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(Path)ways to sustainable living: The impact of the SLIM scenarios on long-term emissions

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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, coined SLIM (Sustainable Living in Models) 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 are more important for enabling lifestyle change in a scenario with than a scenario without strong structural support. With strong structural support, lifestyle changes reduce transport and residential emissions to a larger degree (about 39% for Global North and 27% for Global South overall in 2050 relative to a "Middle-of-the-Road" SSP2 reference scenario in 2050). Thus, lifestyle changes in larger systems change are essential for effective climate change mitigation.

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 for the framing of worldviews

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associated with sustainable transitions and equip policymakers with variables, objects and relations necessary for exerting influence (Beck and Mahony, 2018; Saujot et al., 2020).

Lifestyle analysis can be distinguished in its focus on the intent or impact of the changes (van den Berg et al., 2019). Intent-oriented studies focus more on the motivations of behaviour and lifestyle change, while impact-oriented studies focus more on the outcomes of these changes. In scenario analysis, qualitative scenario narratives are usually more intent-oriented, as they focus on motivations behind behaviour and lifestyle changes in alternative visions about the future (Echegaray, 2021; Green and Vergragt, 2002; Manzini and Jégou, 2003; Mont et al., 2014; Quist et al., 2001; Quist and Leising, 2016; Schmidt-Scheele et al., 2022). For example, they can capture the motivations and influencing factors for lifestyle changes in the sustainable lifestyles research (Akenji and Chen, 2016; Mont et al., 2014; Vita et al., 2019). Quantitative approaches are generally more impact-oriented, focusing more on the impact of different stylised lifestyles or behaviours on emissions or other indicators (Costa et al., 2021; Creutzig et al., 2022; Grubler et al., 2018; Ivanova et al., 2020; van Sluisveld et al., 2016; van Vuuren et al., 2018; Vita et al., 2019). Some of these studies have applied Integrated Assessment Models (IAMs) to analyse the impact of lifestyle change on long-term emissions. For example, (van Sluisveld et al., 2016) and (van Vuuren et al., 2018) analysed the impact of healthy diets, reduced floor space per capita, and a switch to public transit. Furthermore, (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). Even though these studies discuss some underlying narratives (which relate to intent), their primary focus is on the actions and the impacts on emissions. Other studies have analysed regional-specific impacts of lifestyle changes. For example, a recent study by (Hanmer et al., 2022) developed lifestyle change scenarios by downscaling IAM output from the country level and differentiating based on various household archetypes. Another study by (Costa et al., 2021) modelled the potential of behaviour in mobility, diet and housing to contribute to reducing emissions specifically in Europe. A study by (Creutzig et al., 2022) evaluates combinations of demand-side options and well-being outcomes with an impact-oriented approach but with well-being as an indicator. All these quantitative studies showed the potential of behaviour changes for reducing emissions or other indicators, such as improved well-being. Many of the above studies detail some of the motivations for change but lack detailed narratives to explain the underlying logic or motivations of these changes. Instead, lifestyle changes are based on stylised assumptions (e.g. 100 % vegetarian diet in 2050).

This gap can be addressed by combining detailed scenario narratives, which explain motivations of lifestyle changes, with model-based scenarios focused on the outcomes of lifestyle changes. To our knowledge, there is only one study that has yet done so: (Vita et al., 2019) quantified backcasting scenarios (Quist and Leising, 2016) using an Environmentally-Extended Multi-Regional Input-Output (EE-MRIO) model. These scenarios give insights into the motivations for behaviour change by connecting sustainability visions to global consequences. However, as the calculated impacts are static, emission pathways of the visions are not provided. IAMs, in contrast, can provide a more dynamic representation of lifestyle changes for long-term emissions pathways. In combination with informed scenario narratives, IAMs can inform policymakers on alternative futures on why (i.e. intent behind the changes), what (i.e. the changes themselves) and how much it can contribute to climate change mitigation (i.e. the impacts of the 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 barriers and enables are also 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 lifestyle changes 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. Four sustainable lifestyle scenarios, coined Sustainable Living In Models (SLIM) scenarios, were developed in these workshops (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) 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 relevant 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 decompose the emissions caused by 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.

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.

2.1. The scenario development process

In this research, we distinguish between intent and impact orientation when developing the scenario narratives and emission pathways (see Fig. 1). The intent orientation of this research focuses on the motivations behind behaviour and lifestyle changes. This is detailed in the scenario narratives, which provide an excellent way to deal with the

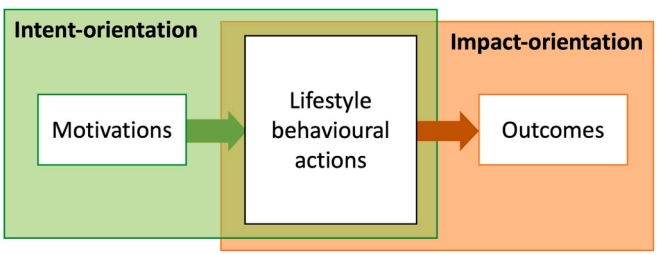

Fig. 1. Intent and impact-orientation in lifestyle and behavioural actions (van den Berg et al., 2019).

more complex aspects of why people would change their behaviours or lifestyles. In an accompanying paper, (van den Berg et al., in review), we describe four scenarios narratives in detail. In this paper, we focus on translating these scenarios' narratives to quantitative emission pathways, focusing on the impacts or outcomes of the behaviour and lifestyle changes. This distinction allows for a holistic approach to modelling lifestyle and behaviour change (van den Berg et al., 2019).

The SLIM scenarios have been developed based on engagements with advisors and policymakers, including expert-attended workshops providing advice and input for elaborating the scenarios by the research team (see Fig. 2 for scenario development process). Scenario planning methods were used to facilitate and engage with advisors and policymakers to develop the scenarios (see specific details in S2). We set up advisor and policymakers engagements in various ways. We convened workshops, smaller group meetings and sent out documents for review by experts ranging from social scientists to modellers (see more detail in Table 1 and anonymous participant details in S1). The advisors and policymakers were selected based on their expertise in sustainable lifestyles, strategic foresight and/or demand-side modelling and regional diversity to ensure a broad range of participants. 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: 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 2.2.1). The advisors could comment, change, and add to 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.

