURS: Work Package 4 Deliverable 4.3: Report on future lifestyle scenarios and backcasting vision workshops.

Raihani, N., & Aitken, D. (2011). Uncertainty, rationality and cooperation in the context of climate change [Article]. *Climatic Change*, *108*(1), 47-55. https://doi.org/10.1007/s10584-010-0014-4

Ramaswami, A., Bernard, M., Chavez, A., Hillman, T., Whitaker, M., Thomas, G., & Marshall, M. (2012). Quantifying carbon mitigation wedges in U.S. Cities: Near-term strategy analysis and critical review [Review]. *Environmental Science and Technology*, *46*(7), 3629-3642. https://doi.org/10.1021/es203503a

Rogers, E. M. (2010). *Diffusion of innovations*. Simon and Schuster.

Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D., & Garnett, T. (2016). Protein futures for Western Europe: potential land use and climate impacts in 2050. *Regional Environmental Change*, *17*(2), 367-377. https://doi.org/10.1007/s10113-016-1013-4

Rose, S. K., Richels, R., Blanford, G., & Rutherford, T. (2017). The Paris Agreement and next steps in limiting global warming. *Climatic Change*, *142*(1-2), 255-270.

Samadi, S., Gröne, M.-C., Schneidewind, U., Luhmann, H.-J., Venjakob, J., & Best, B. (2017). Sufficiency in energy scenario studies: Taking the potential benefits of lifestyle changes into account. *Technological Forecasting and Social Change*, *124*, 126-134. https://doi.org/10.1016/j.techfore.2016.09.013

Saujot, M., Le Gallic, T., & Waisman, H. (2020). Lifestyle changes in mitigation pathways: policy and scientific insights. *Environmental Research Letters*, *16*(1), 015005.

Scalco, A., Macdiarmid, J. I., Craig, T., Whybrow, S., & Horgan, G. (2019). An agent-based model to simulate meat consumption behaviour of consumers in Britain. *Journal of Artificial Societies and Social Simulation*.

Schanes, K., Giljum, S., & Hertwich, E. (2016). Low carbon lifestyles: A framework to structure consumption strategies and options to reduce carbon footprints [Article]. *Journal of Cleaner Production*, *139*, 1033-1043. https://doi.org/10.1016/j.jclepro.2016.08.154

Scherhorn, G., Reisch, L. A., & Schrödl, S. (1997). Wege zu nachhaltigen Konsummustern: Überblick über den Stand der Forschung und vorrangige Forschungsthemen; Ergebnisbericht über den Expertenworkshop" Wege zu nachhaltigen Konsummustern" des BMBF.

Schipper, L., & Marie-Lilliu, C. (1999). *Transportation and CO2 Emissions: Flexing the Link--a Path for the World Bank*. World Bank, Environment Department.

Schmidt-Scheele, R., Hauser, W., Scheel, O., Minn, F., Becker, L., Buchgeister, J., Hottenroth, H., Junne, T., Lehr, U., & Naegler, T. (2022). Sustainability assessments of energy scenarios: citizens' preferences for and assessments of sustainability indicators. *Energy, Sustainability and Society*, *12*(1), 1-23.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy [Article]. *Technology Analysis and Strategic Management*, *20*(5), 537-554. https://doi.org/10.1080/09537320802292651

Schröder, T., & Wolf, I. (2017). Modeling multi-level mechanisms of environmental attitudes and behaviours: The example of carsharing in Berlin. *Journal of Environmental Psychology*, *52*, 136-148.

Schwartz, P. (2012). *The art of the long view: planning for the future in an uncertain world*. Currency.

Schwenkenbecher, A. (2014). Is there an obligation to reduce one's individual carbon footprint [Article]. *Critical Review of International Social and Political Philosophy*, *17*(2), 168-188. https://doi.org/10.1080/13698230.2012.692984

Seriño, M. N. V. (2017). Is decoupling possible? Association between affluence and household carbon emissions in the Philippines. *Asian Economic Journal*, *31*(2), 165-185.

