September 2020

Original submission

Global Scenarios of resource and emissions savings from systemic material efficiency in buildings and cars

Supplementary material 1

[author info omitted for peer review]

1. Additional information: introduction and method

Introduction: the share of passenger vehicles and residential buildings in total final energy consumption was determined as follows:

For passenger vehicles: Directly from IEA statistics: https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20consumption&indicator=Share%20of%20total%20final%20consumption%20(TFC)%20by%20sector queried on September 15, 2020.

> "Explore energy data by category, indicator, country or region": Energy topic: Energy consumption. Indicator: Share of total final consumption (TFC) by sector. Region: world. Sector: Transport: Time: 2018, Value: **29%**
>
> Share of passenger vehicles' energy consumption in total Energy consumption by transport sector, 2012: **61%.**

https://www.eia.gov/outlooks/ieo/pdf/transportation.pdf U.S. Energy Information Administration | International Energy Outlook 2016, Chapter 8: Transportation sector energy consumption, p 126. Multiplying the tow value gives 17,69%, which is reported as 18% in the paper.

For residential buildings: Directly from IEA statistics: https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20consumption&indicator=Share%20of%20total%20final%20consumption%20(TFC)%20by%20sector queried on September 15, 2020.

> "Explore energy data by category, indicator, country or region": Energy topic: Energy consumption. Indicator: Share of total final consumption (TFC) by sector. Region: world. Sector: Residential: Time: 2018, Value: **21%**

Method: Gross domestic product (GDP) was deliberately not chosen as scenario driver nor model input to enable a high-resolution service-level framework that can be used to depict future low carbon lifestyles instead of aggregate demand modelling (e.g. modeling useful energy demand as aggregated function of GDP), for which there is little evidence for decoupling (Haberl et al. 2020).

Only in rare cases where there is a long enough time series, GDP-based extrapolations for the building stock were used for determining future service level in the SSP2 scenario. This approach was used for the USA and Japan.

2. Scenario and model framework

Services are linked to material cycles via the stock-flow-service nexus (Haberl et al. 2017) (Fig. SI1-1). The scheme starts with the energy service cascade to relate values to services to functions to products (and their operation) (Kalt et al. 2019), stock-driven modelling to translate product in-use stock demand into production of new and recycling of old products (Müller 2006), new and old products to material flows via dynamic material flow analysis (MFA) (Brunner and Rechberger 2016), and the material flows to the energy demand and related GHG emissions via environmental extensions as done in previous work (Milford et al. 2013; Modaresi et al. 2014).

Fig. SI1-1 (next page): Calculation scheme for the use phase (here shown as 'product stocks'). Stock levels are determined from historic stocks and scenarios following different storylines. The stock-driven model then determines the age-cohort decomposition of the in-use stock as well as product inflows and outflows and the associated material content. With the total stock broken down into different age-cohorts by the stock-driven model, the function and energy flows of the use phase can then be determined (cf. below) by applying the following parameters in turn: intensity of operation and intensity of use (for service flows) and energy intensity and energy carrier split (for energy use of the use phase). The indices are as follows (cf. RECC config table and RECC index table): t: time, c: age-cohort, r: region, g: good/commodity/product, S: scenario (SSP, RCP, and/or RE), V: service category, n: energy carrier, t_0: starting time of prospective assessment (2015).The red section of this figure is our interpretation and implementation of the energy service cascade (Kalt et al. 2019).

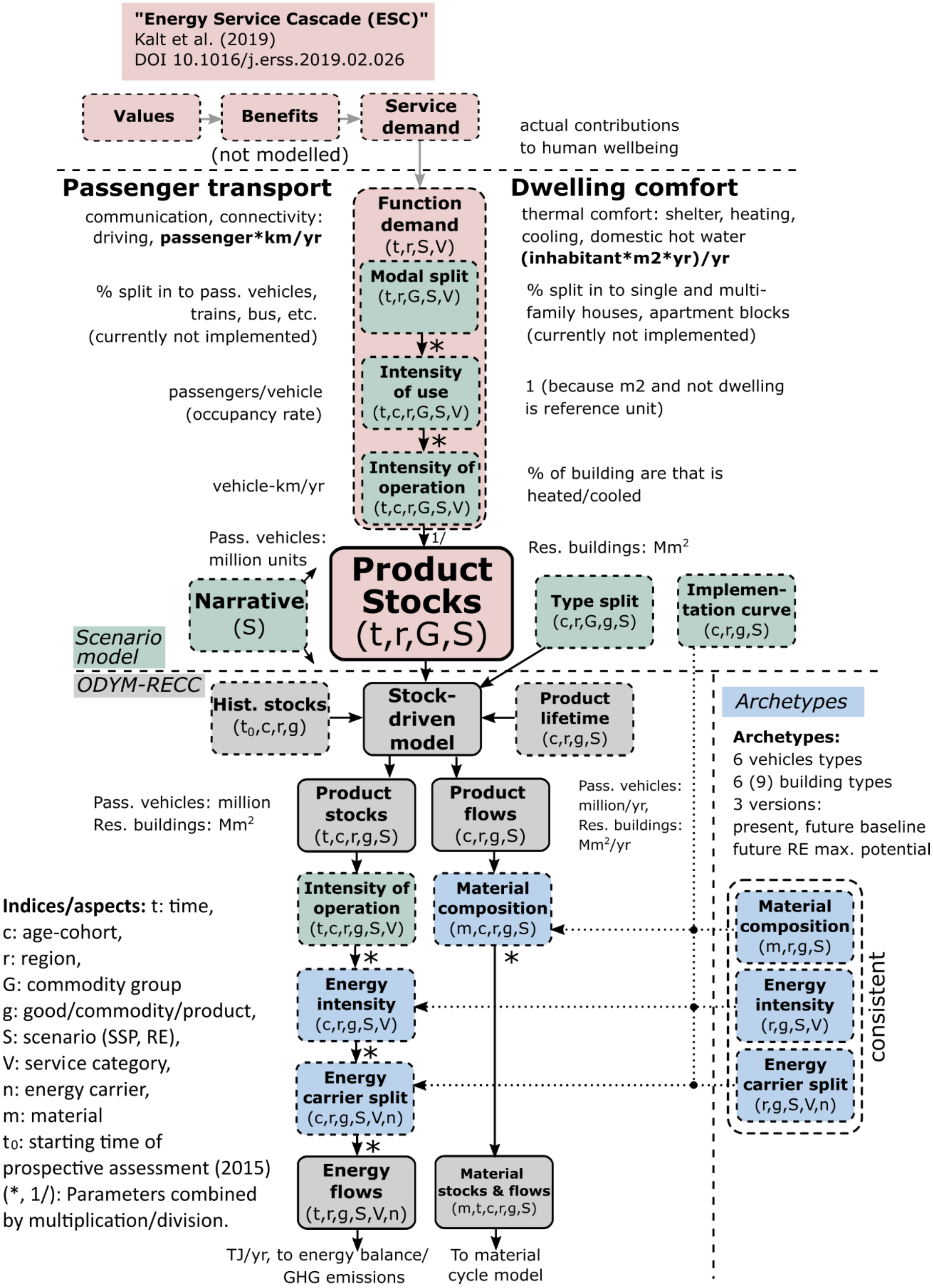


Fig. SI1-1: Implementation of the energy service cascade and the material cycle model.

2.1. ODYM-RECC model

The ODYM-RECC model (open dynamic material systems model for the resource efficiency and climate change mitigation project) is a modular depiction of major end-use sectors and the material cycles for the climate-relevant bulk materials (Pauliuk and Heeren 2020) (https://github.com/YaleCIE/RECC-ODYM). Its system definition [Fig. SI1-2] comprises the use phase of materials (in products) and the material cycle stages mining, primary production, manufacturing, waste management and scrap recovery, and remelting/recycling as well as an energy supply scenario.

ODYM-RECC generates a set of what-if scenarios (Börjeson et al. 2006) for the climate-relevant end-use sectors and bulk material cycles against different socioeconomic, technology deployment, and climate policy backgrounds. It does so by applying a mass-balanced framework for the material cycles (Brunner and Rechberger 2016). It allows us to study the impacts of a broad spectrum of sustainable development strategies on the material cycles and identify trade-offs and constraints. It does not assess the likelihood of realisation of any of the scenarios studied but checks if mass balance constraints (e.g. by long product lifetimes or limited scrap supply) render some scenarios unfeasible from a material cycle point of view.

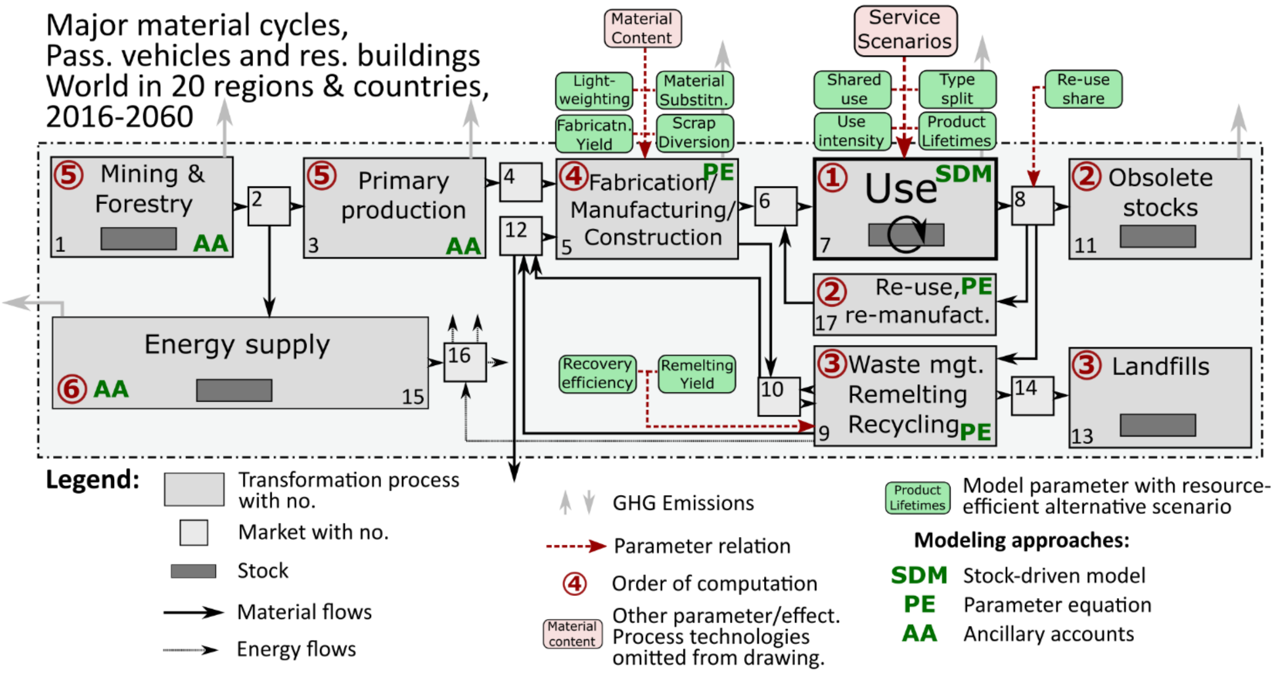


Fig. SI1-2: ODYM-RECC v2.4 system definition

ODYM-RECC is a multi-layer model depicting products, materials, chemical elements, energy flows, and emissions, with mass balance across all processes down to the individual chemical element. ODYM-RECC has six modules that quantify the system in Fig. 0.1 by translating a given service scenario into product stocks, inflows and outflows (module 'use phase UP', using stock-driven modelling (Müller 2006), product outflows into scrap and recycled materials (module 'waste management and recycling WR', using parameter equations), product inflows into material demand and fabrication scrap (module ‘manufacturing MF’ using parameter equations), material demand into primary production and related impacts (module ‘primary production PP’, using environmental extension factors), and by determining the chemical element composition of al stocks and flows (module ‘material-element composition ME’, using mass balance). Finally, the energy consumption and environmental pressure and impact indicators are calculated (module ‘energy and extensions EX’).

For the RECC project, 35 data aspects (time, age-cohort, process, material, chemical element, waste/scrap, environmental extension, socioeconomic scenario…) were defined and each of the 104 model parameters has a specific data model that links it to the data aspects. For example, the parameter for the product lifetime extension potential has the three aspects ‘product’, ‘region’, and ‘scenario. The parameter for the future stock levels needed has the four aspects ‘scenario’, ‘product’, ‘region’, and ‘time’. The resolution of each data aspect is defined in the model configuration file, a summary is given in Table SI1-1.

Table SI1-1: ODYM-RECC model and data resolution.

Model and data aspect	**Resolution**
Time	2016-2060 in steps of 1 year
Age-cohorts/Vintages	Vehicles: 1980-2060, residential and non-residential buildings: 1900-2060, appliances: 1971-2060, industry (electricity generation assets): 1986-2060.
Regions	For passenger vehicles and residential buildings: 20 countries and world regions, covering the entire world. For non-residential buildings and appliances: one aggregate global region. For industrial assets (electricity generation): 11 world regions.
Products	6 passenger vehicle types, 13 residential building types, 4 non-residential building types, 18 electricity generation technologies, and 12 types of appliances.
Engineering materials	construction grade steel, automotive steel, stainless steel, cast iron, wrought Al, cast Al, copper electric grade, plastics, wood and wood products, zinc, concrete
Waste and scrap types	heavy melt, plate, and structural steel scrap; steel shred; Al extrusion scrap, auto rims, clean; Al old sheet and construction waste; Al old cast; copper wire scrap; construction waste, concrete, bricks, tiles, ceramics
Chemical elements	C, Al, Cr, Fe, Cu, Zn, ‘other’
Energy carriers	Electricity, coal, hard coal, diesel, gasoline, natural gas, hydrogen, fuel wood
Service categories	Driving (vehicles), heating, cooling, domestic hot water (residential and non-residential buildings)
Scenarios	Socioeconomic: Low energy demand (LED), SSP1, SSP2 Climate policy: No policy after 2020 (reference scenario), 2 degrees Celsius (66%), corresponding to RCP2.6 forcing pathway.

The model parameters are linked to the system variables (stocks and flows shown in Fig. 0.1) via the model equations, which are grouped into the five ODYM-RECC modules. The parameters are divided into three groups: socioeconomic parameters such as future population, service demand, or intensity of operation of stocks (e.g. vehicle-km per year), technology parameters like energy efficiency of stock operation of the future emissions intensity of energy supply, and resource efficiency parameters describing both the potential for resource efficiency at the different stages of the system (green boxes in Fig. 0.1), and the speed of implementation of these potentials under different socioeconomic and climate policy scenarios.

Each RE strategy can be implemented separately or as part of a cascade of strategies. The model allows for calculating the impact of one strategy at a time (sensitivity analysis) or a bundle of strategies in different orders of implementation, each for different socioeconomic and climate policy scenarios.

Once the first results are mature the model and the corresponding database (barring confidential data) will be released under a permissive license on https://github.com/YaleCIE/RECC-ODYM and on Zenodo:

RECC Global input database: [to be inserted for final publication], DOI [to be inserted for final publication]

RECC Global results: [to be inserted for final publication], DOI [to be inserted for final publication]

2.2. The ODYM-RECC Database

The ODYM-RECC v2.4 database contains 104 model parameters of two to six dimensions each. Parameters range from static values (direct emissions of combustion by MJ of energy carrier) to highly detailed highly uncertain datasets (e.g., the future energy carrier split of buildings by region, time, and operation mode (heating/cooling/hot water).

The ODYM-RECC database was compiled as a community effort involving a large number of experts. Its scope is unprecedented in the industrial ecology community. Data templates and project wide classifications were used to facilitate the compilation of the various types of information.

Depending on data availability, we applied several pathways of data compilation, which are listed and described in detail below.

- Extract mostly socioeconomic parameters from existing scenario models (scenario reference)
- Compile own plausible scenario estimates for socioeconomic parameters in line with the different scenario narratives where established model framework results are not available (group consensus scenarios)
- Extract process-, product, and material-specific data from the engineering and industrial ecology literature (bottom-up data)

- Extract quantitative estimates of resource efficiency strategy potentials, mostly related to prototypes and case studies, from the literature (strategy potentials)
- Simulate energy consumption and material composition of a number of building and vehicle archetypes with specialised software, which are then used as bottom-up product descriptions with and without implementation of RE strategies (archetype descriptions)

2.3. Scenario reference

For the socioeconomic parameters the Shared Socioeconomic Pathways (SSP) database and model results as well as available data from the World Energy Outlook and Energy Technology Perspectives models were used wherever possible, e.g., for future population, future GHG intensity of energy supply, or the drive technology mix for vehicles (Riahi et al. 2017; O'Neill et al. 2014; OECD/IEA 2010a; IEA 2015; OECD/IEA 2017). The data were extracted from available databases (like the SSP scenario database hosted at IIASA: https://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/SSP_Scenario_Database.html) or shared by colleagues, then parsed and reviewed by the RECC team, then aggregated, disaggregated, and interpolated to fit the ODYM-RECC project-wide classification. For each parameter file the data gathering process is documented both in the respective template files in the RECC database (if only Excel was used), in custom scripts (for more comprehensive datasets) and in the data log files archived under https://github.com/YaleCIE/RECC-data.

Group consensus scenarios: For some parameters like the future stock levels or the split of residential buildings into different types no detailed SSP-consistent scenario calculation was available that we could refer to. Hence we assumed a set of plausible target values for a number of socioeconomic parameters in line with the storylines of the individual socioeconomic scenarios. This process is commonly used when translating broad storylines into high product and regional resolution and sector-specific parameters, cf. Riahi et al. (2017) and Grübler et al. (2018). The target values for 2020, 2030, 2040, 2050, and 2060 chosen and the rationale for their choice are documented in scenario target tables, one for each parameter. From there, the target values are read, interpolated, smoothed with a moving average, and exported in ODYM format to be directly used in the ODYM-RECC model. The documentation for the individual parameters is archived in https://github.com/YaleCIE/RECC-data.

The open model and data framework allow for third parties to modify the scenario assumptions and to run calculations with custom parameters and storylines.

Bottom-up data: For the energy intensity, emissions intensity, and material composition of products and processes detailed but representative product or process descriptions were compiled from the literature and available databases. These data include the material composition and specific energy consumption of vehicles and buildings, e.g., (Hawkins et al. 2013; Reyna and Chester 2014; Marcellus-Zamora et al. 2016), the loss and recovery rates for the manufacturing and waste management industries e.g., (Pauliuk et al. 2013; Liu et al. 2012), and the specific energy consumption and process emissions for the manufacturing, waste management, and primary material production industries (Wernet et al. 2016; OECD/IEA 2010b; IEA 2015; OECD/IEA 2017). While the data can be regarded as representative of current average global technology, their main limitation is that they are static and no information on their change under different socioeconomic and climate policy scenarios, in particular, is given. To become more realistic a scenario reference was made wherever possible (cf. above), e.g., for the changing GHG intensity of the supply of different energy carriers, for which a combination of MESSAGE IAM results and IEA Energy Technology Perspective results was used. Also, for the average GHG intensity of primary metal production a scenario analysis based on ecoinvent was calculated to take into account scenario-dependent changes of the GHG intensity of electricity generation.

Resource efficiency **Strategy potentials:** For some parameters, including the improvement potentials for fabrication scrap, end-of-life recovery efficiency of scrap, re-use of steel components in buildings, or product lifetime extension, previous estimates can be used (Milford et al. 2013). The other strategies were covered by the scenario formulation approach described above.

Archetype descriptions: Here, 'archetype' refers to an idealized description of the physical properties (energy intensity of operation and material composition) of a product with a certain functionality, assuming typical user behaviour in a given region.

For passenger vehicles, drive technology, segment (car size), and material design choice together determine the archetypes' material composition, and the three properties above plus the assumed driving cycle determine its specific operational energy consumption (specific = per km driven).

For residential building, building type, energy standard, material intensity (conventional or lightweight design), material design choice, and stylized climate conditions (heating and cooling degree days by region) together determine the archetypes' material composition and specific operational energy consumption (specific = per m2).

For the final product categories residential buildings and vehicles, the product-specific simulation tools BuildME (https://github.com/nheeren/BuildME), GREET (https://greet.es.anl.gov/) and FASTSim (https://www.nrel.gov/transportation/fastsim.html) were used to model the archetype descriptions by deriving model estimates for both the material composition and energy intensity of operation for different building and vehicle configuration. For each of the nine building and six vehicle types four archetypes, representing maximal potential for change, were simulated: a standard product without special consideration of material efficiency, downsizing, or material substitution, a downsized product, a product with ambitious material substitution, and a downsized material-substituted product.