2.2. 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.

2.2.1. Quantitative assumptions of the SLIM 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 advisors 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 S2 and S3, respectively. It should be noted that the list of assumptions sent to the advisors was extensive and that we could not guarantee that all aspects were considered in equal detail. However, the important issues would be noticed by the advisors.

We translated the adoption rates and speed of adoption from the stakeholder engagements (see Table 2) 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 Fig. 3). The earlier the Innovators group reaches saturation, and consequently the other adopter groups, the faster the adoption speed.

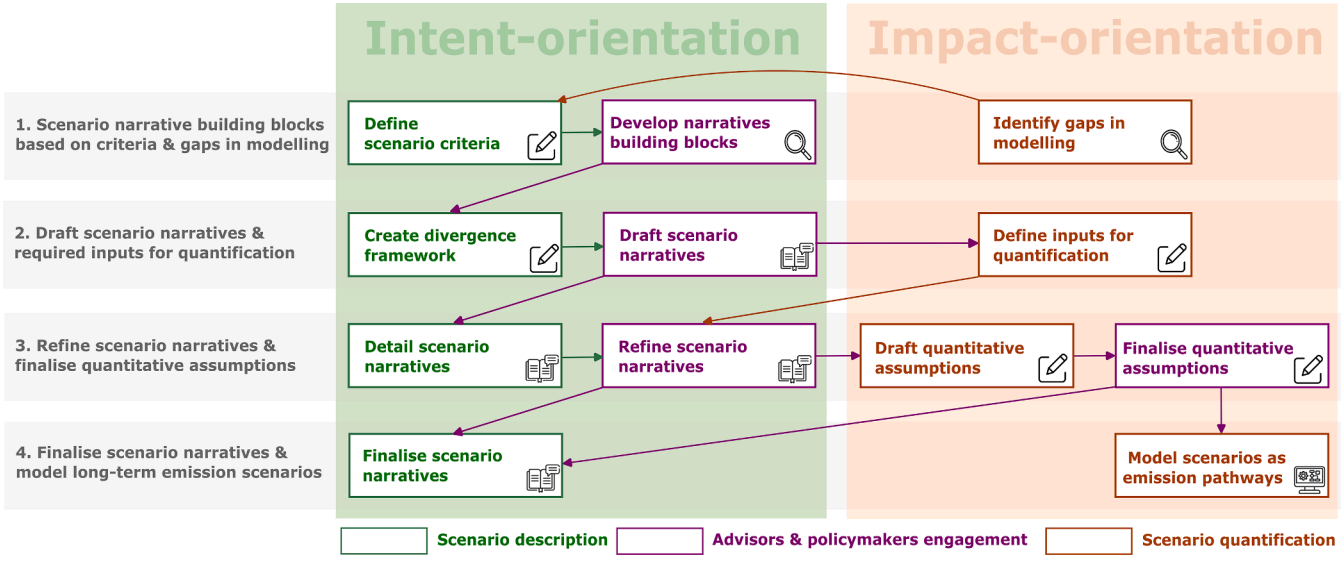

Fig. 2. Scenario development process (adapted from van den Berg et al., in review).

Table 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 h) 04/02/2021 (2 h)	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 the 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 h) 08/04/2021 (3 h)	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 h)	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 h)	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

Table 2
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	Which references substantiate these assumptions?

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 the change happens). We replicate this approach for all behavioural actions modelled in this research.

2.2.2. Scenario modelling using the IMAGE integrated assessment model

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 sub-model, 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 others. In this research, we translate the descriptions of behavioural change adoption over time (see Section 2.2.1) 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 are 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). Preferences account for government policies and consumer preferences and aim to represent factors other than costs important for decision-making (e.g., the 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 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 being accounted for (Daioglou et al., 2012). We explain the specific details of how these sectors are modelled below.

Based on the IMAGE model's relatively detailed TIMER model, notably the transport and residential sector, it can effectively model the behaviour changes of the SLIM scenarios. The transport and residential sectors are described below.

2.2.3. Modelling details of the passenger transport sector

We model the travel behavioural actions of the scenario narratives in TIMER, by adjusting inputs (see Fig. 4) 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. Changes in transport infrastructure, especially relevant for train travel, are not explicitly modelled and are instead represented implicitly

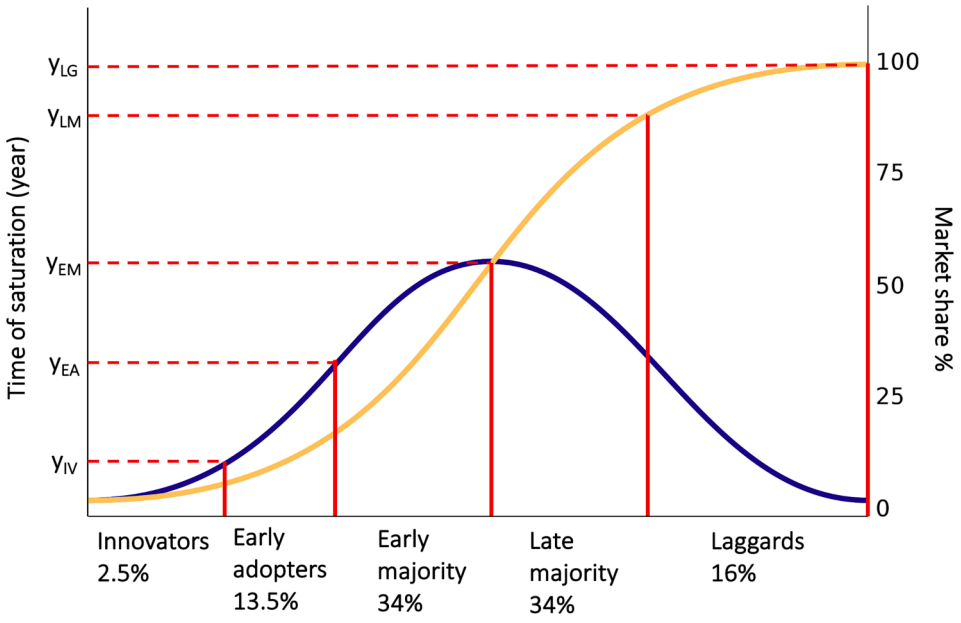

Fig. 3. Adoption speed based on adopter groups from the diffusion of innovation theory: On the x-axis are the adopter groups and their percentage, the cumulative market share on the right y-axis with the time of saturation on the left y-axis indicating adoption speed (adapted from Rogers, 2010).

within mode preferences. This affects the Travel Money Budget (TMB)[1] constraint, which adjusts the travel demand for each mode, and affects the Travel Time Budget (TTB)[2], 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 fleet composition.