Small, K. A., Verhoef, E. T., & Lindsey, R. (2007). *The economics of urban transportation*. Routledge.

Sopha, B. M., Klöckner, C. A., & Hertwich, E. G. (2011). Exploring policy options for a transition to sustainable heating system diffusion using an agent-based simulation. *Energy Policy*, *39*(5), 2722-2729.

Sopha, B. M., Klöckner, C. A., & Febrianti, D. (2017). Using agent-based modeling to explore policy options supporting adoption of natural gas vehicles in Indonesia. *Journal of Environmental Psychology*, *52*, 149-165.

Sörlin, S., & Lane, M. (2018). Historicizing climate change—engaging new approaches to climate and history. *Climatic Change*, *151*(1), 1-13.

Stefanelli, A., & Seidl, R. (2017). Opinion communication on contested topics: How empirics and arguments can improve social simulation. *Journal of Artificial Societies and Social Simulation*, *20*(4), 3.

Stehfest, E., Bouwman, L., van Vuuren, D. P., den Elzen, M. G. J., Eickhout, B., & Kabat, P. (2009). Climate benefits of changing diet. *Climatic Change*, *95*(1-2), 83-102. https://doi.org/10.1007/s10584-008-9534-6

Stehfest, E., van Vuuren, D., Kram, T., Bouwman, L., Alkemade, R., Bakkenes, M., Biemans, H., Bouwman, A., den Elzen, M., Janse, J., Lucas, P., van Minnen, J., Muller, C., & Prins, A. G. (2014). *Integrated Assessment of Global Environmental Change with IMAGE 3.0 - Model description and policy implications*. PBL Netherlands Environmental Assessment Agency.

Stern, P. C., Dietz, T., & Kalof, L. (1993). Value Orientations, Gender, and Environmental Concern. *Environment and Behavior*, *25*(5), 322-348. https://doi.org/10.1177/0013916593255002

Stern, P. C., & Wolske, K. S. (2017). Limiting climate change: What's most worth doing? [Review]. *Environmental Research Letters*, *12*(9), Article 091001. https://doi.org/10.1088/1748-9326/aa8467

Sun, J. (1998). Changes in energy consumption and energy intensity: a complete decomposition model. *Energy Economics*, *20*(1), 85-100.

Suski, P., Speck, M., & Liedtke, C. (2021). Promoting sustainable consumption with LCA–A social practice based perspective. *Journal of Cleaner Production*, *283*, 125234.

Thaler, R. H., & Sunstein, C. R. (1999). *Nudge: Improving decisions about health, wealth, and happiness*. HeinOnline.

Truelove, H. B., & Parks, C. (2012). Perceptions of behaviors that cause and mitigate global warming and intentions to perform these behaviors [Article]. *Journal of Environmental Psychology*, *32*(3), 246-259. https://doi.org/10.1016/j.jenvp.2012.04.002

UN. (2015). *The Paris Agreement*. HeinOnline

UNEP. (2011). *Visions for Change: Recommendations for Effective Policies on Sustainable Lifestyles*.

UNEP. (2015). *Sustainable Consumption Guide for Policymakers: Debunking Myths and Outlining Solutions (Asia Edition)*. U. N. E. Programme.

Unilever. (2013). *Inspiring Sustainable Liviing: expert insights into consumer behaviour & Unilever's five levers for change*. Unilever.