For a detailed description and definition of all model aspects, the classifications used for them, the system variables and parameters, the model equation and their division into modules and the data compilation, (dis)aggregation and formatting process, we refer to the ODYM-RECC model documentation.

The ODYM-RECC database is formatted in standardised spreadsheets and archived on Zenodo (dataset DOIs [to be inserted for final publication]).

2.4. Model resolution

The information presented here is a summary only. The full info about the resolution of the RECC project is documented in the Master classification file, which is part of the project's database: **RECC_Classifications_Master_V2.0.xlsx**

Time and age-cohort, dimension: Time:

- The time frame is 1900-2060, as some historic data reach back to 1900 and before. The Actual modelling period is 2016 to 2060, where usually, results until 2050 are extracted for reporting and publication.

Regions, dimension: Region:

- The two end-use sectors passenger vehicles and residential buildings are implemented for 20 countries and world regions: (cf. RECC_Classifications_Master_V2.0.xlsx for details):
    - R32CAN Canada
    - R32CHN China
    - R32EU12-M "New" EU countries, medium income
    - R32IND India
    - R32JPN Japan
    - R32USA USA
    - France
    - Germany
    - Italy
    - Poland
    - Spain
    - UK
    - Oth_R32EU15 Other "old" EU countries,
    - Oth_R32EU12-H Other "new EU countries, high income
    - R5.2OECD_Other Other OECD countries
    - R5.2REF_Other Countries of the former USSR
    - R5.2ASIA_Other Other Asian countries
    - R5.2MNF_Other Middle East and Northern African Countries
    - R5.2SSA_Other Sub-Saharan Africa Country
    - R5.2LAM_Other Latin-American Countries

Eningering_Materials, dimension: Material:

- Construction grade steel
- Automotive steel
- stainless steel
- Cast iron
- Wrought Al
- Cast Al
- Copper electric grade
- Plastics
- Cement
- Wood and wood products
- Zinc
- Concrete
- Concrete aggregates

UsePhase, dimension: Process:

- Cf. Products resolution

Products, dimension: Good_Product:

- **Passenger vehicles:**
  Internal Combustion Engine, gasoline (ICEG)
  Internal Combustion Engine, diesel (ICED)
  Hybrid Electric Vehicles (HEV)
  Plugin Hybrid Electric Vehicles (PHEV)
  Battery Electric Vehicles (BEV)
  Fuel Cell Vehicles (FCV)

EoL goods, dimension: Good_Product:

- Cf. Products resolution

Energy, dimension: Energy carriers:

- Electricity
- Coal, hard coal
- Diesel
- Gasoline
- Natural gas
- Hydrogen
- Fuel wood

SSP_Scenarios, dimension: Scenario:

- LED (low energy demand)
- SSP1 (Shared Socioeconomic Pathway 1)
- SSP2 (Shared Socioeconomic Pathway 2)

RCP_Scenarios, dimension: Scenario:

- RCP2.6, 2°C-pathway
- Baseline (no new climate policy after 2020)

Env. extensions, dimension: Extensions:

- CO_2 emisisons per main output
- CH_4 emissions per main output
- N_2O emissions per main output
- SF_6 emisisons per main output
- GHG emissions
- GHG emissions, supply chain

Env. midpoints, dimension: Extensions:

- GWP 20/100/500
- GTP 20/100/500

Chemical Elements, dimension: Element:

- C
- Al
- Cr
- Fe
- Cu
- Zn
- 'Other'

MaterialProductionProcess, dimension: Process:

- One (average) primary production process for each material.

ManufacturingProcess, dimension: Process:

- One average manufacturing process for each product/good

Waste management process, dimension: Process:

- One waste mgt. (dismantling, shredding, sorting) process to convert each of the 15 products into waste/scrap at the end of life, one re-melting process for each scrap category

Waste/scrap, dimension: Material:

- Heavy melt, plate, and structural steel scrap
- Steel shred
- Al extrusion scrap, auto rims, clean
- Al old sheet and construction waste
- Al old cast
- Copper wire scrap
- Construction waste, concrete, bricks, tiles, ceramics
- Thermoplastic waste
- Used wood

Car segments, Good_Product:

- microcar
- passenger car
- minivan_SUV
- light truck

3. RECC 2.4 database and scenario drivers

Here, we list the changes in the main drivers and the country/region-level plots.

2016-2060 relative change in main material cycle drivers			LED	SSP1	SSP2
France	RCP2.6	Population	→ 0%	→ 0%	→ 0%
France	RCP2.6	per capita in-use stock, residential buildings	↘ -26%	→ 0%	→ 16%
France	RCP2.6	per capita in-use stock, passenger vehicles	↘ -10%	→ 0%	↗ 44%
Germany	RCP2.6	Population	→ 0%	→ 0%	→ 0%
Germany	RCP2.6	per capita in-use stock, residential buildings	↘ -28%	→ 0%	→ 18%
Germany	RCP2.6	per capita in-use stock, passenger vehicles	↘ -19%	→ 0%	↗ 48%
Italy	RCP2.6	Population	→ 0%	→ 0%	→ 0%
Italy	RCP2.6	per capita in-use stock, residential buildings	↘ -30%	→ 0%	→ 17%
Italy	RCP2.6	per capita in-use stock, passenger vehicles	↘ -20%	→ 0%	↗ 62%
Oth_R32EU12-H	RCP2.6	Population	↘ -8%	→ 0%	↘ -8%
Oth_R32EU12-H	RCP2.6	per capita in-use stock, residential buildings	↘ -21%	→ 0%	→ 18%
Oth_R32EU12-H	RCP2.6	per capita in-use stock, passenger vehicles	↘ -21%	→ 0%	↗ 31%
Oth_R32EU15	RCP2.6	Population	→ 0%	→ 0%	→ 0%
Oth_R32EU15	RCP2.6	per capita in-use stock, residential buildings	↘ -25%	→ 0%	→ 18%
Oth_R32EU15	RCP2.6	per capita in-use stock, passenger vehicles	↘ -14%	→ 0%	↗ 41%
Poland	RCP2.6	Population	→ 0%	→ 0%	→ 0%
Poland	RCP2.6	per capita in-use stock, residential buildings	↘ -21%	→ 0%	→ 18%
Poland	RCP2.6	per capita in-use stock, passenger vehicles	↘ -20%	→ 0%	→ 26%
R5.2ASIA_Other	RCP2.6	Population	→ 14%	→ 0%	→ 14%
R5.2ASIA_Other	RCP2.6	per capita in-use stock, residential buildings	↘ -14%	→ 0%	→ 14%
R5.2ASIA_Other	RCP2.6	per capita in-use stock, passenger vehicles	↓ -75%	→ 0%	↑ 99%
R5.2LAM_Other	RCP2.6	Population	→ 13%	→ 0%	→ 13%
R5.2LAM_Other	RCP2.6	per capita in-use stock, residential buildings	↘ -13%	→ 0%	↗ 31%
R5.2LAM_Other	RCP2.6	per capita in-use stock, passenger vehicles	↓ -75%	→ 0%	↑ 99%
R5.2MNF_Other	RCP2.6	Population	→ 15%	→ 0%	→ 15%
R5.2MNF_Other	RCP2.6	per capita in-use stock, residential buildings	↘ -25%	→ 0%	→ 13%
R5.2MNF_Other	RCP2.6	per capita in-use stock, passenger vehicles	↓ -53%	→ 0%	↑ 76%
R5.2OECD_Other	RCP2.6	Population	→ 8%	→ 0%	→ 8%
R5.2OECD_Other	RCP2.6	per capita in-use stock, residential buildings	↘ -25%	→ 0%	→ 13%
R5.2OECD_Other	RCP2.6	per capita in-use stock, passenger vehicles	↘ -38%	→ 0%	↗ 36%
R5.2REF_Other	RCP2.6	Population	→ 9%	→ 0%	→ 9%
R5.2REF_Other	RCP2.6	per capita in-use stock, residential buildings	↘ -25%	→ 0%	→ 13%
R5.2REF_Other	RCP2.6	per capita in-use stock, passenger vehicles	↘ -38%	→ 0%	↗ 36%
R5.2SSA_Other	RCP2.6	Population	→ 19%	→ 0%	→ 19%
R5.2SSA_Other	RCP2.6	per capita in-use stock, residential buildings	↘ -29%	→ 0%	→ 25%
R5.2SSA_Other	RCP2.6	per capita in-use stock, passenger vehicles	↓ -75%	→ 0%	↑ 99%
R32CAN	RCP2.6	Population	→ -3%	→ 0%	→ -3%
R32CAN	RCP2.6	per capita in-use stock, residential buildings	↓ -42%	→ 0%	→ 24%
R32CAN	RCP2.6	per capita in-use stock, passenger vehicles	↘ -26%	→ 0%	↗ 40%
R32CHN	RCP2.6	Population	→ 4%	→ 0%	→ 4%
R32CHN	RCP2.6	per capita in-use stock, residential buildings	↘ -25%	→ 0%	→ 25%
R32CHN	RCP2.6	per capita in-use stock, passenger vehicles	↘ -37%	→ 0%	↗ 63%
R32EU12-M	RCP2.6	Population	→ 4%	→ 0%	→ 4%
R32EU12-M	RCP2.6	per capita in-use stock, residential buildings	↘ -21%	→ 0%	→ 18%
R32EU12-M	RCP2.6	per capita in-use stock, passenger vehicles	↘ -18%	→ 0%	↗ 36%
R32IND	RCP2.6	Population	→ 16%	→ 0%	→ 16%
R32IND	RCP2.6	per capita in-use stock, residential buildings	↘ -13%	→ 0%	↗ 33%
R32IND	RCP2.6	per capita in-use stock, passenger vehicles	↓ -65%	→ 0%	↑ 93%
R32JPN	RCP2.6	Population	↘ -6%	→ 0%	↘ -6%
R32JPN	RCP2.6	per capita in-use stock, residential buildings	↘ -23%	→ 0%	→ 19%
R32JPN	RCP2.6	per capita in-use stock, passenger vehicles	↘ -28%	→ 0%	↑ 91%
Spain	RCP2.6	Population	→ 0%	→ 0%	→ 0%
Spain	RCP2.6	per capita in-use stock, residential buildings	↘ -21%	→ 0%	→ 19%
Spain	RCP2.6	per capita in-use stock, passenger vehicles	↘ -13%	→ 0%	↗ 37%
UK	RCP2.6	Population	→ 0%	→ 0%	→ 0%
UK	RCP2.6	per capita in-use stock, residential buildings	↘ -25%	→ 0%	→ 13%
UK	RCP2.6	per capita in-use stock, passenger vehicles	↘ -11%	→ 0%	↗ 43%
R32USA	RCP2.6	Population	→ -3%	→ 0%	→ -3%
R32USA	RCP2.6	per capita in-use stock, residential buildings	↓ -44%	→ 0%	↗ 30%
R32USA	RCP2.6	per capita in-use stock, passenger vehicles	↘ -19%	→ 0%	↑ 67%

Fig. SI3: Overview of major material cycle drivers: cars, residential buildings, and population.

Figures SI4-1 – SI4-20 below show the temporal development of the main drivers and stock parameters by country/region for both the residential building and the passenger vehicle sectors.

Legend for all figures: First row: residential floor space: buildings in m²/cap; share of light-weighted buildings in new construction, unit: 1; share of material-substituted (timber-intensive) buildings in new construction, unit: 1. Second row: population, million; car ownership rate, cars per person; share of downsized (segment-shifted) cars in newly registered cars, unit: 1; share of material-substituted (light-weighted) cars in newly registered cars, unit: 1. Third row: OR: Vehicle occupancy rate, passengers per car; PKM: total passenger-km delivered by entire fleet, billion km; VKM: total vehicle-km delivered by entire fleet, billion km)

Fig. SI4-1: Drivers and in-use stock parameters, USA.

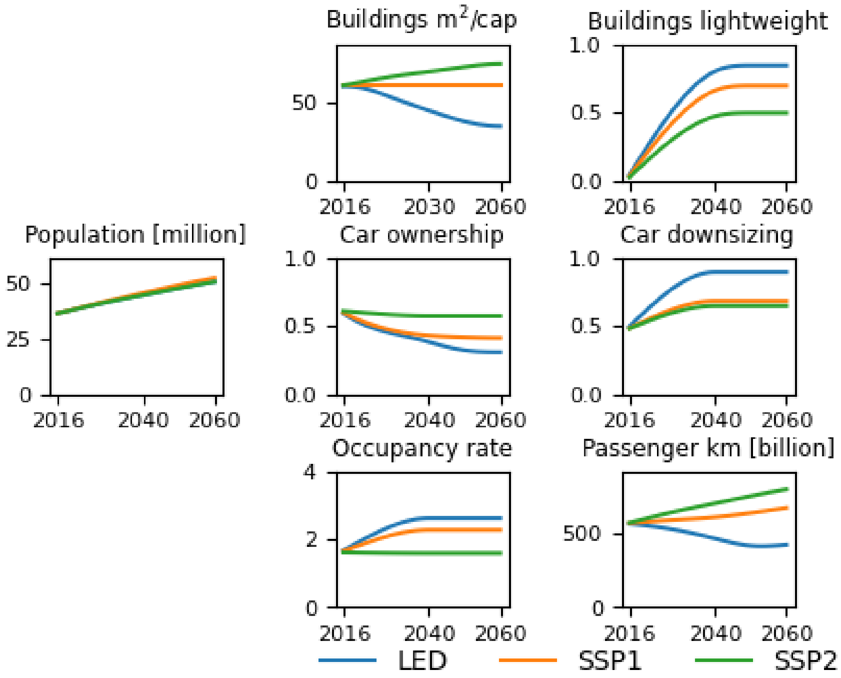


Fig. SI4-2: Drivers and in-use stock parameters, Canada.

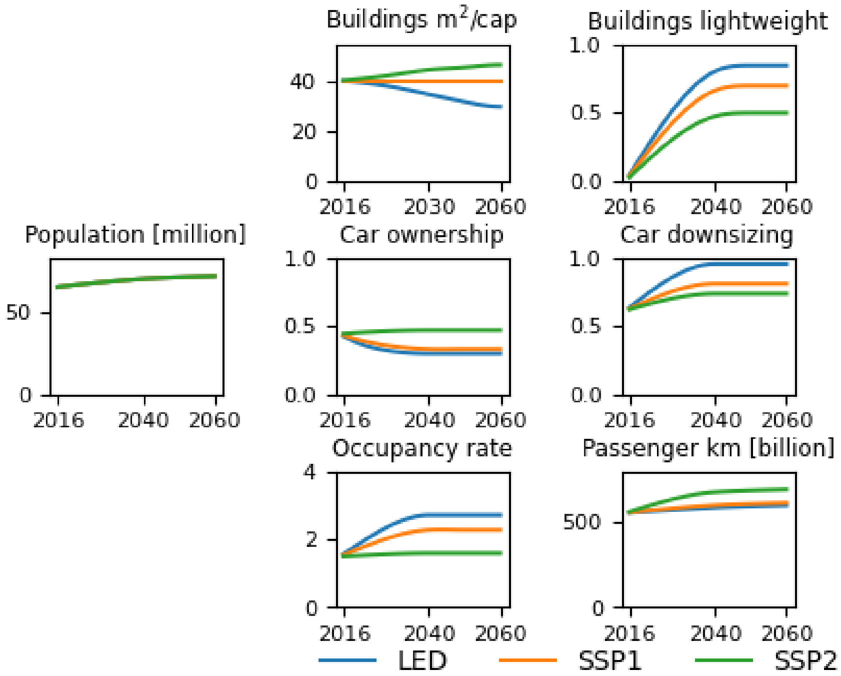


Fig. SI4-3: Drivers and in-use stock parameters, France.

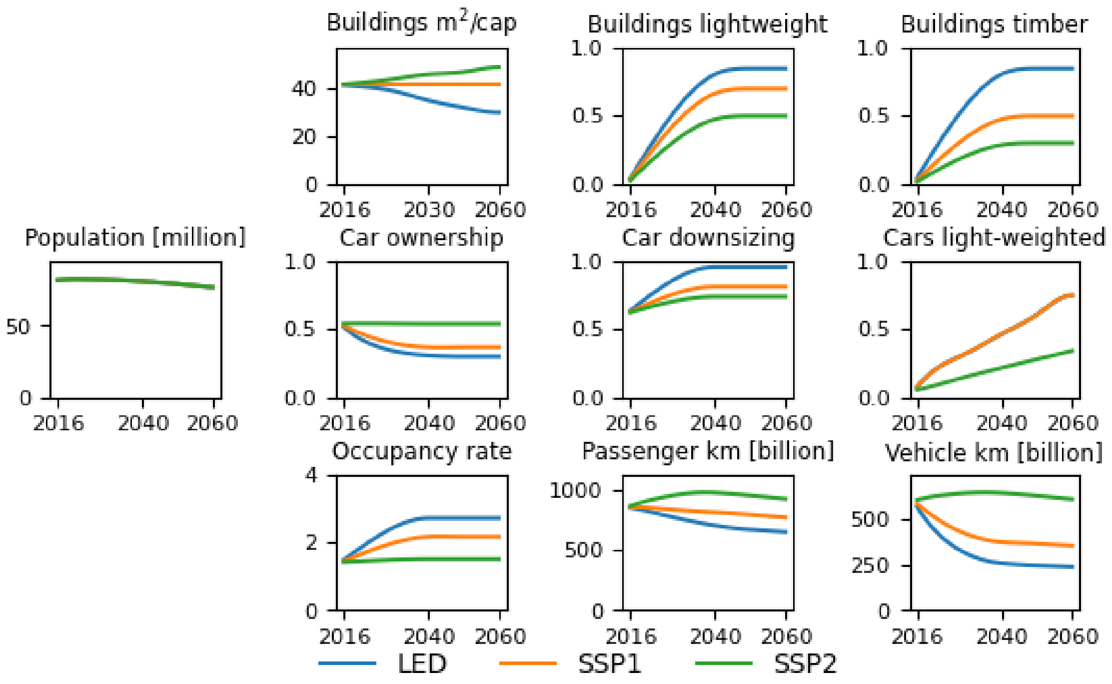


Fig. SI4-4: Drivers and in-use stock parameters, Germany.

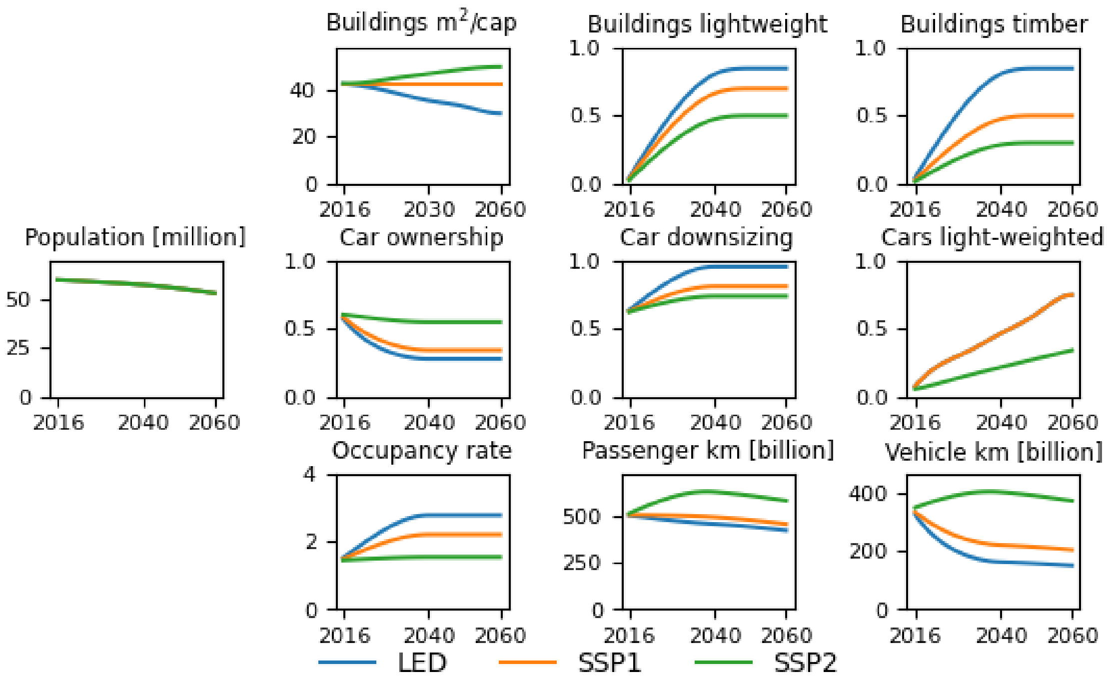


Fig. SI4-5: Drivers and in-use stock parameters, Italy.