2.2.4. *Modelling details of the residential sector*

A similar approach was used for behaviour related to the residential sector (Fig. 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. These drivers affect the demand for energy services: cooking, appliances, space heating and cooling, water heating and lighting (Daioglou et al., 2012).

2.2.5. *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" for comparison (O'Neill et al., 2017) (see Table 3). We chose this reference scenario over the other SSPs, given its central position. Using other SSPs as a reference alternative starting point could also have been an interesting sensitivity analysis, but to compare but would deviate from our main message of focusing on the impact of lifestyle changes. Therefore, we have included the SSP2 reference (without climate policy) and a mitigation pathway (with a carbon price) to reach emissions aligned with a 2 °C and 1.5 °C climate target.

[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

3. SLIM scenarios

In this paper, we model two of the SLIM scenarios, i.e., 'Designed World' and 'Pocket Lifestyles'. We have included the non-modelled SLIM scenario narratives, Global Commons and Big Village, for comparison. Capturing the key characteristics of these latter scenarios in IAMs is more difficult. For example, Global Commons and Big Village's substantial changes in governance to more collectivist values, social cohesion, alternative work patterns, local governance and community activities are more challenging to capture by IAMs focusing on global regions. In the discussion (see Section 5), we elaborate on opportunities to model these other scenarios. Therefore, throughout this research, we focus on Designed World and Pocket Lifestyles but include the larger scenario framework, including Global Commons and Big Village, for reference. Note that the lifestyle changes assumed in the SLIM scenarios interact with climate policy to various extents. Lifestyle measures could be influenced by a carbon tax, for example, a shift towards more public transport. These types of enabling factors are represented in addition to motivations for changes in lifestyles. Vice versa, lifestyle changes could reduce the cost of climate policy.

3.1. *Scenario narrative descriptions*

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.

In Table 4, we introduce the taglines and descriptions of the SLIM scenarios, and in Table 5, 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

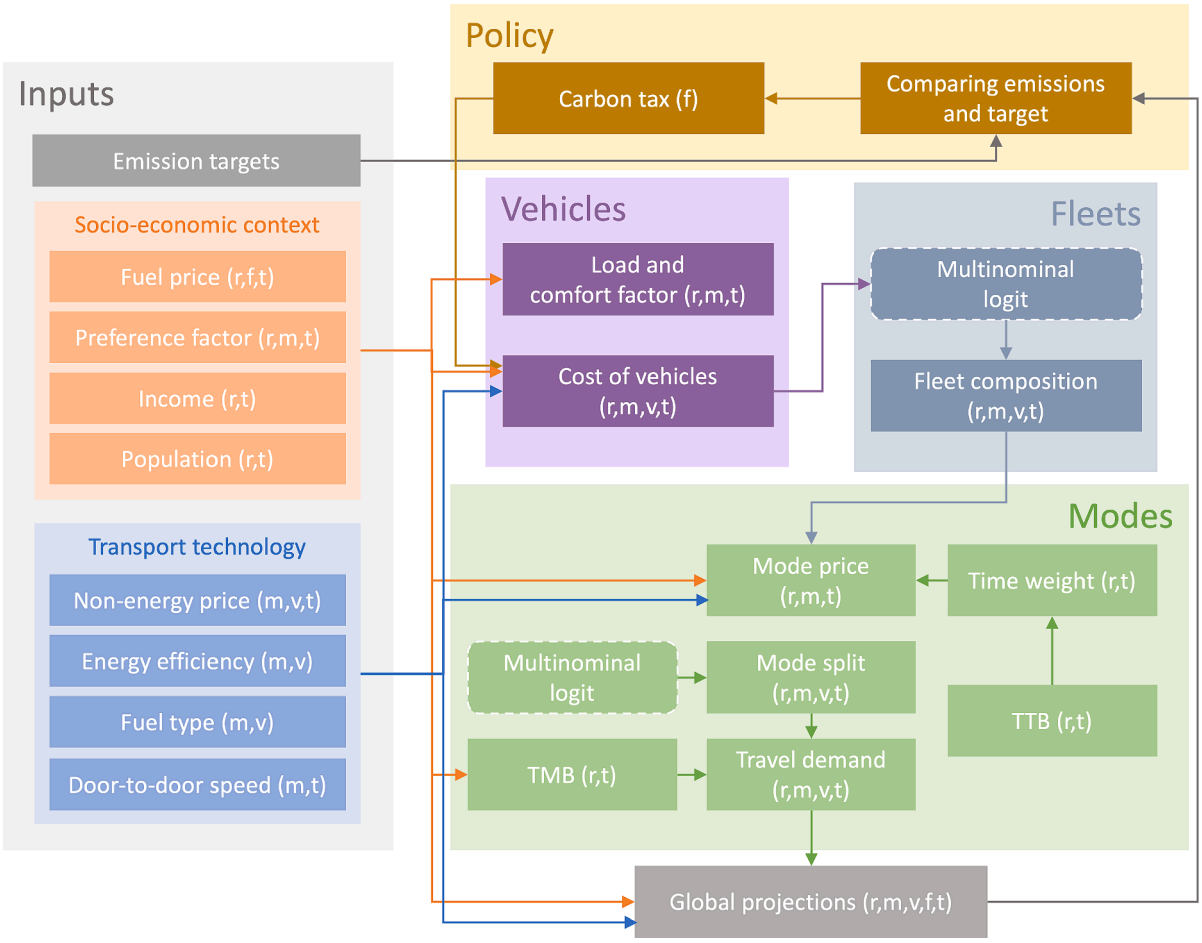

Fig. 4. TRAVEL model in TIMER-IMAGE with factors dependent on region (r), travel mode (m), vehicle type (v), fuel type (f) and time (t) (adapted from Girod et al., 2013).