Urquhart, N., Powers, S., Wall, Z., Fonzone, A., Ge, J., & Polhill, J. G. (2019). Simulating the actions of commuters using a multi-agent system. *Journal of Artificial Societies and Social Simulation*, *22*(2).

van Beek, L., Hajer, M., Pelzer, P., van Vuuren, D., & Cassen, C. (2020). Anticipating futures through models: the rise of Integrated Assessment Modelling in the climate science-policy interface since 1970. *Global Environmental Change*, *65*, 102191.

van de Ven, D. J., González-Eguino, M., & Arto, I. (2017). The potential of behavioural change for climate change mitigation: a case study for the European Union [Article in Press]. *Mitigation and Adaptation Strategies for Global Change*, 1-34. https://doi.org/10.1007/s11027-017-9763-y

van den Berg, N. J., Hof, A. F., Akenji, L., Edelenbosch, O. Y., van Sluisveld, M. A., Timmer, V. J., & 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., & 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*(1), 015004.

van den Berg, N. J., Hof, A.F., Timmer, V.J., Akenji, L., van Vuuren, D.P. (in review). (Path)ways to sustainable living: the impact of sustainable lifestyles on long-term emission scenarios.

van den Berg, N. J., Thu, L., Hof, A. F., Timmer, T. J., Akenji, L., & van Vuuren, D. P. (in review). A Diversity of Sustainable Lifestyles in 2050: future scenario narratives for climate change mitigation.

van den Berg, N. J., van Soest, H. L., Hof, A. F., den Elzen, M. G., van Vuuren, D. P., Chen, W., Drouet, L., Emmerling, J., Fujimori, S., & Höhne, N. (2019). Implications of various effort-sharing approaches for national carbon budgets and emission pathways. *Climatic Change*, 1-18.

van Sluisveld, M. A. E., Martínez, S. H., Daioglou, V., & van Vuuren, D. P. (2016). Exploring the implications of lifestyle change in 2°C mitigation scenarios using the IMAGE integrated assessment model [Article]. *Technological Forecasting and Social Change*, *102*, 309-319. https://doi.org/10.1016/j.techfore.2015.08.013

van Voorn, G. A., Polhill, J. G., Edmonds, B., & Hofstede, G. J. (2019). Editorial–agent-based modelling for resilience. *Ecological Complexity*.

Van Vuuren, D. P., Stehfest, E., den Elzen, M. G., Kram, T., van Vliet, J., Deetman, S., Isaac, M., Klein Goldewijk, K., Hof, A., & Mendoza Beltran, A. (2011). RCP2. 6: exploring the possibility to keep global mean temperature increase below 2 C. *Climatic change*, *109*(1), 95-116.

van Vuuren, D. P., Stehfest, E., Gernaat, D. E. H. J., van den Berg, M., Bijl, D. L., de Boer, H. S., Daioglou, V., Doelman, J. C., Edelenbosch, O. Y., Harmsen, M., Hof, A. F., & van Sluisveld, M. A. E. (2018). Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies. *Nature Climate Change*, *8*(5), 391-397. https://doi.org/10.1038/s41558-018-0119-8

van Wee, B., Annema, J. A., & Banister, D. (2013). *The transport system and transport policy: an introduction*. Edward Elgar Publishing.

Vergragt, P., Brown, H. S., Timmer, V., Timmer, D., Appleby, D., Pike, C., Eaves, S., McNeill, R., Stutz, J., & Eaves, Z. (2016). *Fostering and Communicating Sustainable Lifestyles: Principles and Emerging Practices*. C. a. I. B. U. E. United Nations Environment Programme - Sustainable Lifestyles.

Vergragt, P. J., Dendler, L., de Jong, M., & Matus, K. (2016). Transitions to sustainable consumption and production in cities [Article]. *Journal of Cleaner Production*, *134*(Part A), 1-12. https://doi.org/10.1016/j.jclepro.2016.05.050

Vita, G., Lundström, J. R., Hertwich, E. G., Quist, J., Ivanova, D., Stadler, K., & Wood, R. (2019). The Environmental Impact of Green Consumption and Sufficiency Lifestyles Scenarios in Europe: Connecting Local Sustainability Visions to Global Consequences. *Ecological Economics*, *164*, 106322.

Volkery, A., & Ribeiro, T. (2009). Scenario planning in public policy: Understanding use, impacts and the role of institutional context factors. *Technological forecasting and social change*, *76*(9), 1198-1207.