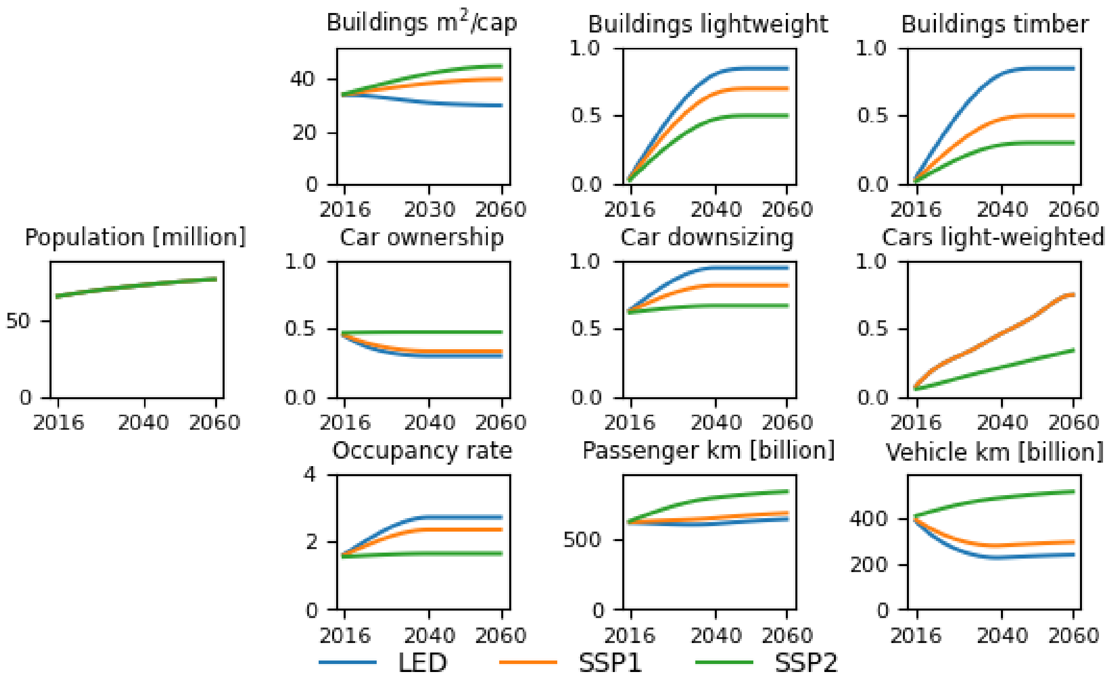


Fig. SI4-6: Drivers and in-use stock parameters, UK.

Fig. SI4-7: Drivers and in-use stock parameters, Japan.

Fig. SI4-8: Drivers and in-use stock parameters, China.

Fig. SI4-9: Drivers and in-use stock parameters, India.

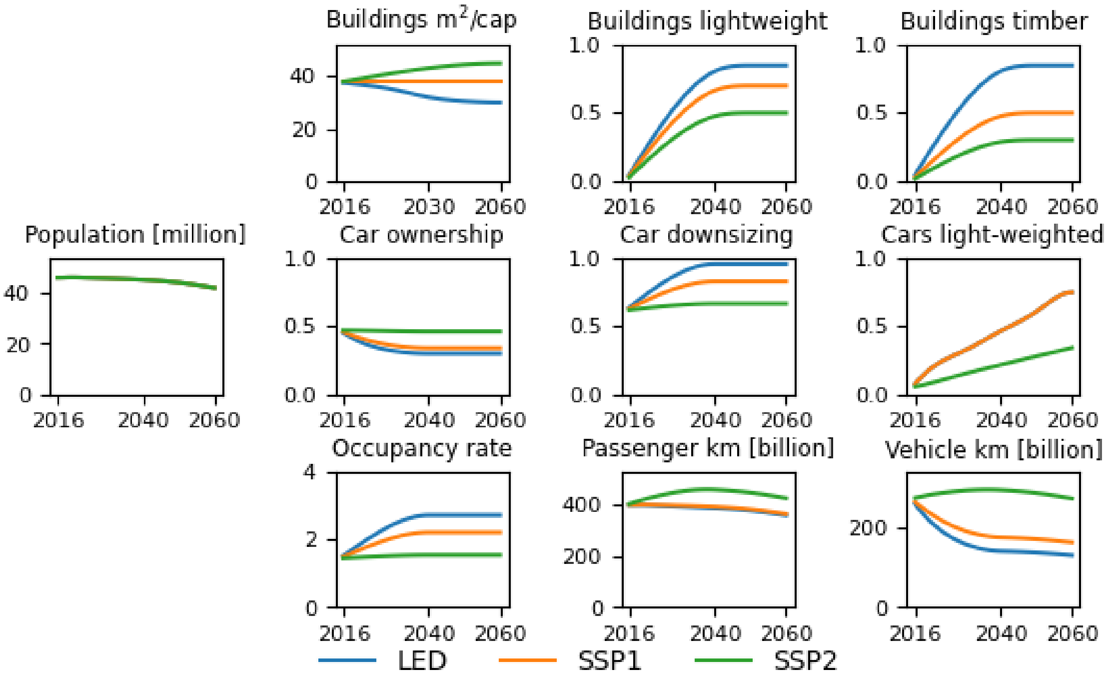


Fig. SI4-10: Drivers and in-use stock parameters, Spain.

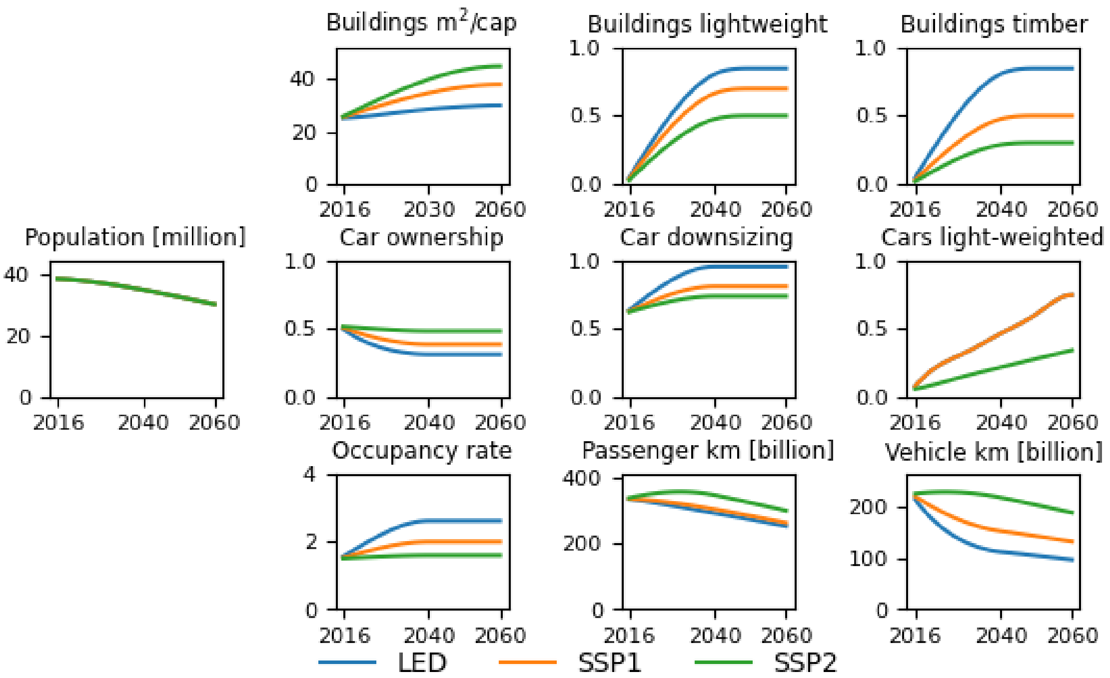


Fig. SI4-11: Drivers and in-use stock parameters, Poland.

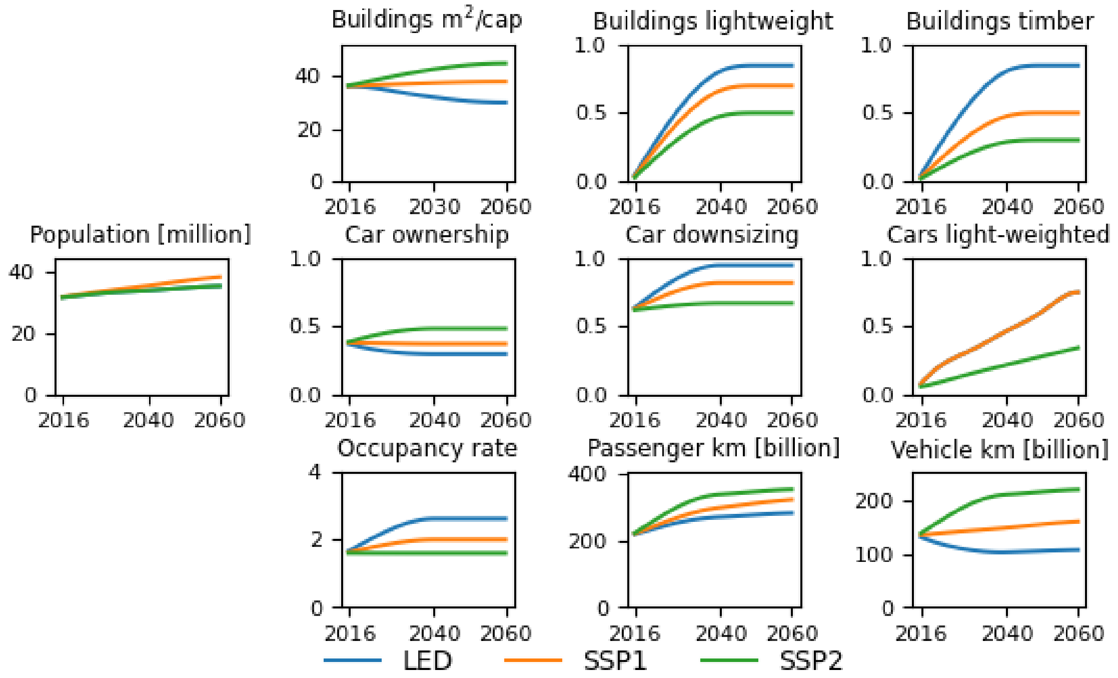


Fig. SI4-12: Drivers and in-use stock parameters, R32EU12-H.

Fig. SI4-13: Drivers and in-use stock parameters, R32EU15.

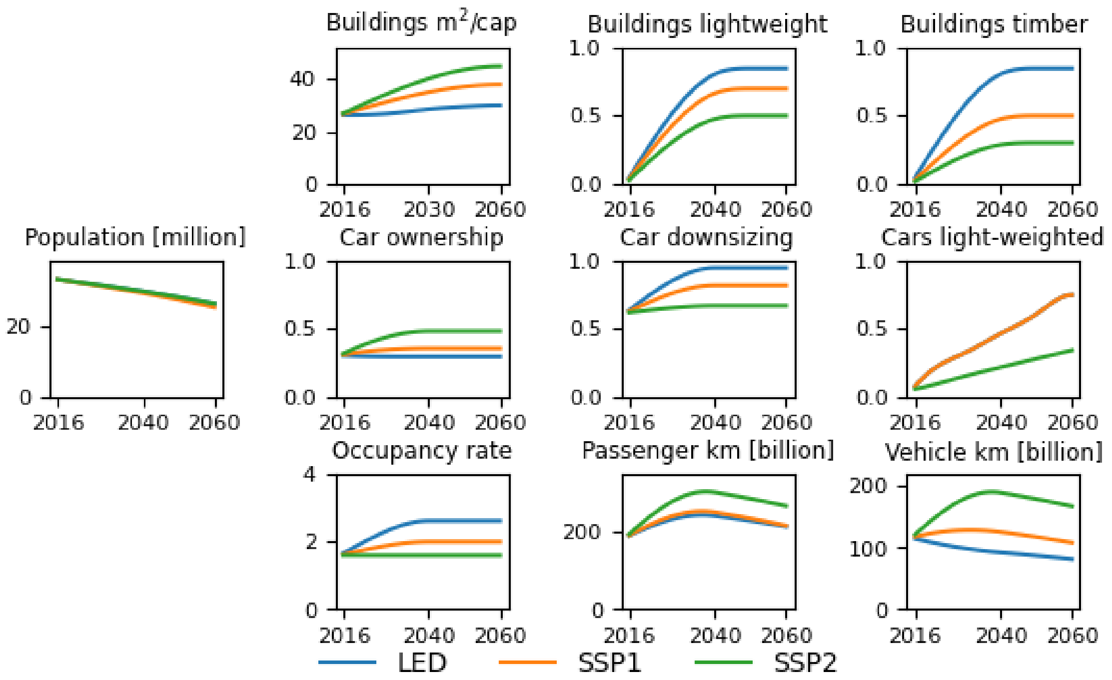


Fig. SI4-14: Drivers and in-use stock parameters, R32EU12-M.

Fig. SI4-15: Drivers and in-use stock parameters, R5.2OECD_Other.

Fig. SI4-16: Drivers and in-use stock parameters, R5.2Asia_Other.

Fig. SI4-17: Drivers and in-use stock parameters, R5.2SSA_Other.

Fig. SI4-18: Drivers and in-use stock parameters, R5.2MNF_Other.

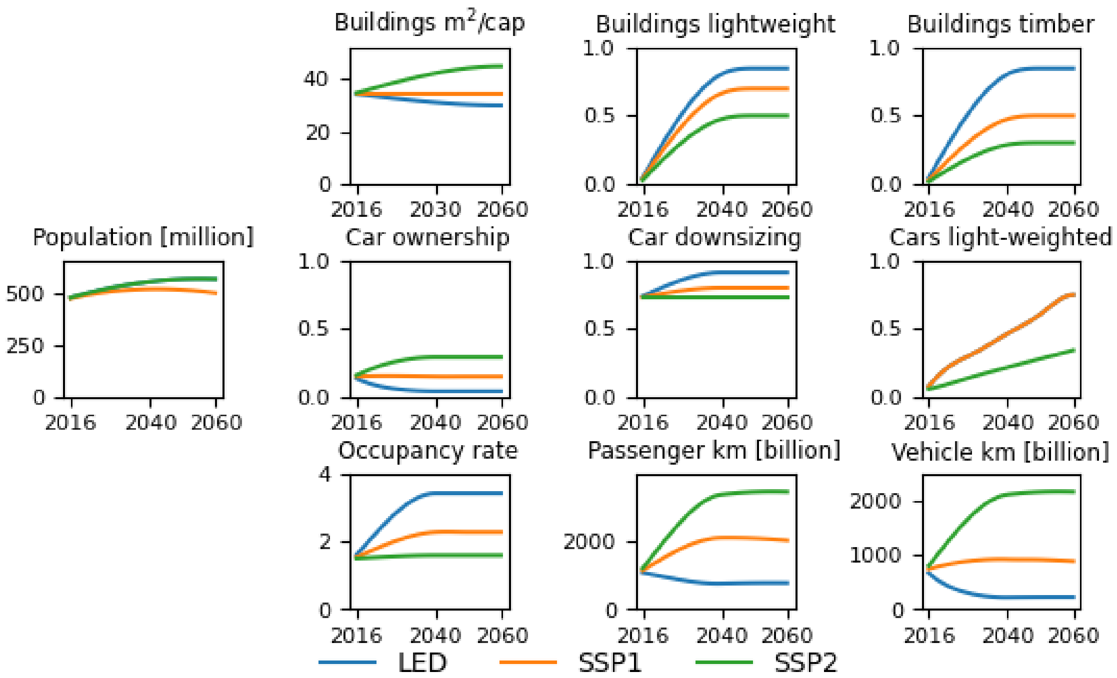


Fig. SI4-19: Drivers and in-use stock parameters, R5.2LAM_Other.

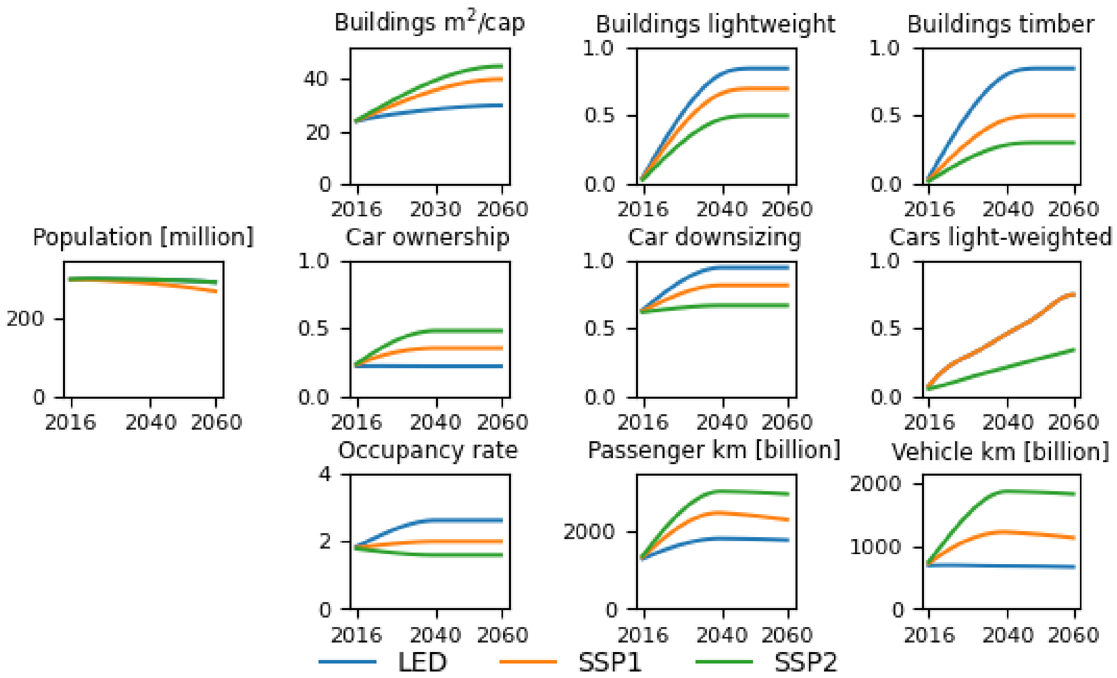


Fig. SI4-20: Drivers and in-use stock parameters, R5.2REF_Other.

Main stock and service parameters, passenger vehicles, by country/region. Figures SI5-1 – SI5-20 below show the temporal development of the passenger vehicle fleet (total number of vehicles by drive technology, left y axis) and the annual change of the total fleet size (stock change, right y axis).