Designed World. It should be noted that one of the scenarios could be more likely to happen in a particular region than another. When quantifying the assumptions, we account for this by differentiating between Global North and Global South regarding the uptake of lifestyle actions. For example, the adoption of electric vehicles depends heavily on the investment in charging infrastructure, and in Global South regions, this would likely be slower.

In Fig. 6, we illustrate the SLIM scenario framework and detail the relevant aspects of Pocket Lifestyles and Designed World for modelling the scenarios (see the full scenario framework in S5). The framework highlights the different levels of change for each scenario. 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 Fig. 6), 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 measures include heat recovery (e.g. shower heat recovery), adopting heat pumps, insulating homes and installing rooftop solar panels.

The overlapping characteristics (Fig. 6) in Designed World and Pocket Lifestyles 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 Fig. 6), 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.

This section described the SLIM scenario narratives of Pocket Lifestyles and Designed World within the scenario framework (a thorough description of the SLIM scenario narratives can be found in (van den Berg et al., in review)).

3.2. *Scenario quantification and scenario inputs*

In this section, we specify the scenario narratives descriptions and scenario framework for scenario quantification to translate the scenario narratives to scenario inputs. The outcomes of developing explicit descriptions of behaviour changes (see stages 3 and 4 in Section 2.1, 'Feedback review' in Table 1, and methodological details in Section

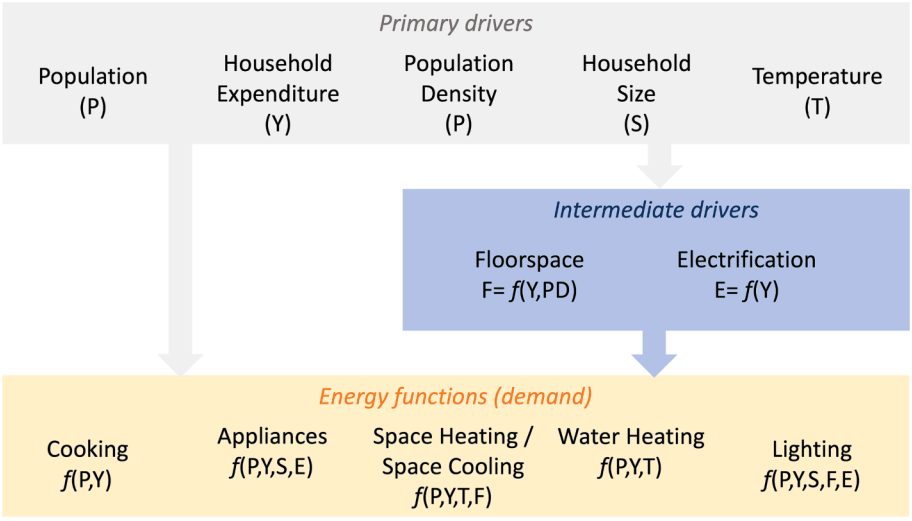

Fig. 5. Relationship between residential energy functions and drivers (adapted from Daioglou et al., 2012).

Table 3
Reference scenario descriptions.

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 Reference (Mitigation 2 °C and 1.5 °C)	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.

2.2.1) are summarised in Table 6, Table 7 and Table 8. These are shown per domain, categorised as 'cross-cutting', 'passenger transport', and 'residential' actions.

Since lifestyle changes happen across domains and not within, we identify the cross-cutting actions (see Table 6) that could influence the behavioural actions within the domains (see passenger transport in Table 7 and residential in Table 8).

For the cross-cutting actions in Designed World, money is invested in low-carbon solutions and innovations, such as 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 7 and Table 8 show the motivations and the contextual factors affecting them, the different adoption rates for Global North and Global South reached by

Table 4
The SLIM scenarios' detailed information (the text of the modelled scenarios are in black and non-modelled scenarios in grey).

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.
Scenario **Pocket Lifestyles**	Tagline: peer-to-peer lifestyle platforms People take it upon themselves to adopt and rapidly spread ambitious sustainable lifestyles, behaviours and practices through 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.
Scenario **Global Commons**	Tagline: inclusive global governance system 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.
Scenario **Big Village**	Tagline: community-based sustainable living People band together in communities regionally while remaining networked globally to support bottom-up innovation, shared infrastructures, and belonging.

Table 5
SLIM scenario characteristics (the modelled scenarios are in black and non-modelled scenarios in grey).

Scenarios / Characteristics	Tech-innovation	Pocket Lifestyles	Designed World	Global Commons	Big Village
Individual agency	Low	High	Low	Medium	High
Technology support for lifestyle change	Digitally enhanced	Digitally enhanced	Digitally enhanced	Digital, low-tech	Low-tech
Pace of life	Fast pace	Fast pace	Fast pace	Medium pace	Slower pace
Inclusive access / social equity	Low	Low	Medium	High	Medium
Security and safety	Low	Medium	High	High	Medium
Public / Private / Community	Private	Market / Private	Public-Private & City	More public	Medium
Transition speed	Slow	Fast	Slow-medium	Medium	Medium-fast
Uptake of lifestyle actions	Low	Low-medium	High	Medium-high	Low-medium