Von Borgstede, C., Andersson, M., & Johnsson, F. (2013). Public attitudes to climate change and carbon mitigation-Implications for energy-associated behaviours [Article]. *Energy Policy*, *57*, 182-193. https://doi.org/10.1016/j.enpol.2013.01.051

Wack, P. (1985). Scenarios: uncharted waters ahead. *Harvard business review*, *63*(5), 72-89.

Wade, W. (2012). *Scenario planning: A field guide to the future*. John Wiley & Sons.

Wang, X. (2018). The role of attitudinal motivations and collective efficacy on Chinese consumers' intentions to engage in personal behaviors to mitigate climate change [Article]. *Journal of Social Psychology*, *158*(1), 51-63. https://doi.org/10.1080/00224545.2017.1302401

Webb, J. (2013). Society and a low-carbon future: Individual behaviour change or new social values and priorities? [Article]. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, *103*(2), 157-163. https://doi.org/10.1017/S1755691013000054

Weyant, J. (2017). Some contributions of integrated assessment models of global climate change. *Review of Environmental Economics and Policy*, *11*(1), 115-137.

Wilson, C., Kriegler, E., van Vuuren, D. P., Guivarch, C., Frame, D., Krey, V., Osborn, T. J., Schwanitz, V. J., & Thompson, E. L. (2017). *Evaluating Process-based integrated assessment models of climate change mitigation*. JSTOR.

Yu, B., Wei, Y.-M., Kei, G., & Matsuoka, Y. (2018). Future scenarios for energy consumption and carbon emissions due to demographic transitions in Chinese households. *Nature Energy*, *3*(2), 109-118.

ACKNOWLEDGEMENTS

It was an easy decision to accept this PhD position then titled “Integrated Assessment on Sustainable Behaviour”. I already knew some of the team from my internship at PBL, the topic matched well with my multidisciplinary background, and its relevance made it even more worthwhile. Therefore, I want to thank the IMAGE-SL team (Detlef, Andries, Vanessa and Lewis) and the KR Foundation for setting up this project and constantly inspiring and challenging me throughout. Your insights from different disciplines have shaped my research, career, and personal development in many ways.

Specifically, I would like to express my gratitude to my promotor Detlef van Vuuren, who, despite being generally very busy, always made time for a chat, work-related or not. He has always encouraged me to think big, allowing me to explore this topic while avoiding getting lost in its complexity. You have been a wonderful mentor, and I appreciate your (positive) criticism and compliments. I want to thank one of my co-promotors, Andries Hof, who has supported me endlessly throughout this project. I could always “bug” him with any minor question or update. He has also become a good friend. A big thanks to my other co-promotor, Vanessa Timmer, for opening me up to the field of sustainable lifestyles during many uplifting and fun meetings. Her guidance has helped me navigate the multidisciplinarity of this research. Also, thanks to Lewis Akenji, who has given me invaluable insights and encouragement throughout the project.

To my colleagues and friends in the IMAGE team, thank you for the many stimulating conversations, feedback, and for being a supportive, tight-knit community. Despite several lockdowns, we maintained morale by finding ways to connect, notably my work buddies in The Hague, Giannis, Hsing Hsuan, Isabela and Lotte. Also, thanks to my colleagues at the Copernicus Institute and Urban Futures Studio at the UU, PBL and international partners that have positively influenced this project. Special thanks to the co-authors and friends who contributed to my thesis chapters, Kaj, Lauren, Mariësse, Nicole-Anne, Oreane and Vassilis.

A big thanks to my friends and family(-in-law), especially my mom, who showed me incredible support and love. In addition, I would like to thank my brother, Maurits, and Clinton, for sharing this journey with me. I also want to thank my dad, who consistently made an effort to reach out, visit, and support, despite living far away.

Finally, a huge thanks to my partner, Ward, who has supported me daily and continues to motivate me in my work and life.