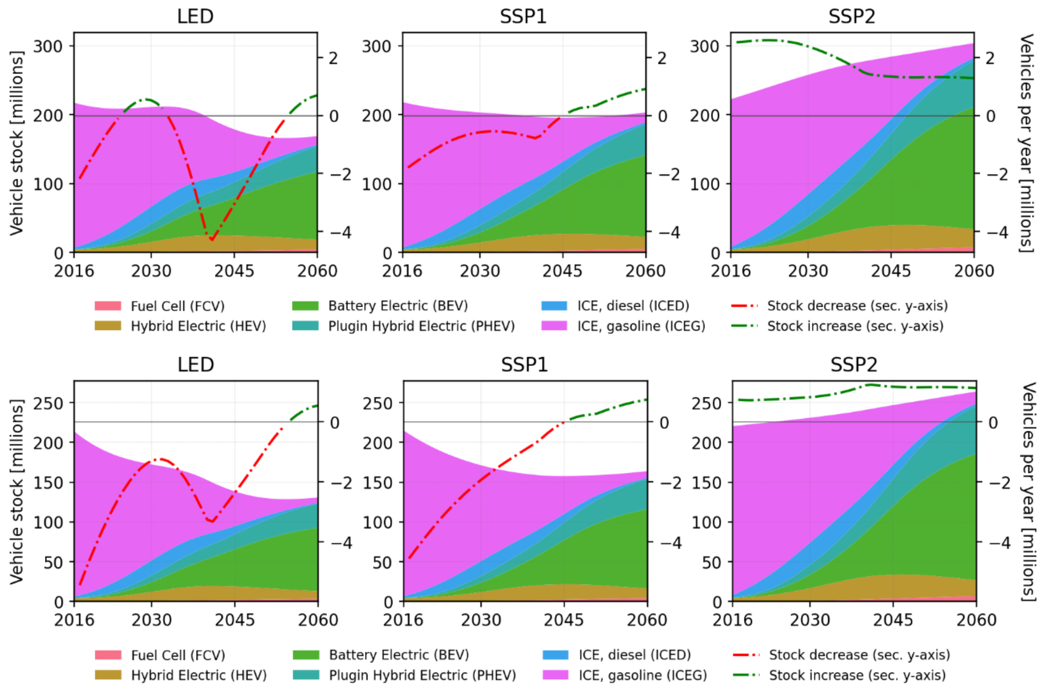


Fig. SI-5-1: Drivers and stock parameters, passenger vehicles, USA. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

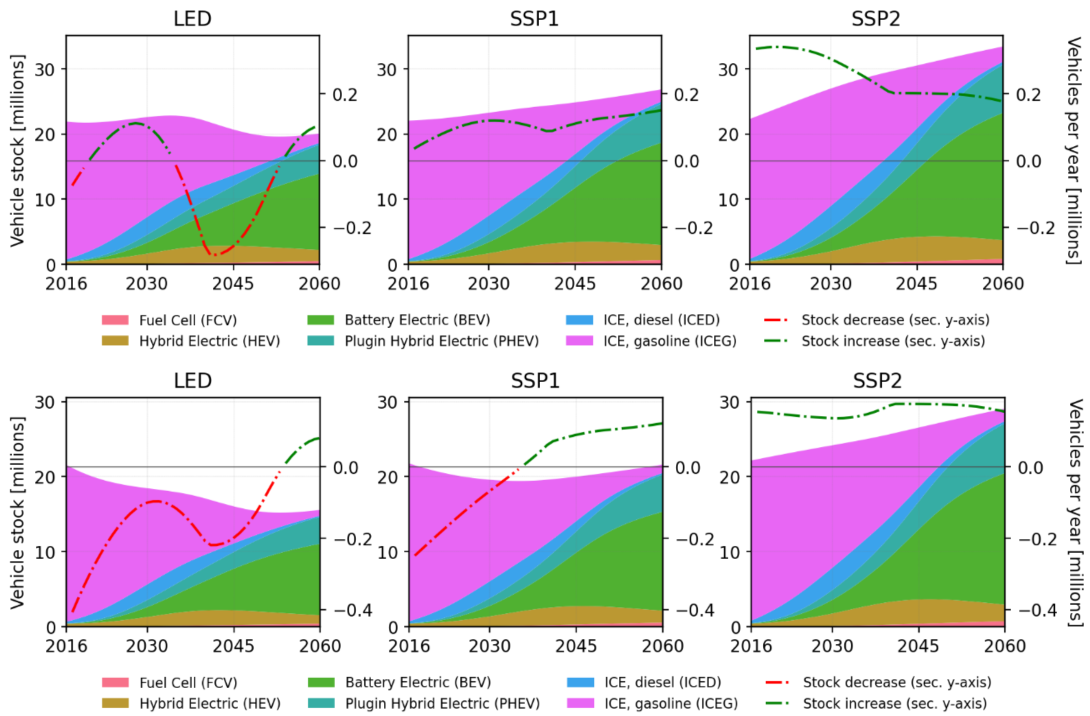


Fig. SI-5-2: Drivers and stock parameters, passenger vehicles, Canada. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

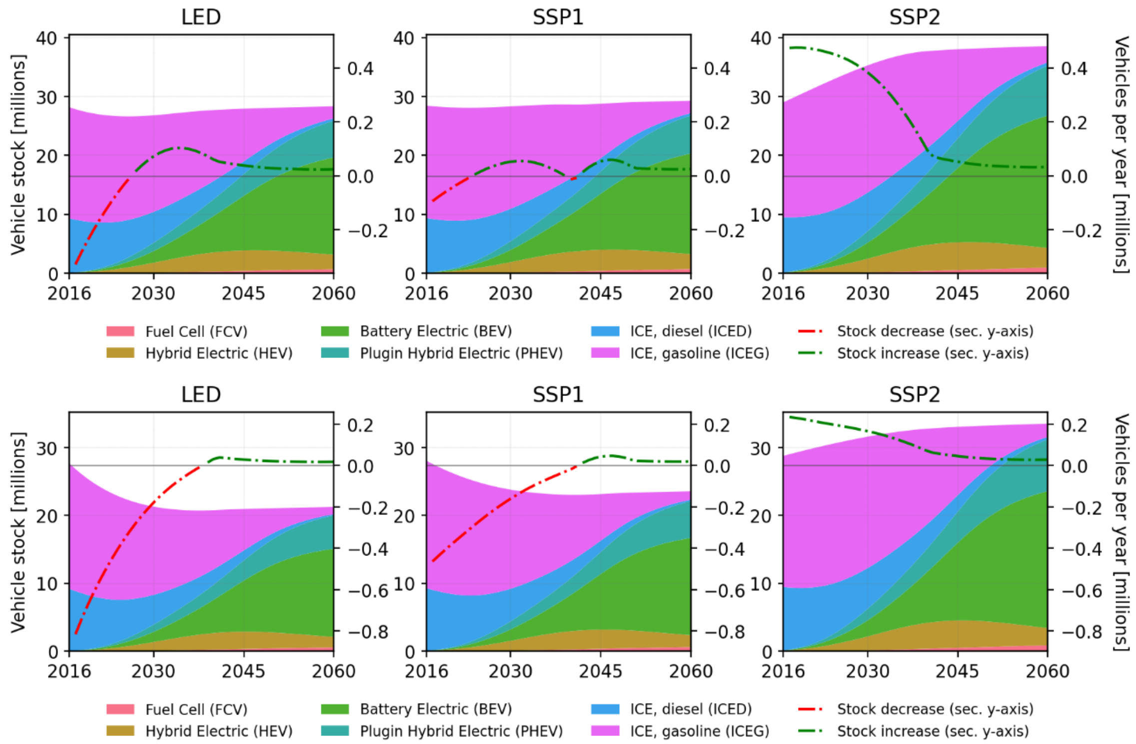


Fig. SI-5-3: Drivers and stock parameters, passenger vehicles, France. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

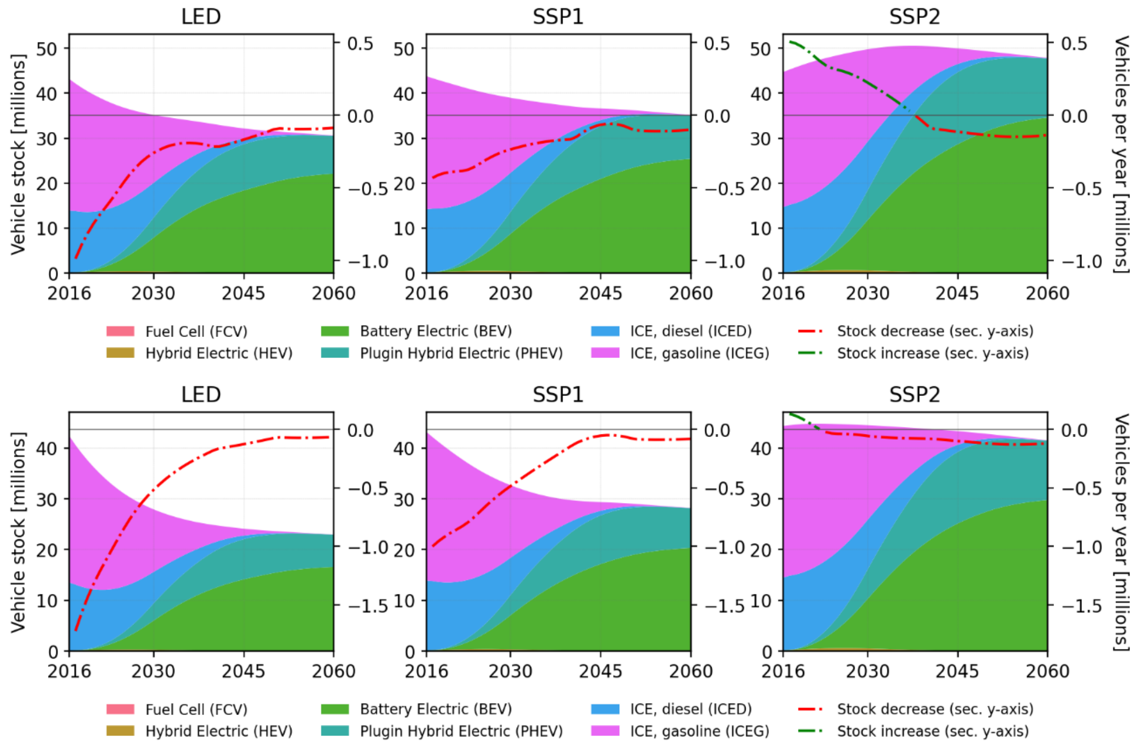


Fig. SI-5-4: Drivers and stock parameters, passenger vehicles, Germany. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

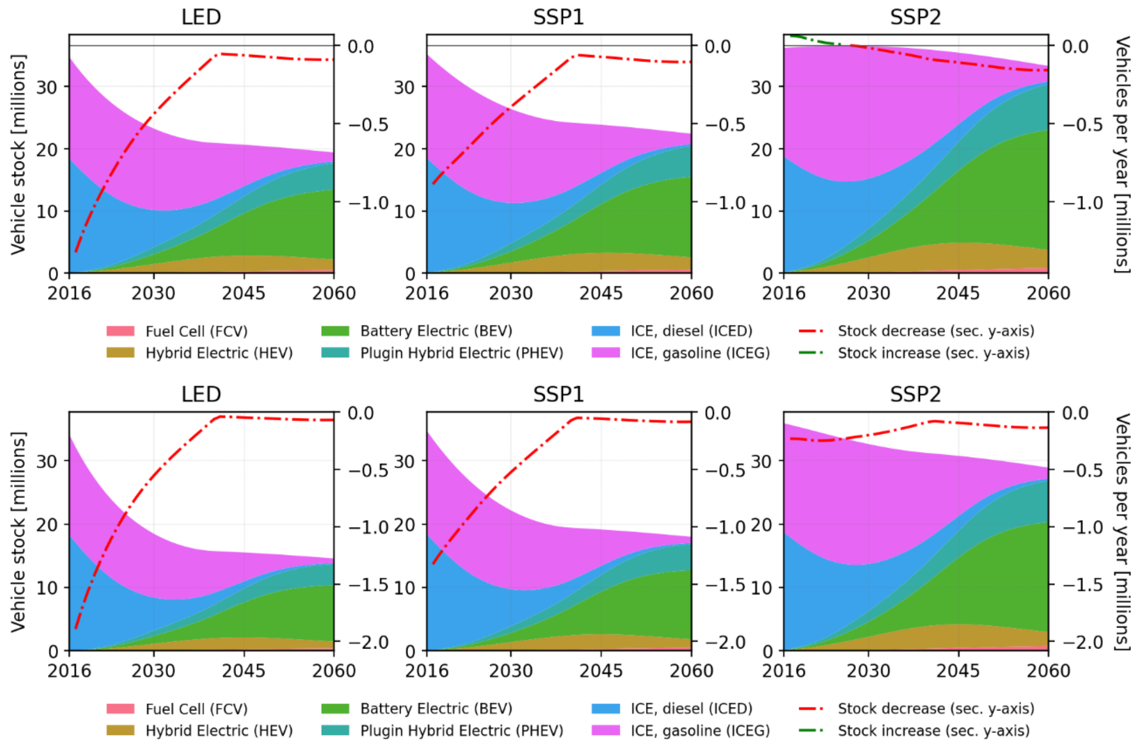


Fig. SI-5-5: Drivers and stock parameters, passenger vehicles, Italy. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

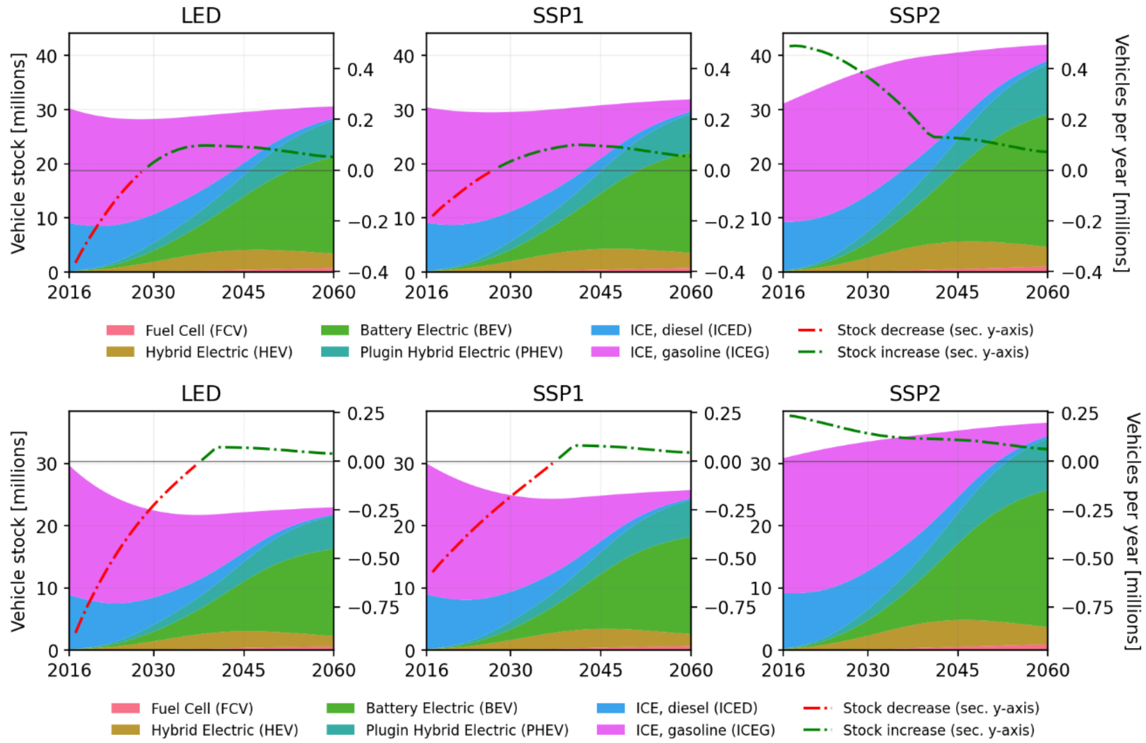


Fig. SI-5-6: Drivers and stock parameters, passenger vehicles, UK. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

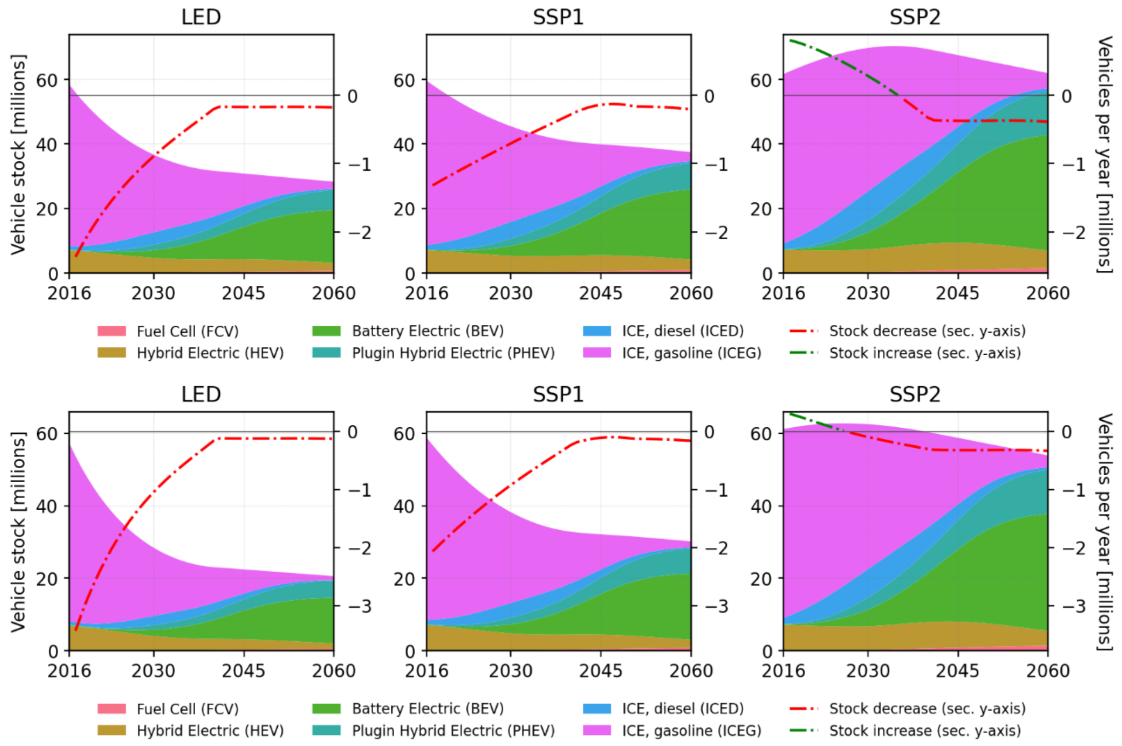


Fig. SI-5-7: Drivers and stock parameters, passenger vehicles, Japan. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

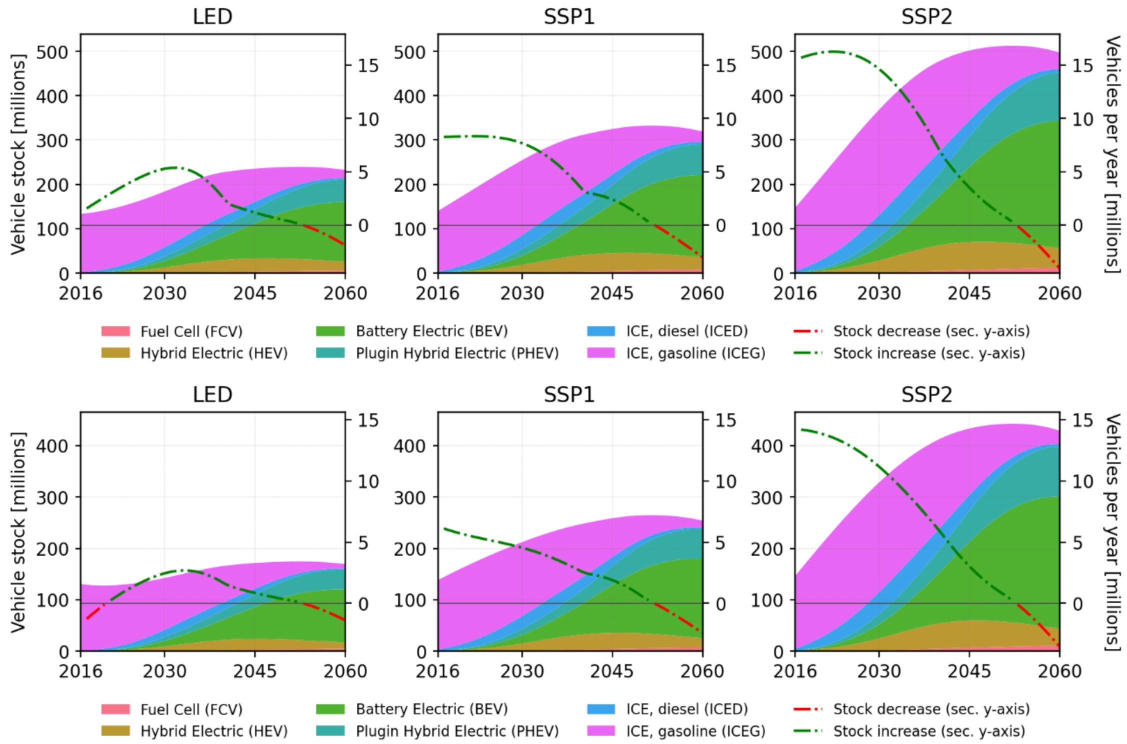


Fig. SI-5-8: Drivers and stock parameters, passenger vehicles, China. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