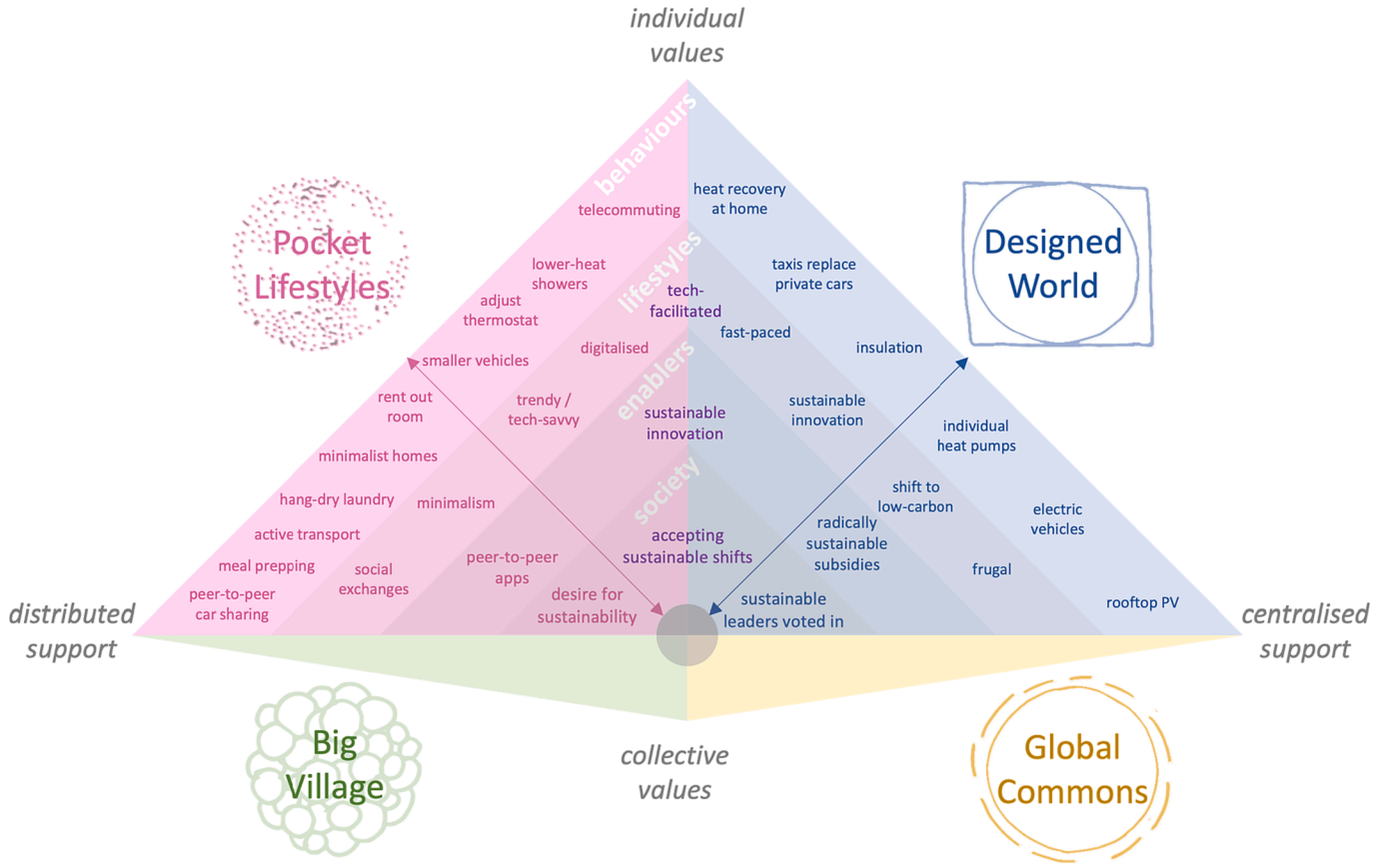

Fig. 6. SLIM Scenarios: Pocket Lifestyles and Designed World in context of Big Village and Global Commons.

2050 for each action, and the transition speed. In S4, 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 tele-commuting innovation. We assume a medium adoption rate for Global

Table 6
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 7
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 8
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
	Heat pumps			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

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. An indirect effect of car sharing is that the ownership of personal vehicles is significantly reduced, and other public transport modes (e.g. buses and trains) are utilised more frequently. 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.

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.

4.1. Scenario emissions pathways in the context of climate targets

Fig. 7 shows per capita emission pathways for reference, mitigation and lifestyle scenarios (see S5 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. Fig. 8 shows these values, with transport and residential emissions combined, as relative changes between 2015 and 2050 for Global North (left) and Global South (right).

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 reference, 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 °C 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