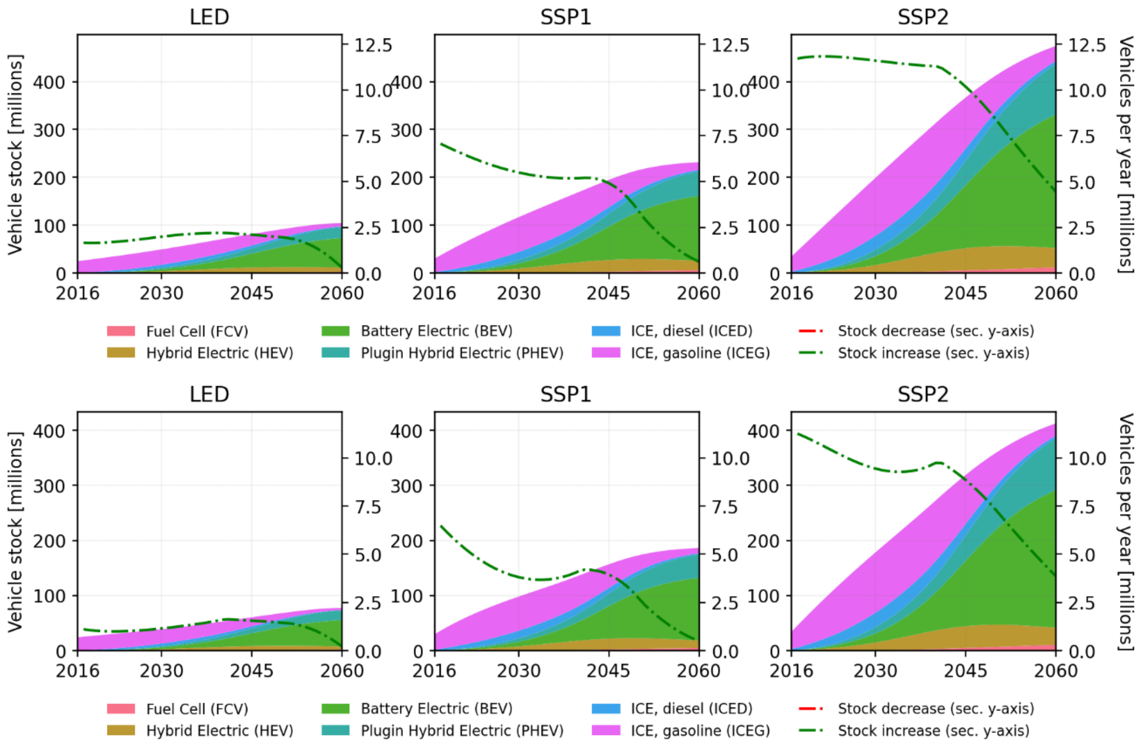


Fig. SI-5-9: Drivers and stock parameters, passenger vehicles, India. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

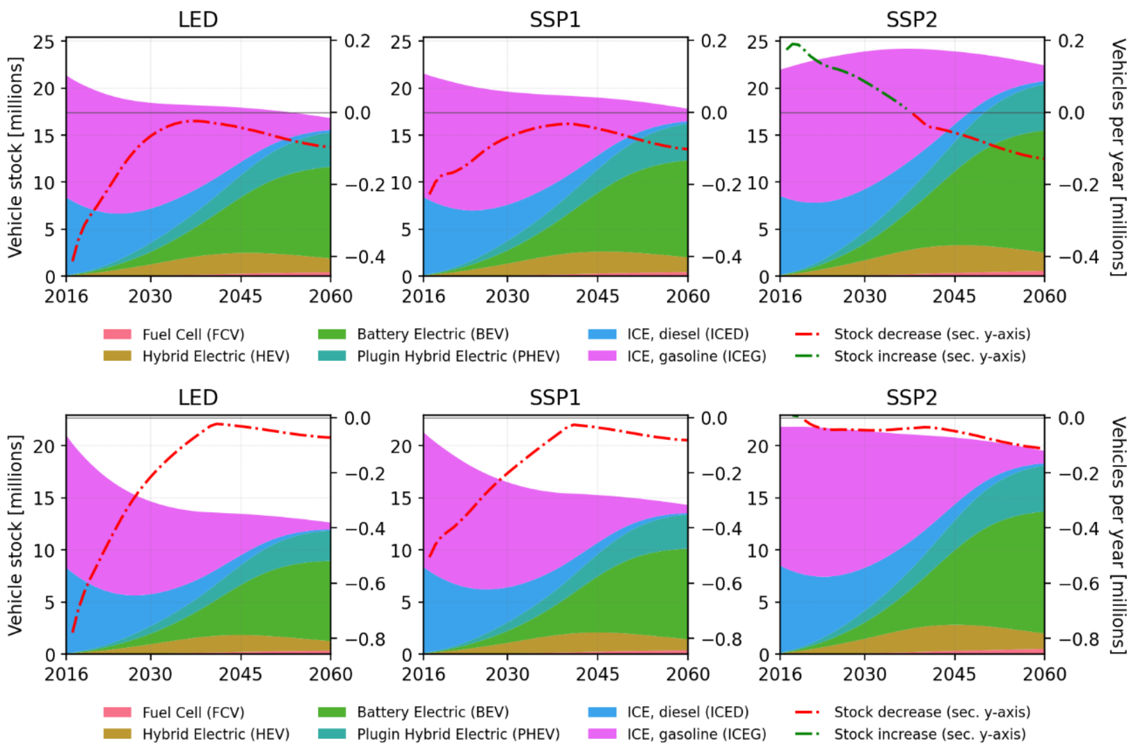


Fig. SI-5-10: Drivers and stock parameters, passenger vehicles, Spain. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

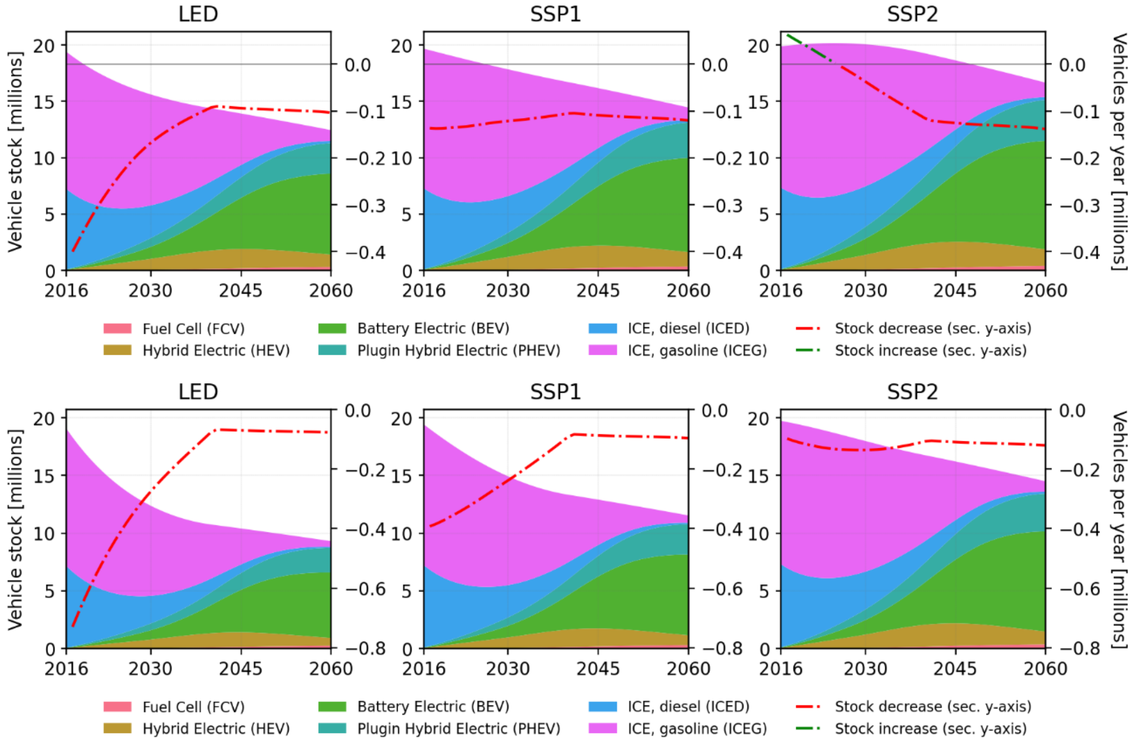


Fig. SI-5-11: Drivers and stock parameters, passenger vehicles, Poland. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

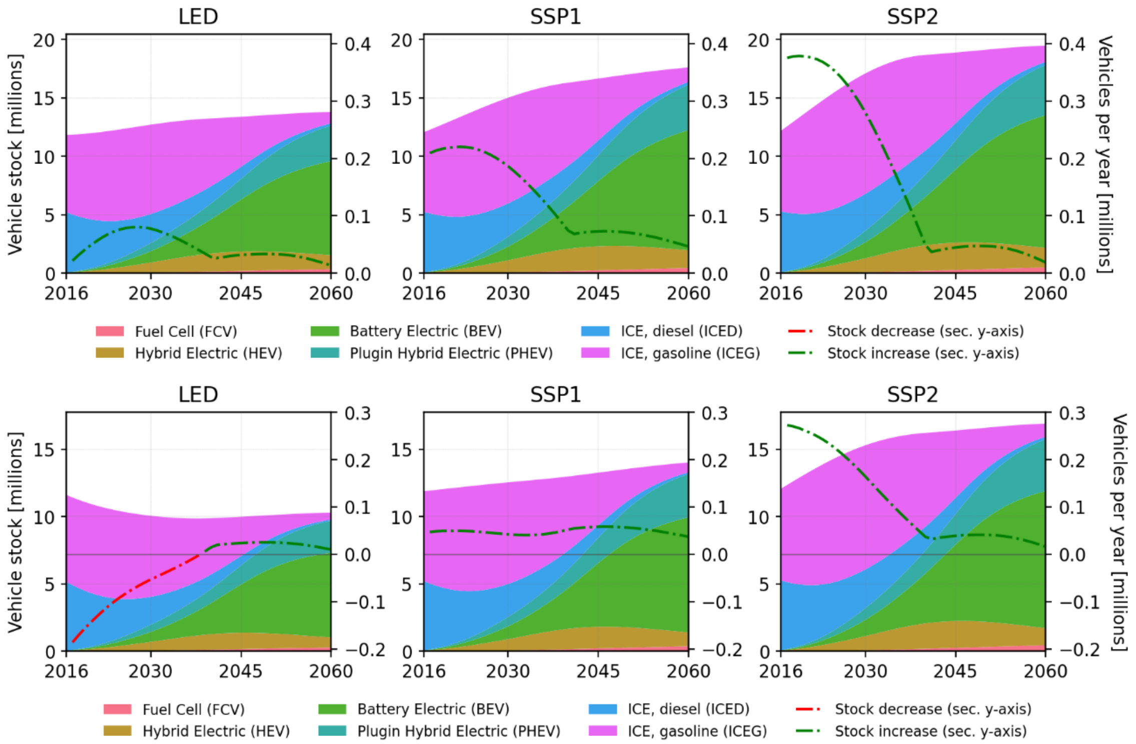


Fig. SI-5-12: Drivers and stock parameters, passenger vehicles, Oth_R32EU12-H. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

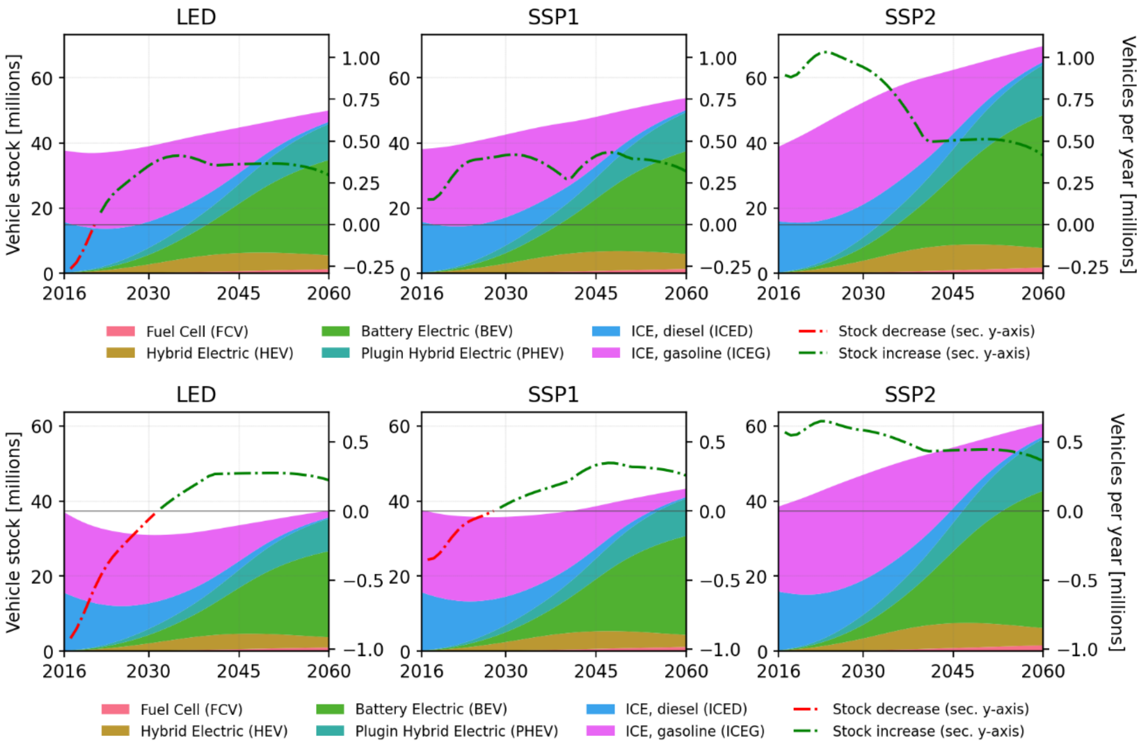


Fig. SI-5-13: Drivers and stock parameters, passenger vehicles, Oth_R32EU15. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

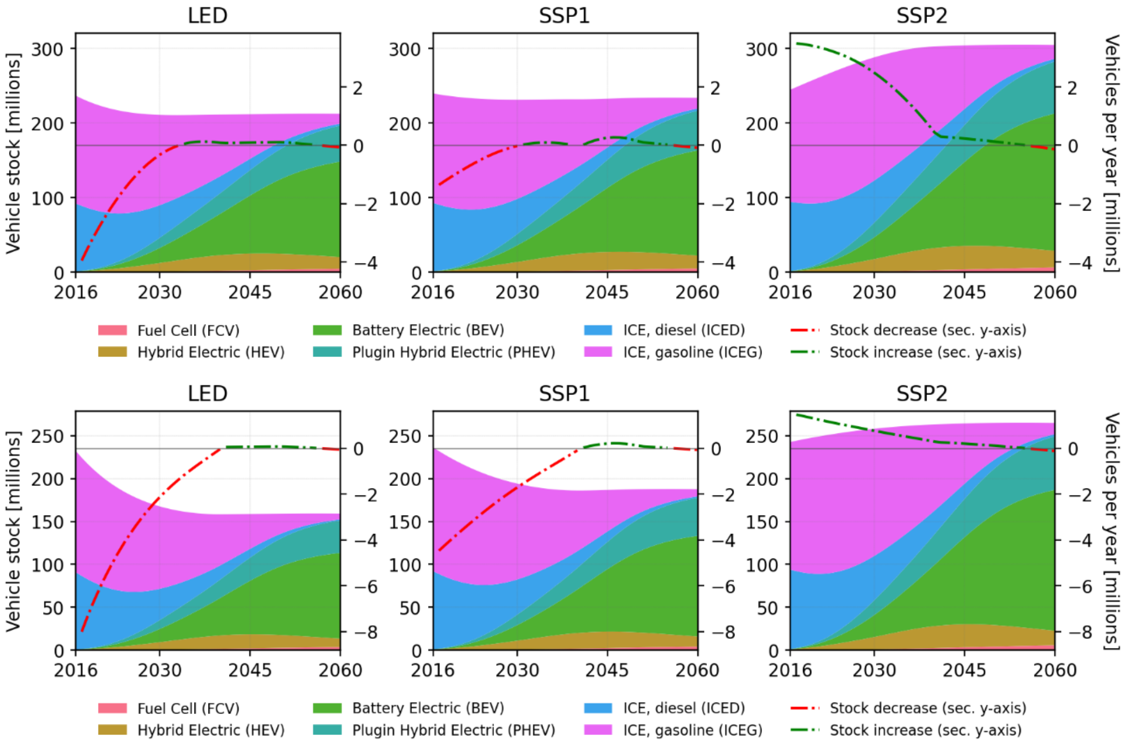


Fig. SI-5-14: Drivers and stock parameters, passenger vehicles, EU28. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

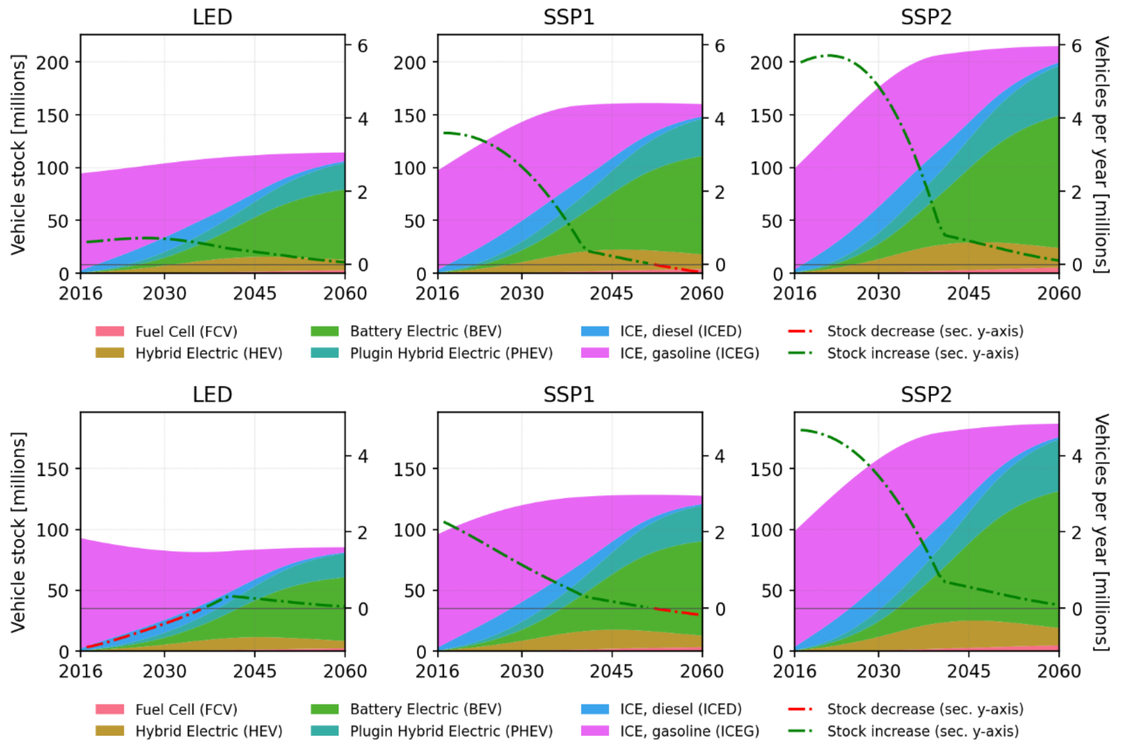


Fig. SI-5-15: Drivers and stock parameters, passenger vehicles, R5.2OECD_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

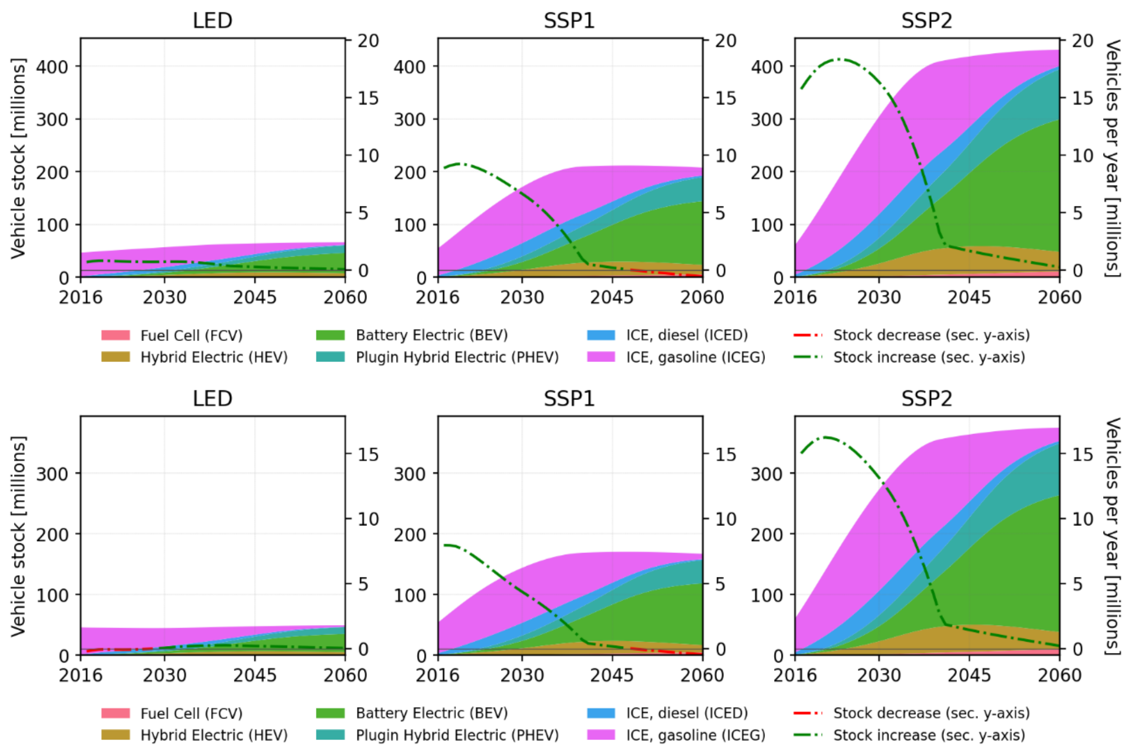


Fig. SI-5-16: Drivers and stock parameters, passenger vehicles, R5.2Asia_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

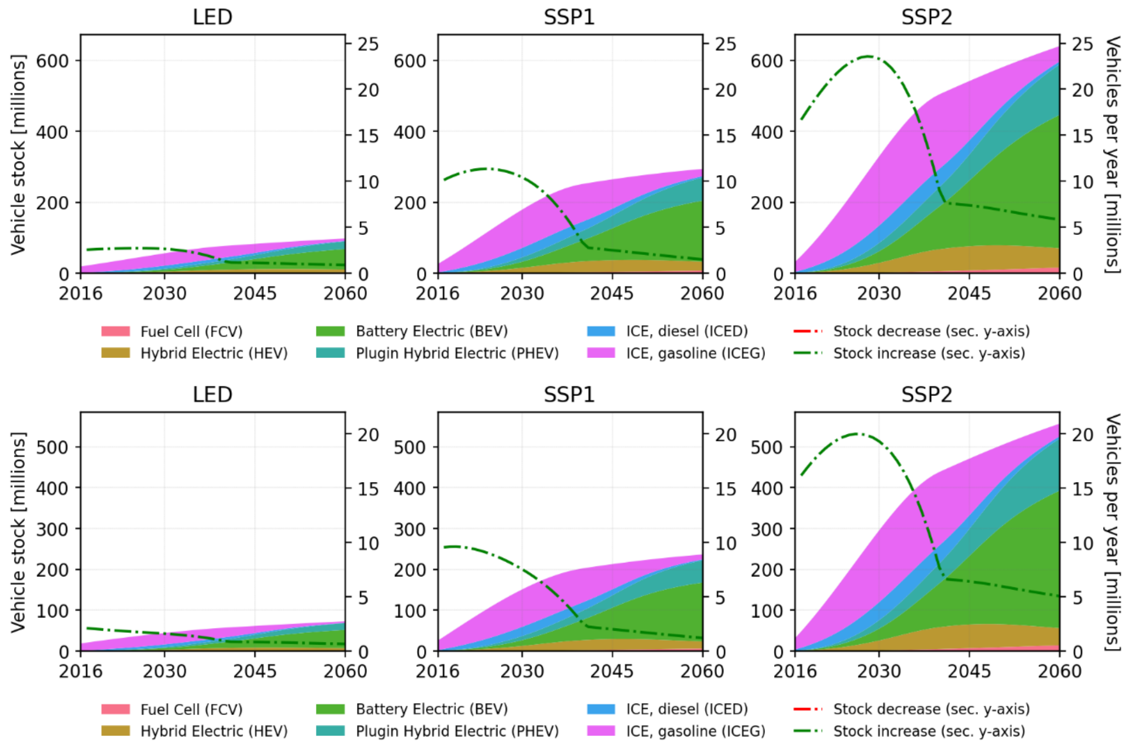


Fig. SI-5-17: Drivers and stock parameters, passenger vehicles, R5.2SSA_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

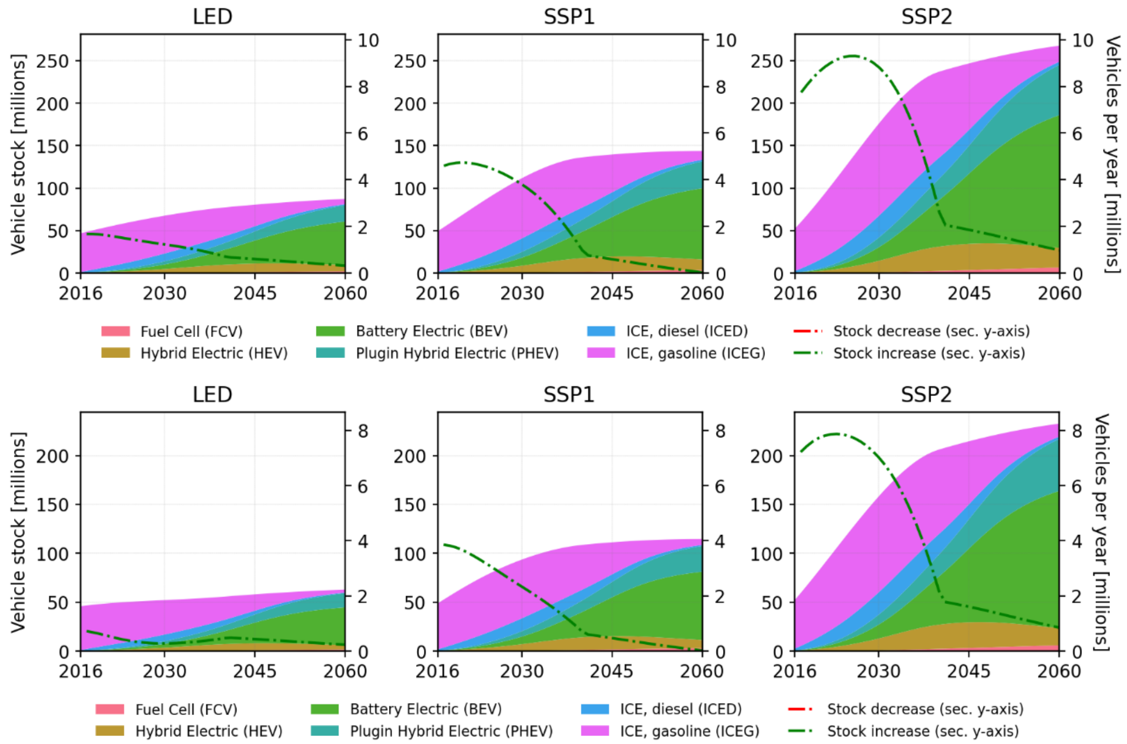


Fig. SI-5-18: Drivers and stock parameters, passenger vehicles, R5.2MNF_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

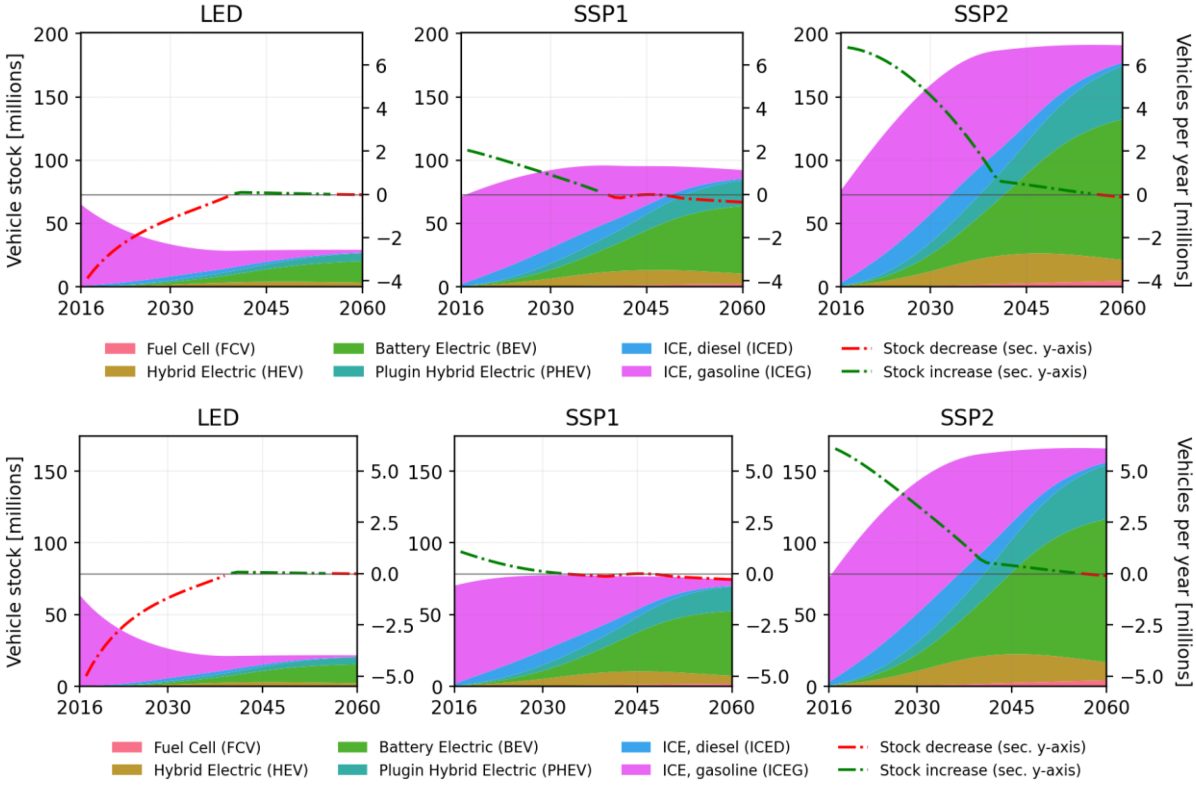


Fig. SI-5-19: Drivers and stock parameters, passenger vehicles, R5.2LAM_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

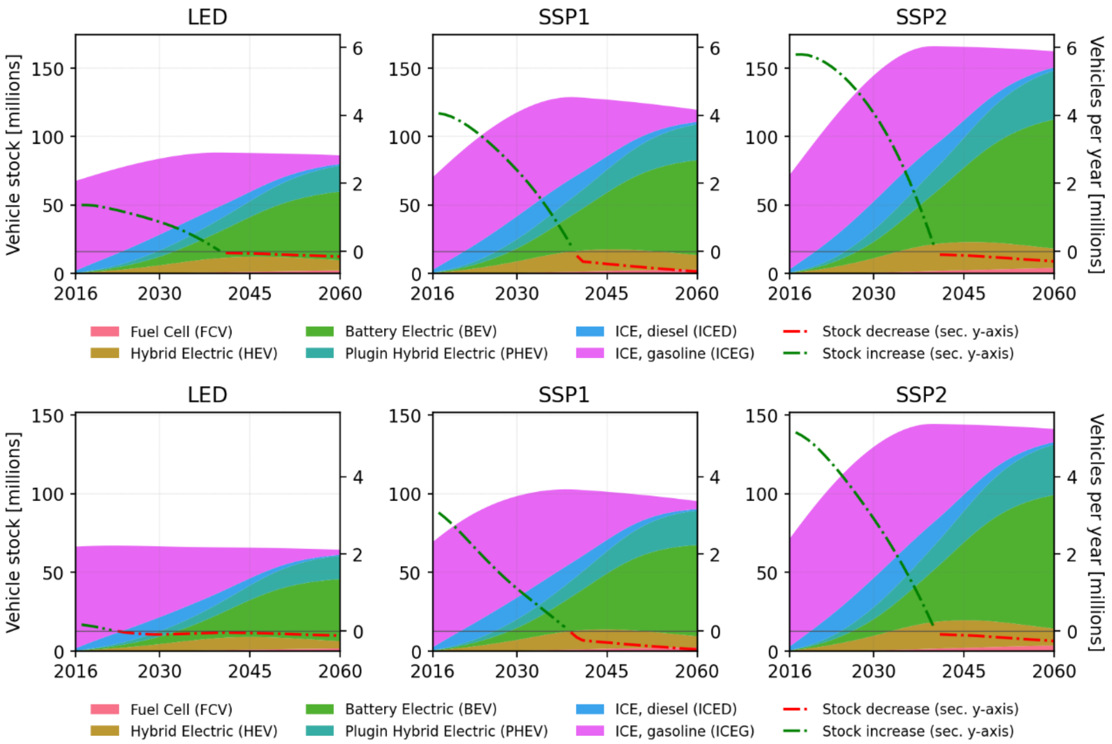


Fig. SI-5-20: Drivers and stock parameters, passenger vehicles, R5.2REF_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

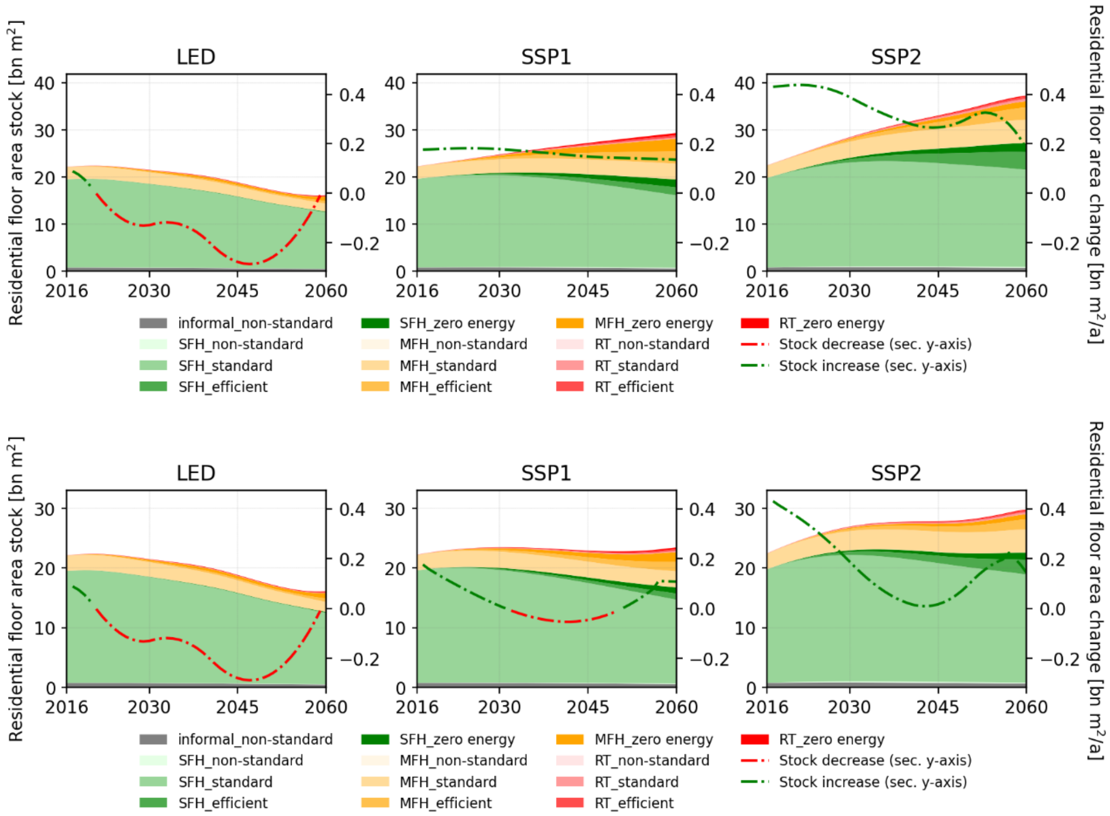


Fig. SI-6-1: Drivers and stock parameters, residential buildings, USA. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

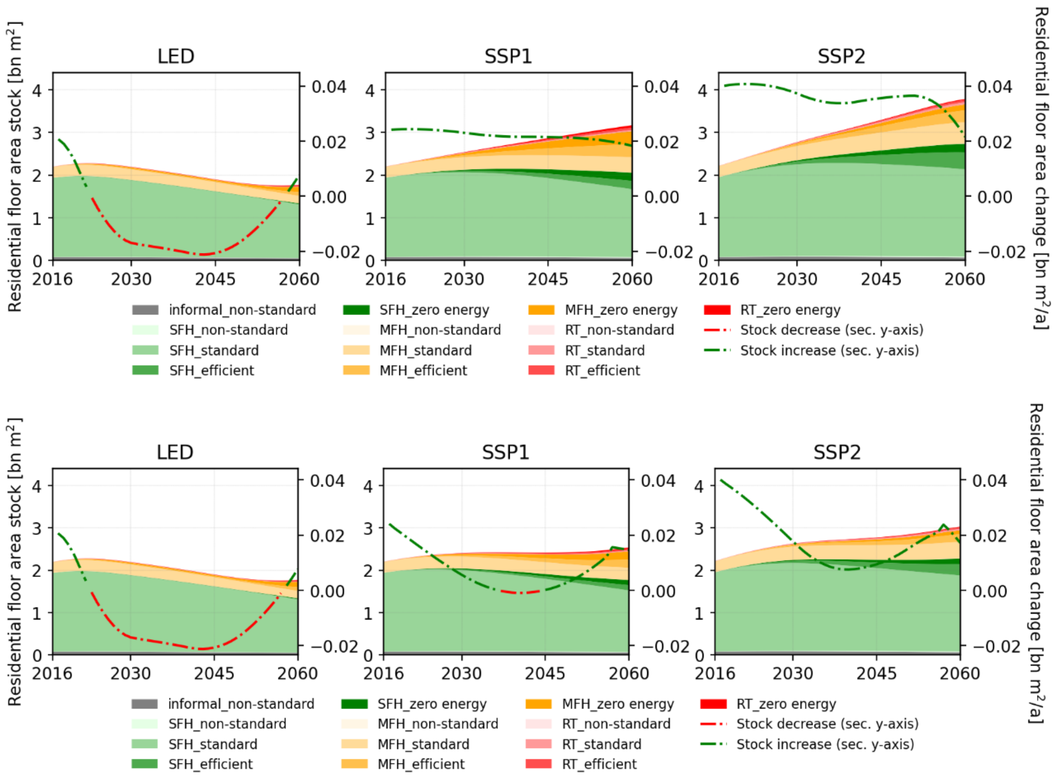


Fig. SI-6-2: Drivers and stock parameters, residential buildings, Canada. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

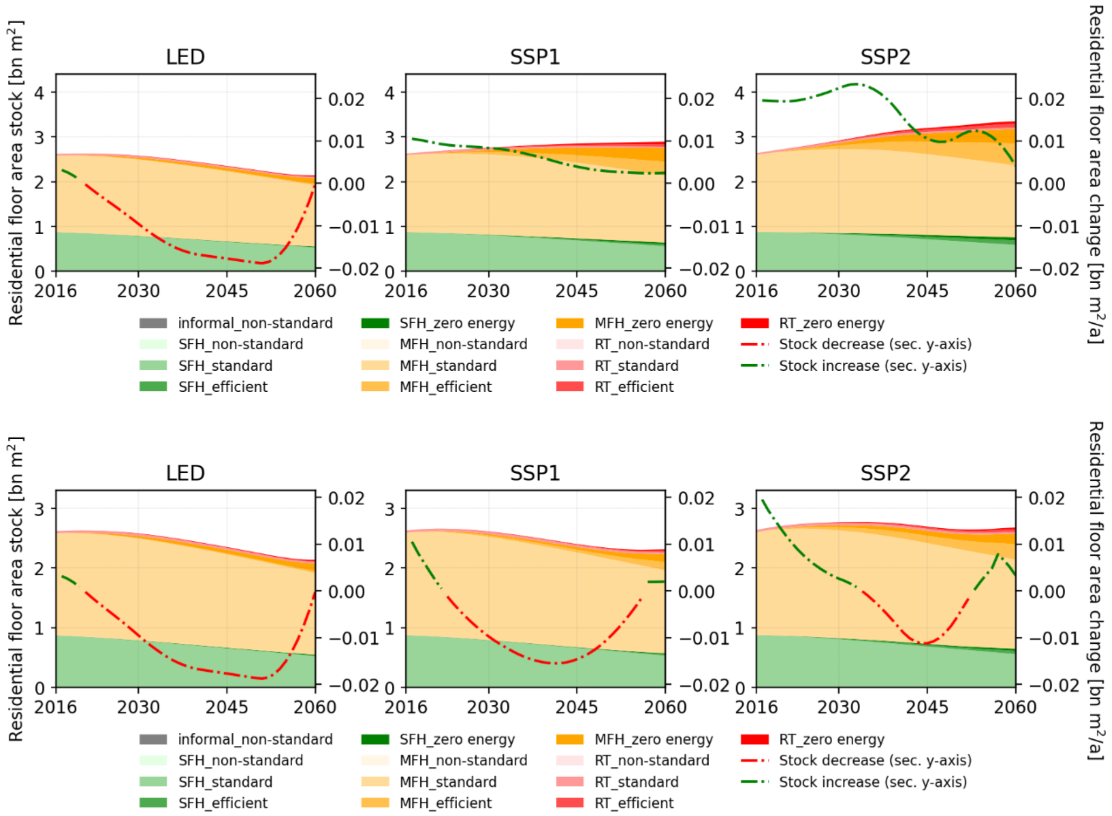


Fig. SI-6-3: Drivers and stock parameters, residential buildings, France. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