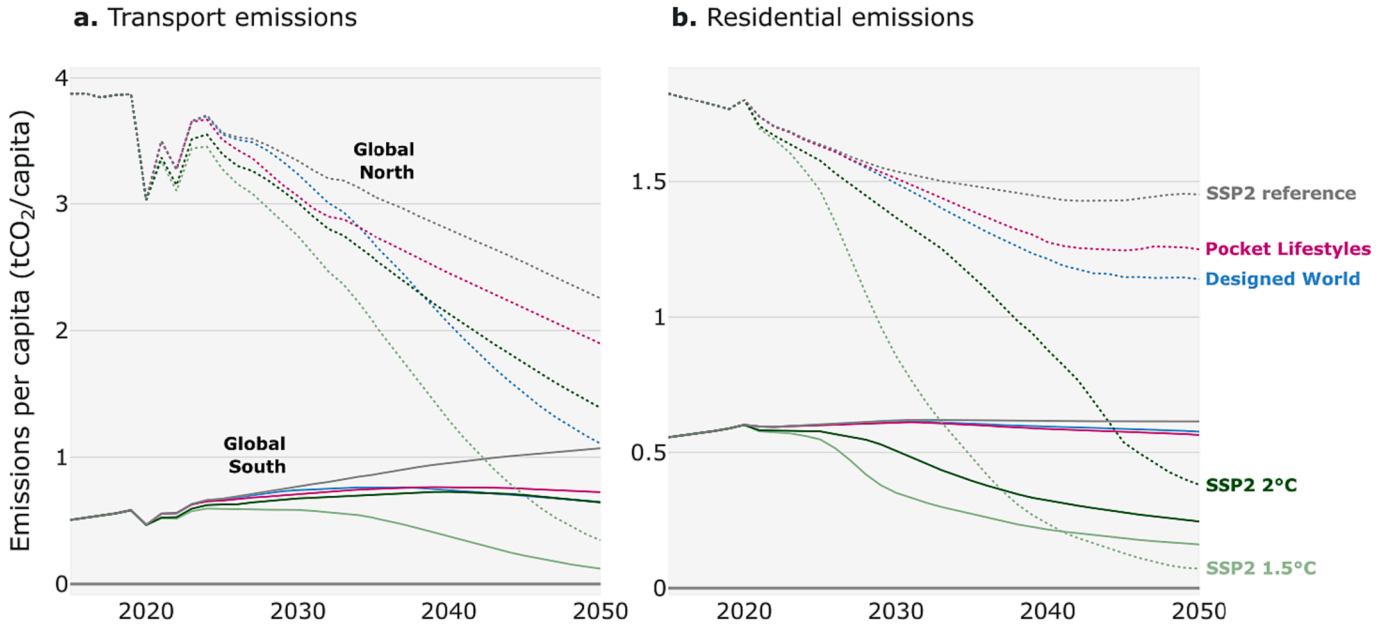

Fig. 7. Long-term scenarios between different regions Global North and Global South (shown by dashed and solid lines, respectively) on transport (a) and residential per capita emissions (b). The scenarios include SSP2 scenarios without (see SSP2 reference in dark grey) and with a carbon price to reach climate targets (see SSP2 2 °C and SSP2 1.5 °C), and the lifestyle scenarios Designed World (in blue) and Pocket Lifestyles (in pink). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

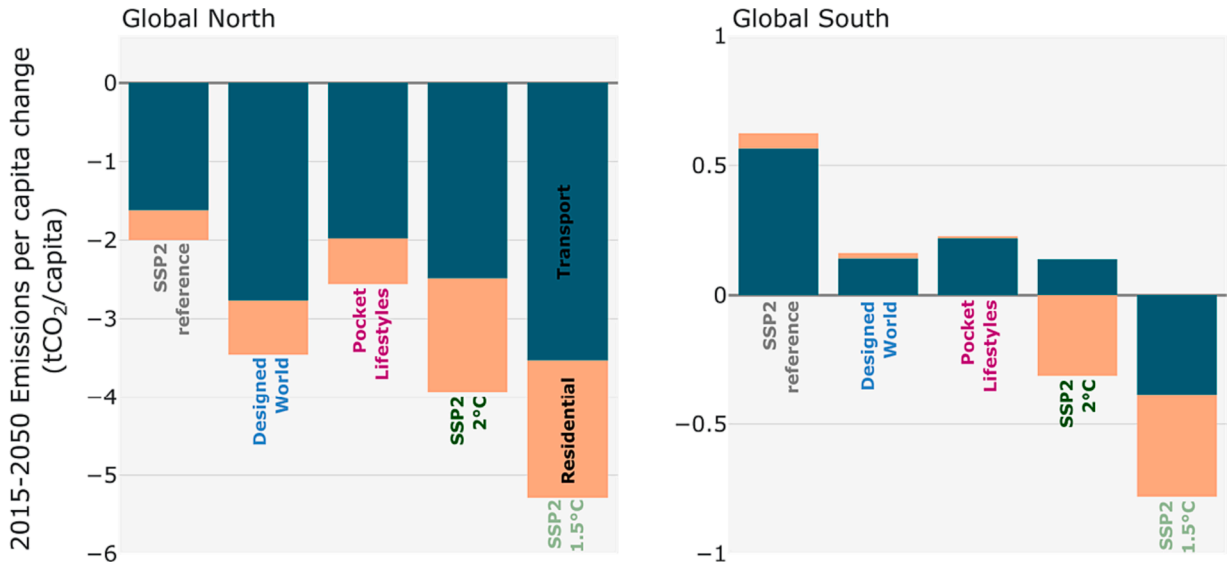

Fig. 8. Change in emissions from 2015 to 2050 per scenario, separated as transport (green) and residential (orange) for Global North (left) and Global South (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