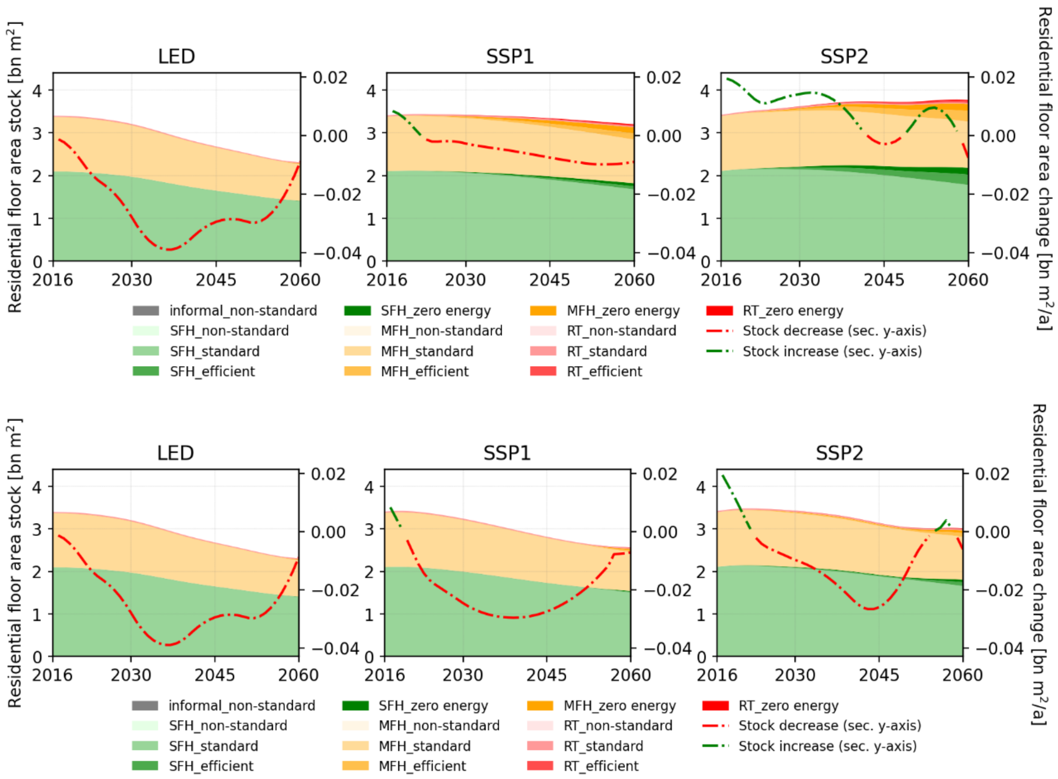


Fig. SI-6-4: Drivers and stock parameters, residential buildings, Germany. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

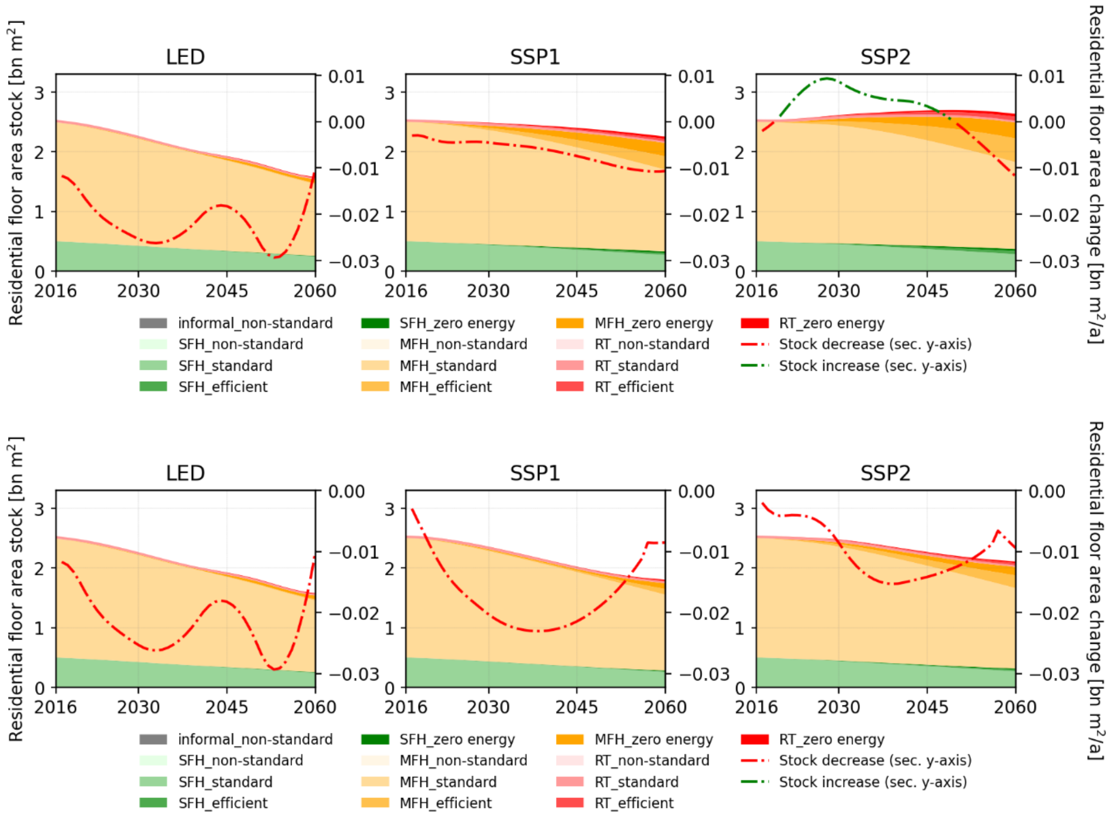


Fig. SI-6-5: Drivers and stock parameters, residential buildings, Italy. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

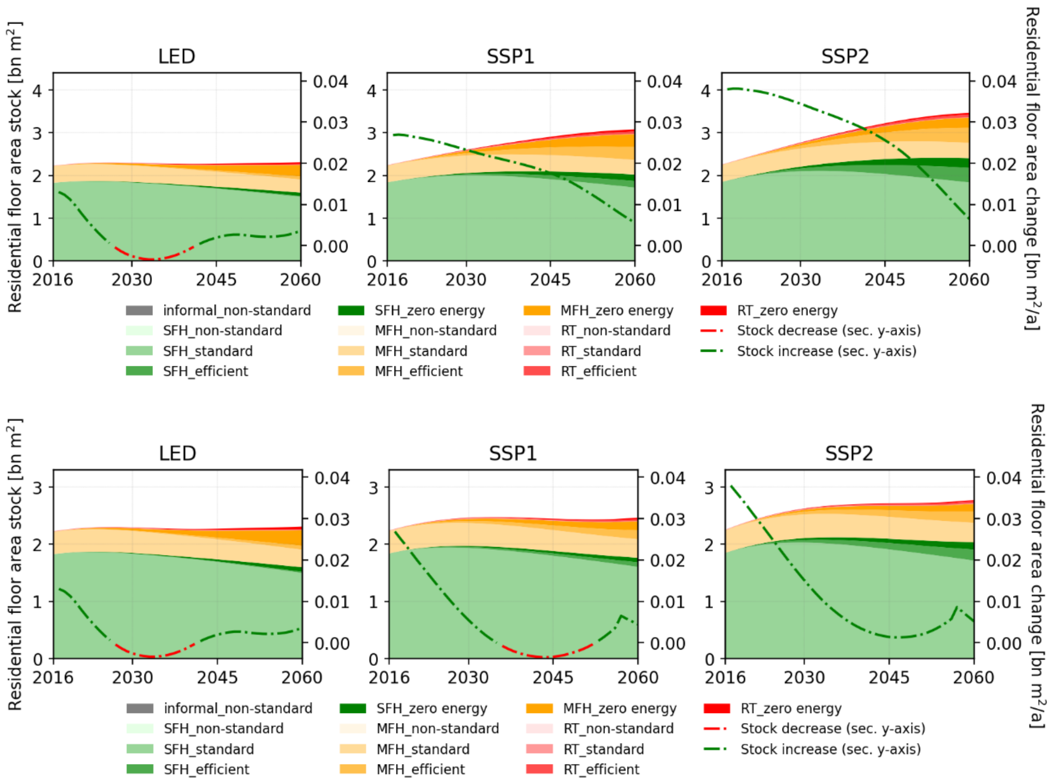


Fig. SI-6-6: Drivers and stock parameters, residential buildings, UK. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

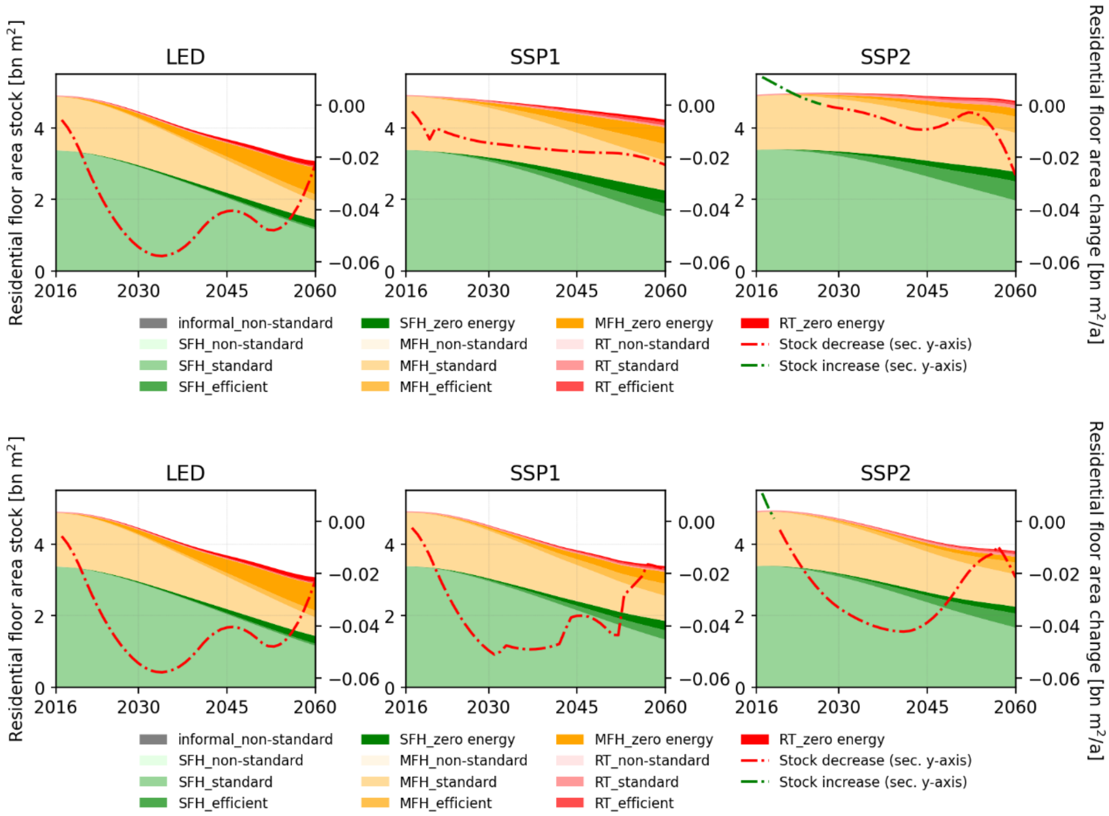


Fig. SI-6-7: Drivers and stock parameters, residential buildings, Japan. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

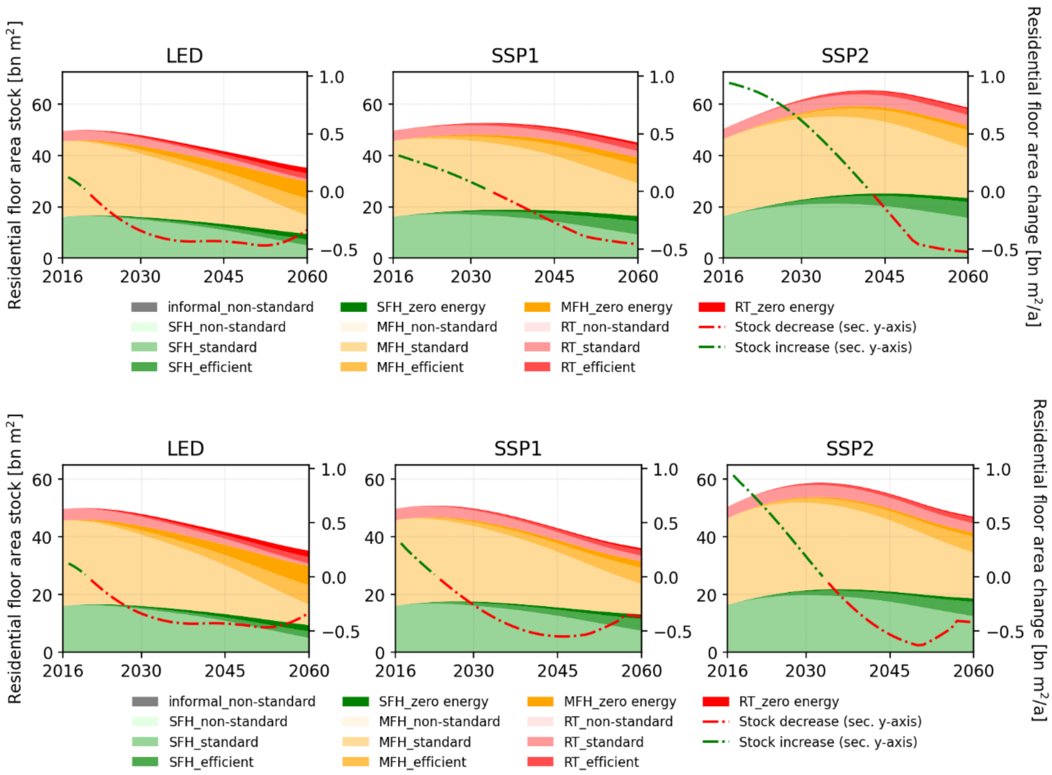


Fig. SI-6-8: Drivers and stock parameters, residential buildings, China. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

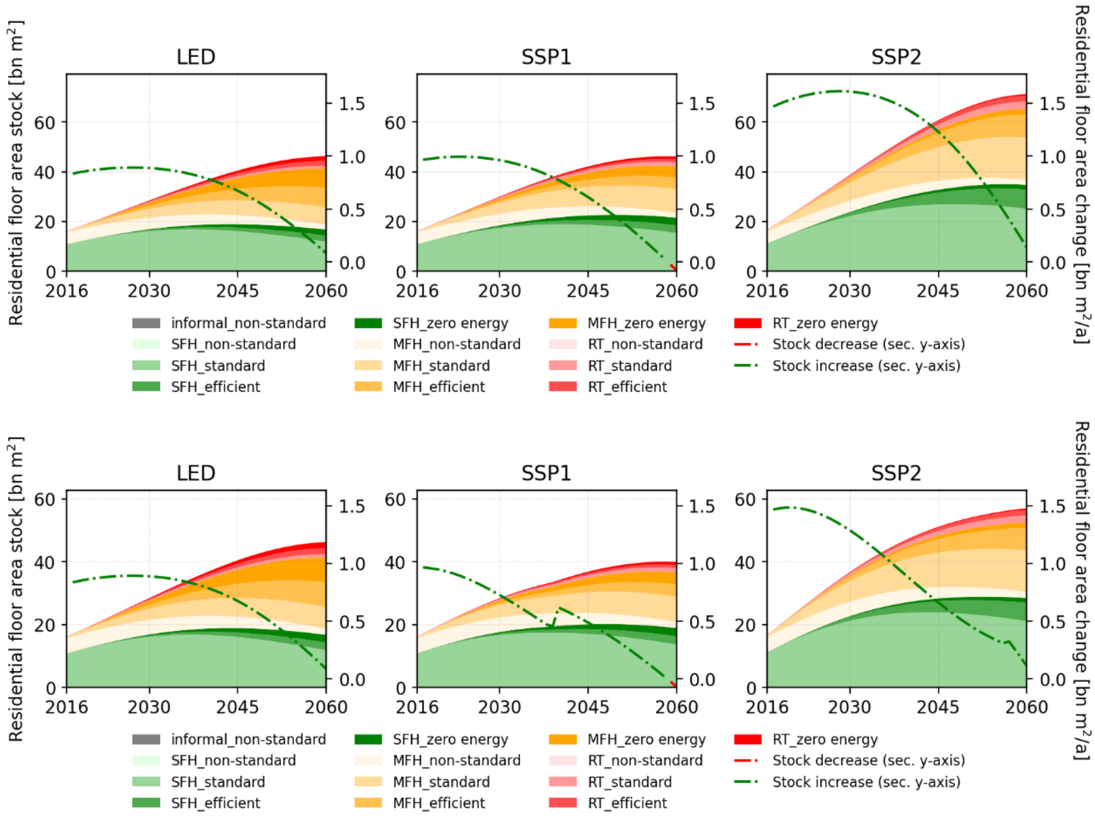


Fig. SI-6-9: Drivers and stock parameters, residential buildings, India. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

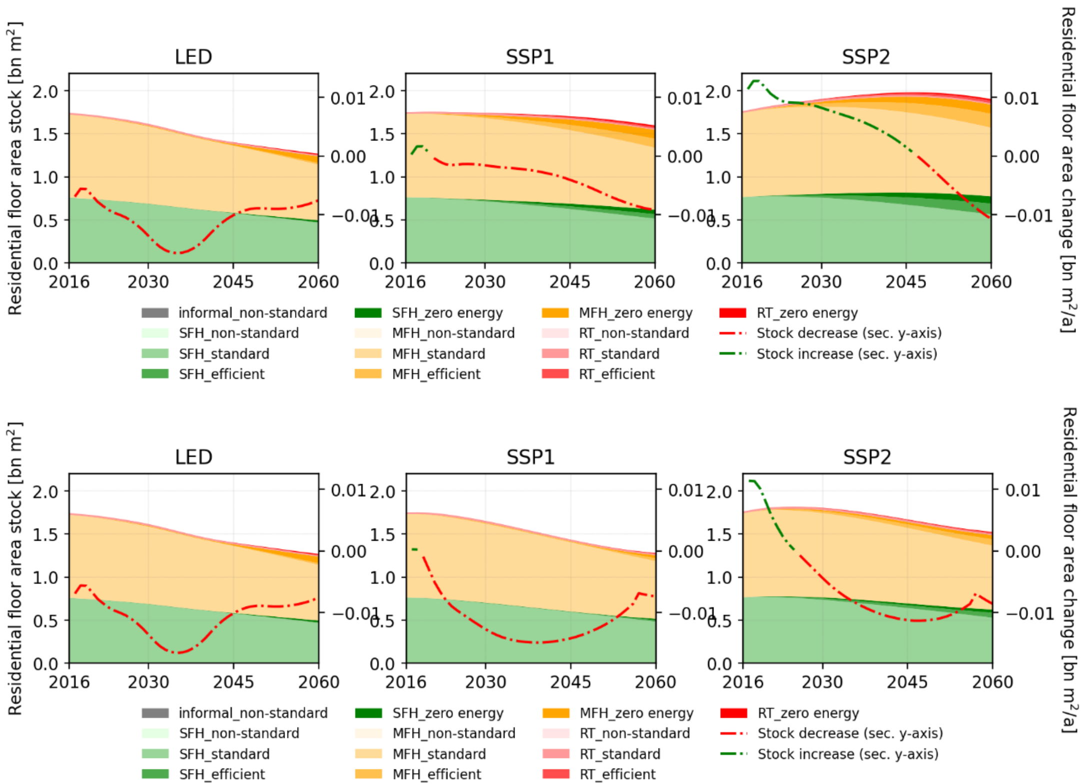


Fig. SI-6-10: Drivers and stock parameters, residential buildings, Spain. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