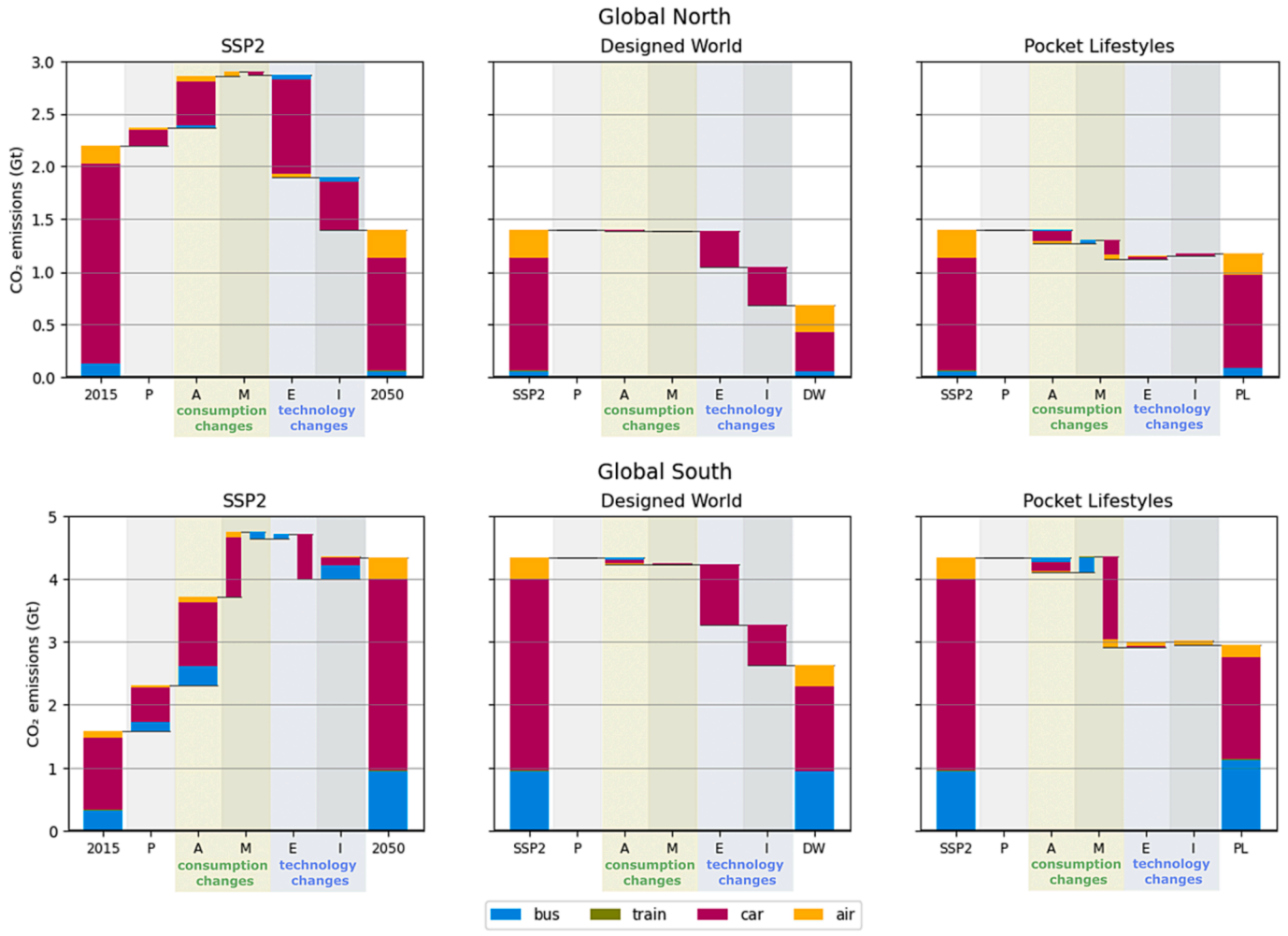

Fig. 9. Passenger transport decomposition results of the reference scenario SSP2 and the lifestyle scenarios, Designed World and Pocket Lifestyles. The different colours represent the different transport modes. The waterfall charts depict the change in emissions from various factors, population (P), activity (A), mode structure (M), efficiency (E) and CO2 intensity (I).

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 better understand the drivers of the substantial differences in emissions between the lifestyle scenarios and between the Global North and the Global South.

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 Fig. 9 and Fig. 10 and Tables in S7.1–7.4). 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 I 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.

4.2.1. Passenger transport

While total passenger transport emissions in the Global North decrease by 36 % in SSP2 reference scenario from 2015 to 2050 (2.2–1.4 $GtCO_2$), they increase by 175 % in the Global South in the same scenario (1.6–4.3 $GtCO_2$) (see Fig. 9). 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. In Global South regions, activity increases substantially, and people shift from bus transport to less sustainable car transport, explained by increasing per-capita income levels in emerging economies. The improvement in efficiency only partially offsets this increase.

The lifestyle measures in Designed World compared to the SSP2 reference in 2050 (see Table 7) 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 (see Fig. 9). The emission reductions are almost entirely caused by efficiency improvements (24 % in Global North and 22 % in Global South) and CO_2 intensity improvements (26 % in Global North and 15 % in Global South), notably through the increased use of electric vehicles (refer to Tables S7.1 and S7.2).

The lifestyle changes in Pocket Lifestyles (see Table 7) 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, compared to the SSP2 reference scenario in 2050. In contrast to Designed World, lower emissions 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 % in Global South) (see Fig. 9 and Tables S7.1 and S7.2).

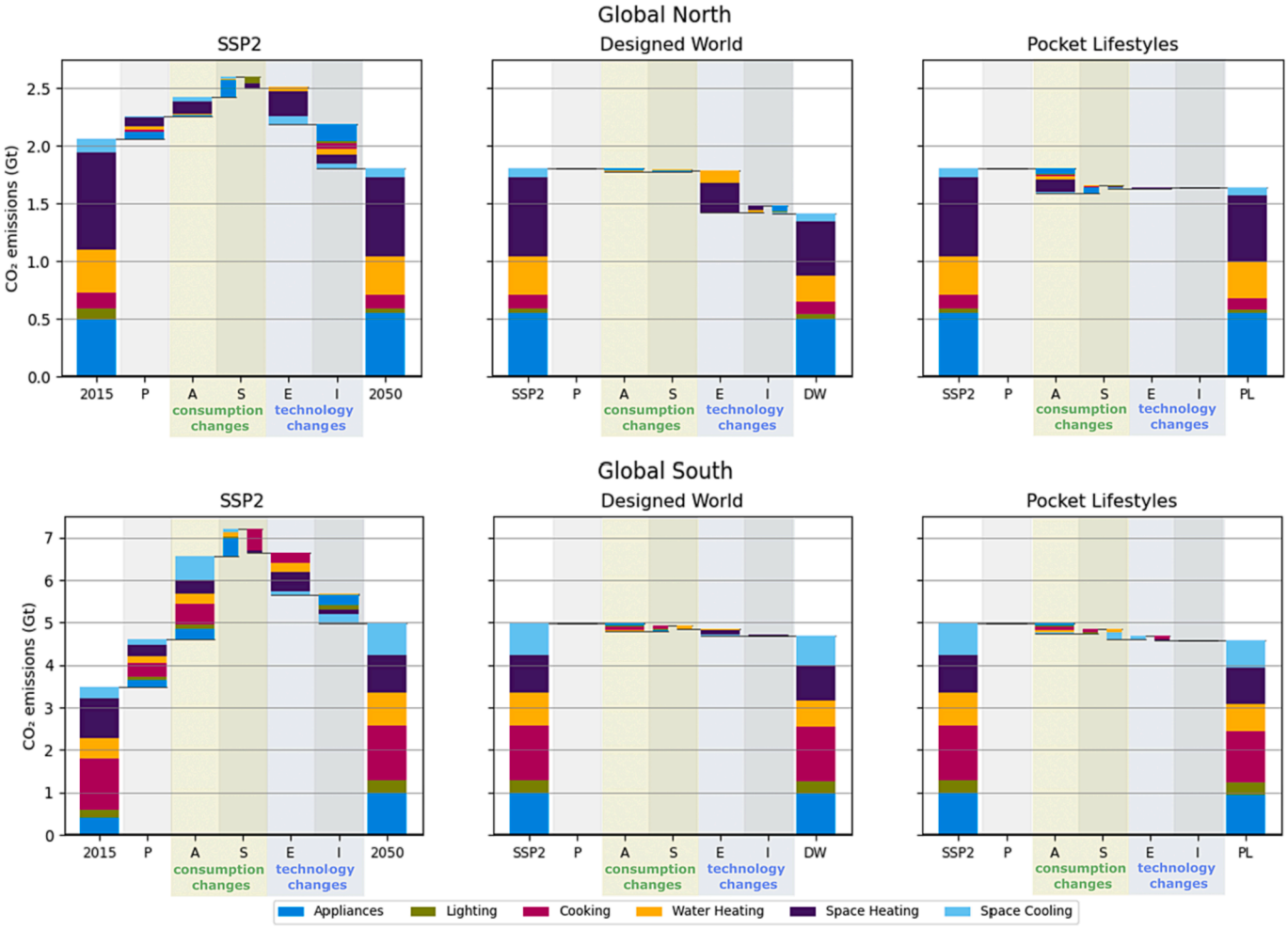

Fig. 10. Residential decomposition results of the reference scenario SSP2 and the lifestyle scenarios: Designed World and Pocket Lifestyles. The different colours represent the energy services that make up the residential sector. The waterfall charts depict the change in emissions from various factors, population (P), activity (A), service (S), efficiency (E) and CO_2 intensity (I).

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. As charging infrastructure is essential for widespread EV driving, it is realistic to assume that infrastructural changes might be costly and, thus, slower to develop in the Global South. 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 (in Global South) and the USA (in Global North) differs substantially, so the change assumptions depend on the existing modal split.

4.2.2. Residential

In the SSP2 reference scenario, from 2015 to 2050, total residential emissions would decrease by 13 % in Global North (2.07 to 1.81 $GtCO_2$), less substantial than the decrease in transport emissions (see Fig. 10). 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 Fig. 10). 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 for Global North would lead to 21 % (0.39 Gt CO_2) lower emissions compared to the SSP2 reference scenario in 2050 and 6 % (0.31 Gt CO_2) for Global South (see Fig. 10). In Global North, most emission reductions result from efficiency improvements (20 % out of the 21 %) (especially from the switch to heat pumps in space heating). In Global South, emissions reduction is mainly due to decreased activity (4 % out of the 6 %), notably from appliances and cooking. Reductions from efficiency improvements are also noteworthy, particularly from heat pumps and insulation affecting space heating and electrification in space cooling (refer to Tables S7.3 and S7.4).

The lifestyle changes in Pocket Lifestyles lower 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 scenario in 2050 (see Fig. 10). In Global North, a notable effect on emissions is a reduction of per-capita floor space (net 12 % out of the 9 %), mainly affecting emissions from space heating. In Global South, the reductions in emissions are mainly caused by a decrease in activity (5 % out of 8 %) and service changes (3 % out of 8 %) (refer to Tables S7.3 and S7.4).

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.

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. Most notably, this is due to the fewer efficiency improvements and shifts to sustainable fuels, and fewer people travelling by public transport in Pocket Lifestyles. 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 Behaviour Change scenario and the 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 and assumption 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 S3). 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. Furthermore, the representation of transport infrastructure of travel modes is not explicit (as mentioned in Section 2.2.3), so the assumptions had to be made through mode preferences. 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. Furthermore, in some instances, we had to make some strong assumptions (see S2, S3 and S4). For example, we only distinguished Global North and Global South in the SLIM scenarios. Even though these are applied to the 26 IMAGE regions and account for differences in regional contexts (e.g. preferences, infrastructure), more detailed regional differences in the types of changes could improve the SLIM scenarios. The assumptions could be improved with more access to elaborate data sources and expertise. Even though we received significant feedback from advisors, it should be noted that it was an extensive list of assumptions that required comprehensive reviewing, and it is quite possible that advisors will have missed some aspects.

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) 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 3, 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 in future work to model these scenarios in IMAGE. There are vast opportunities to represent more transformative value shifts to collective values, such as those in Global Commons and Big Village. The fundamental societal shift towards a less market-based and more collective social structure implied in the Global Commons and Big Village scenarios is less easily represented. In principle, underlying assumptions in IMAGE around cost-effectiveness can be overruled to represent more heterogenous decision-making. However, the overall dynamics in the scenario are likely to be very different from scenarios currently explored – also for topics not directly represented in IAMs. For instance, the scenarios have important implications for the role of governments and their income. More fundamental exploration using a diverse set of tools to explore futures is therefore needed. We would strongly encourage future work on this.

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.

This scenario development approach aims to help inform policy by illustrating both a future narrative and the outcomes of these futures. By developing the scenario narratives, we can inform policymakers about various lifestyle changes and associated interventions under different contexts. By also quantifying these futures in terms of emission pathways, policymakers are also informed about the impacts of those lifestyle changes and the contribution to climate change mitigation. Therefore, the holistic approach allows for understanding how lifestyles can change *and* the extent to which it helps us reach our climate targets.

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. 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 various groups (i.e. different incomes, rural or urban households) were also 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.

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 emissions are reduced more strongly in Designed World 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 how quickly varies 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 °C 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 fewer systems changes 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.

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 almost entirely achieved through lifestyle changes related to efficiency and CO_2 intensity improvements. For Global North, these improvements contribute to transport emission reductions of 50 % (out of 51 % total) and for residential, 20 % (out of 21 % total), relative to the emissions of the SSP2 reference scenario in 2050. For Global South, the improvements would lead to 37 % emission reduction (out of 40 % total) for transport and 3 % (out of 6 % total) for residential. In Pocket Lifestyles, consumption changes (i.e. less and shifts in activity) would play a major role. For Global North, these consumption changes would result in emission reductions for transport of 16 % (out of 12 % net total) and for residential of 10 % (out of 9 % net total) compared to the SSP2 reference scenario in 2050. Global South's consumption changes would lead to 27 % (out of 27 % total) and 8 % (out of 8 % total) emission reduction compared to the SSP2 reference scenario in 2050. 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.

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.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2023.102774.

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