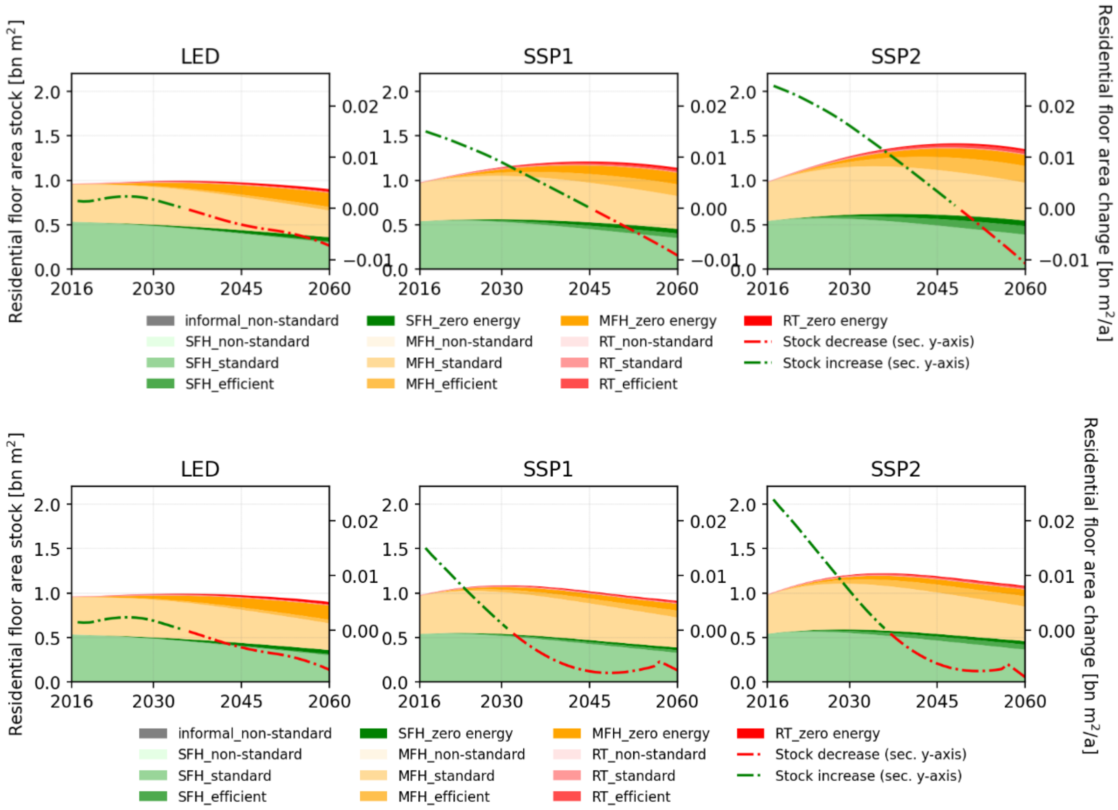


Fig. SI-6-11: Drivers and stock parameters, residential buildings, Poland. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

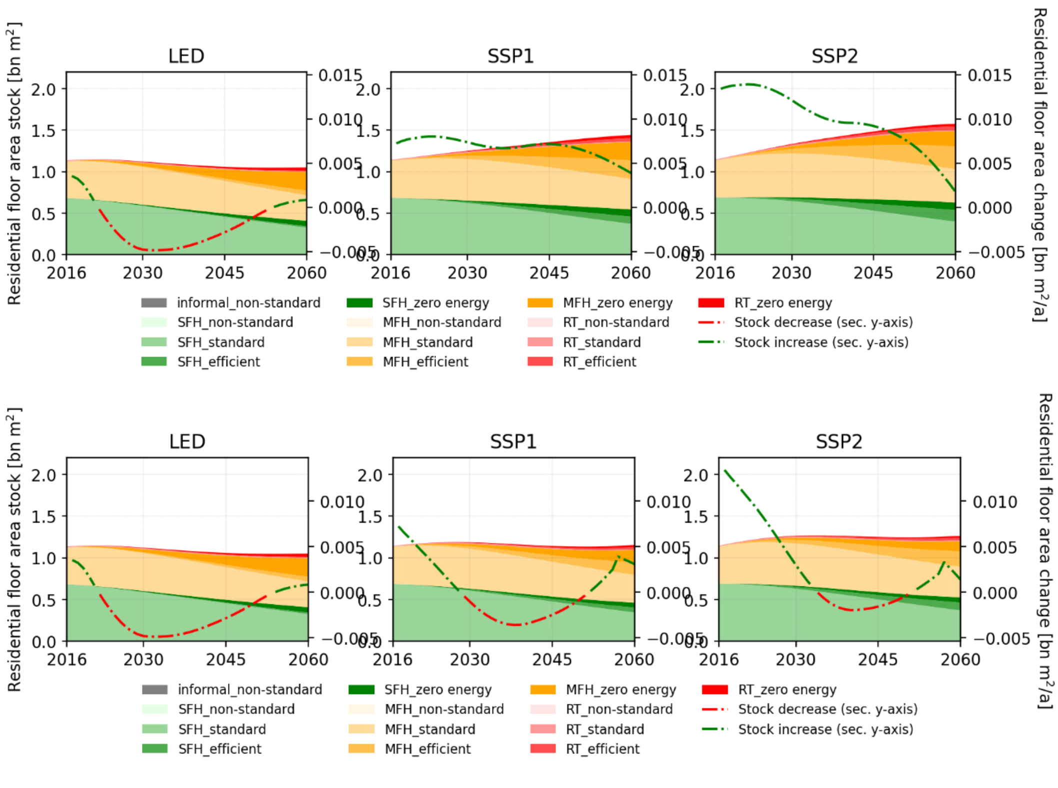


Fig. SI-6-12: Drivers and stock parameters, residential buildings, Oth_R32EU12-H. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

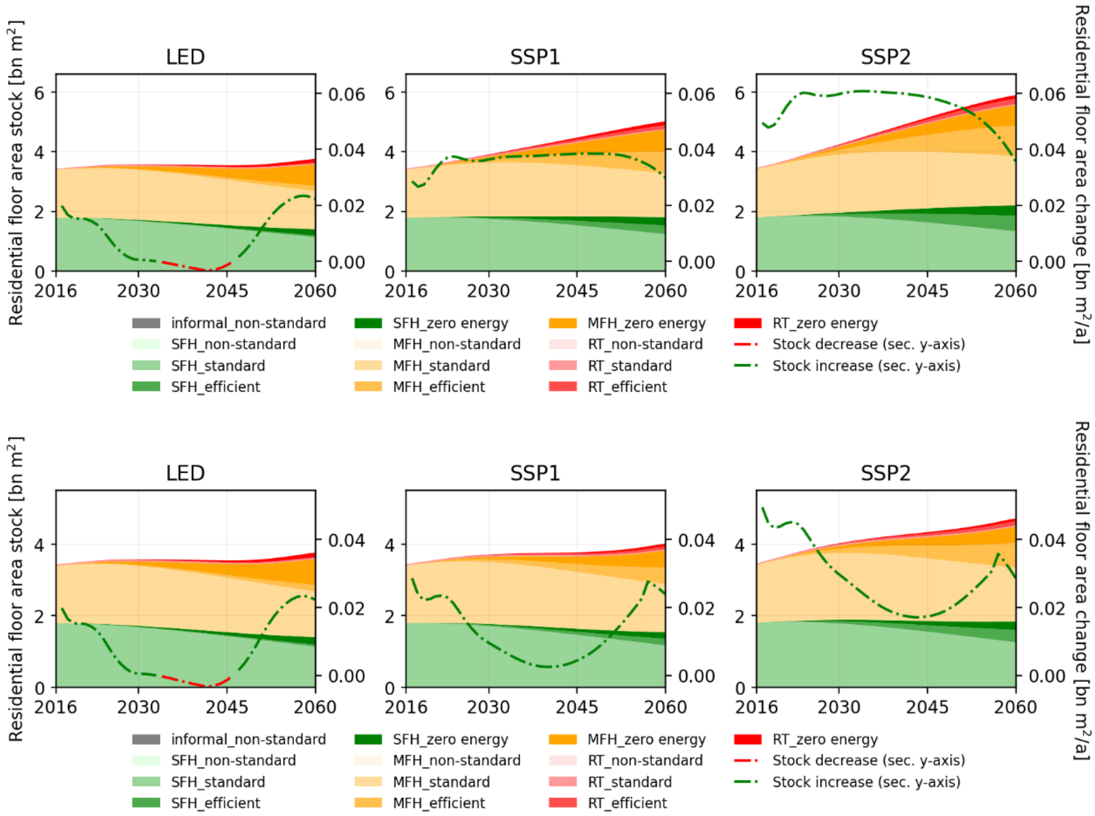


Fig. SI-6-13: Drivers and stock parameters, residential buildings, Oth_R32EU15. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

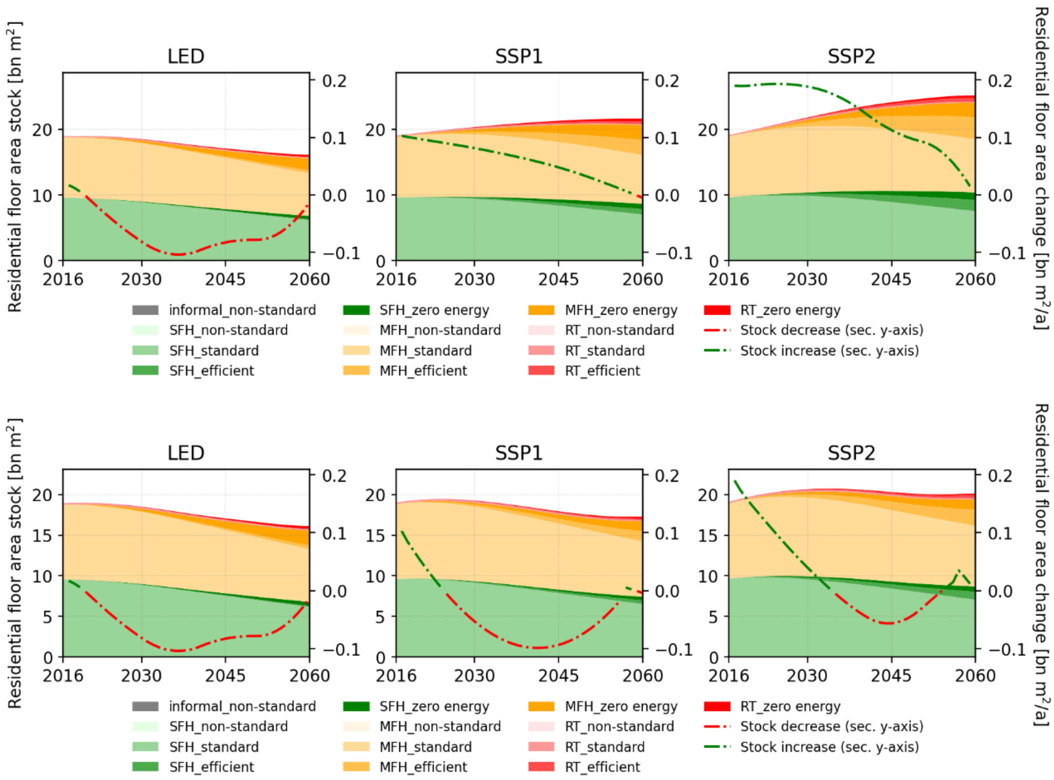


Fig. SI-6-14: Drivers and stock parameters, residential buildings, EU28. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

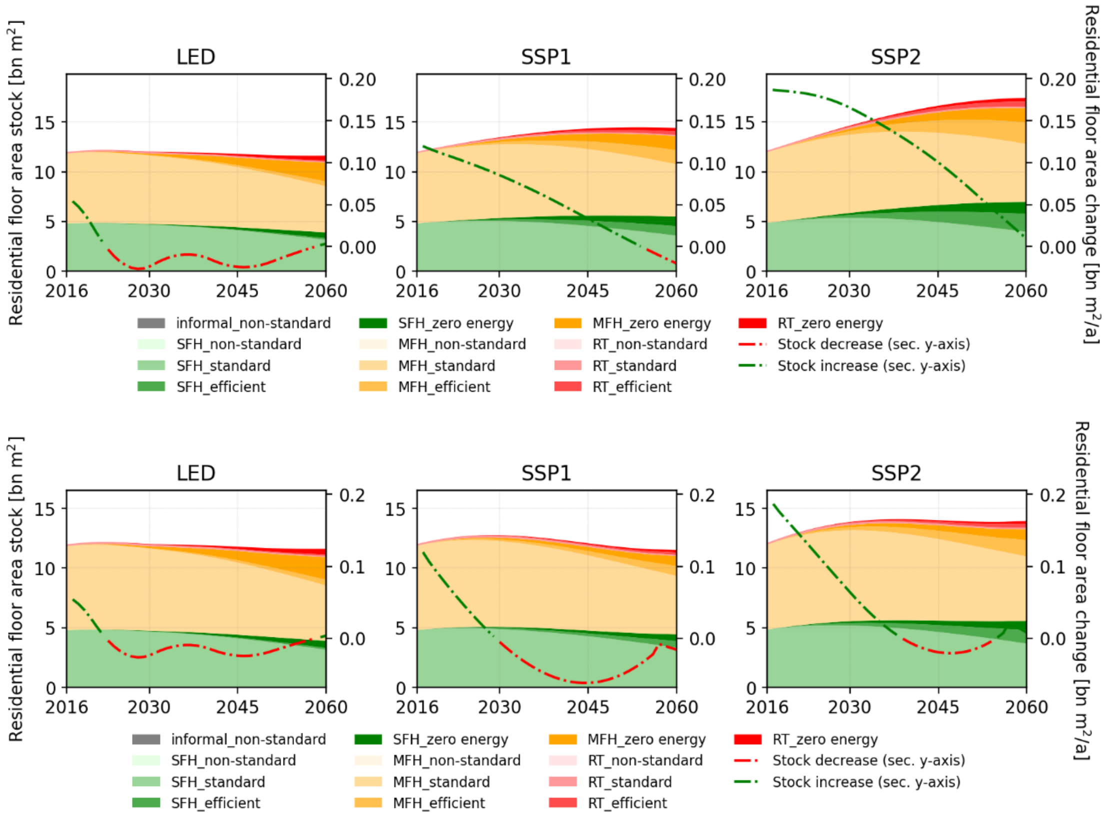


Fig. SI-6-15: Drivers and stock parameters, residential buildings, R5.2OECD_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

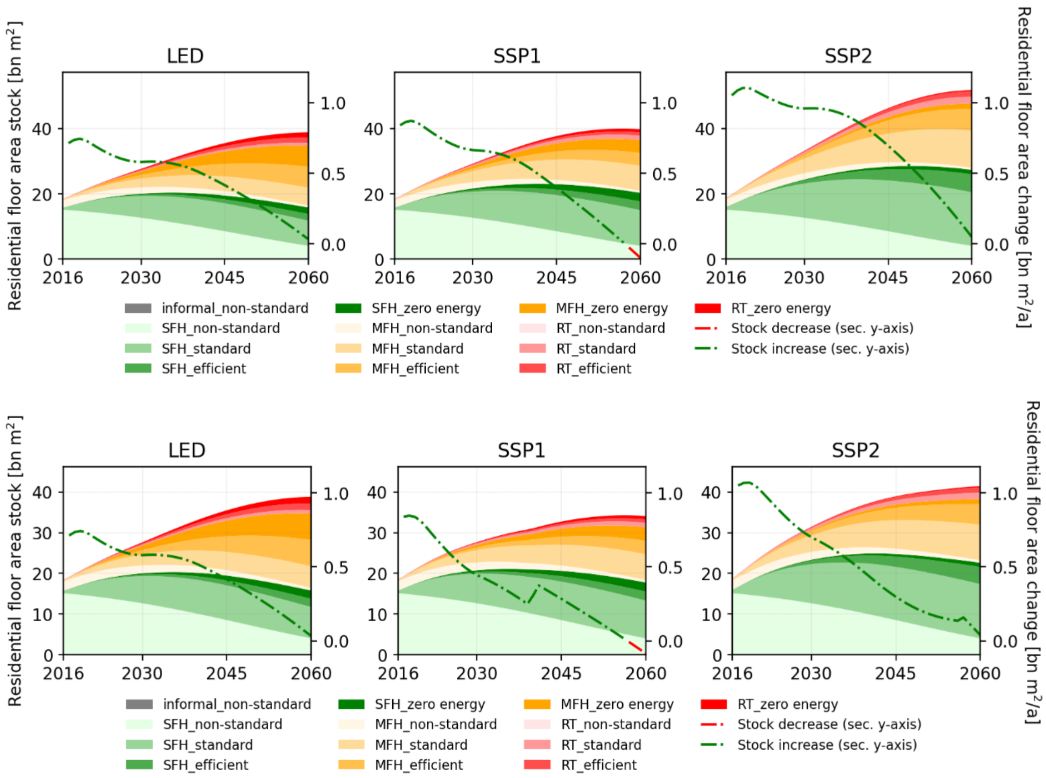


Fig. SI-6-16: Drivers and stock parameters, residential buildings, R5.2Asia_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

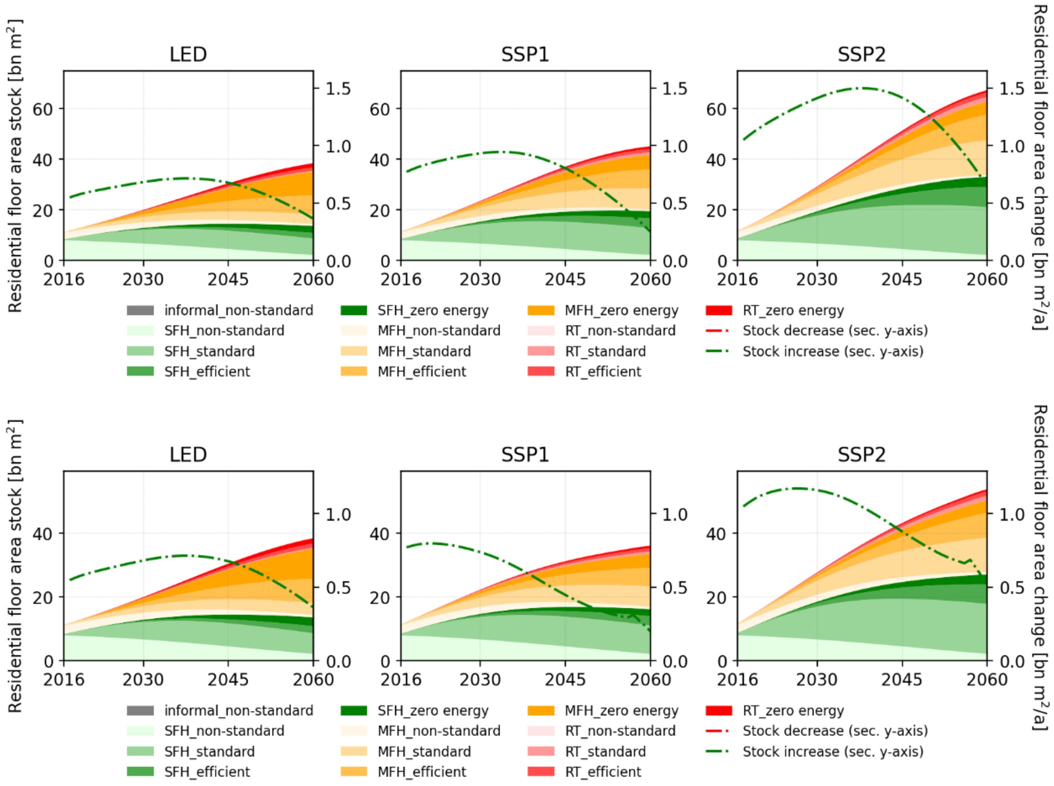


Fig. SI-6-17: Drivers and stock parameters, residential buildings, R5.2SSA_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

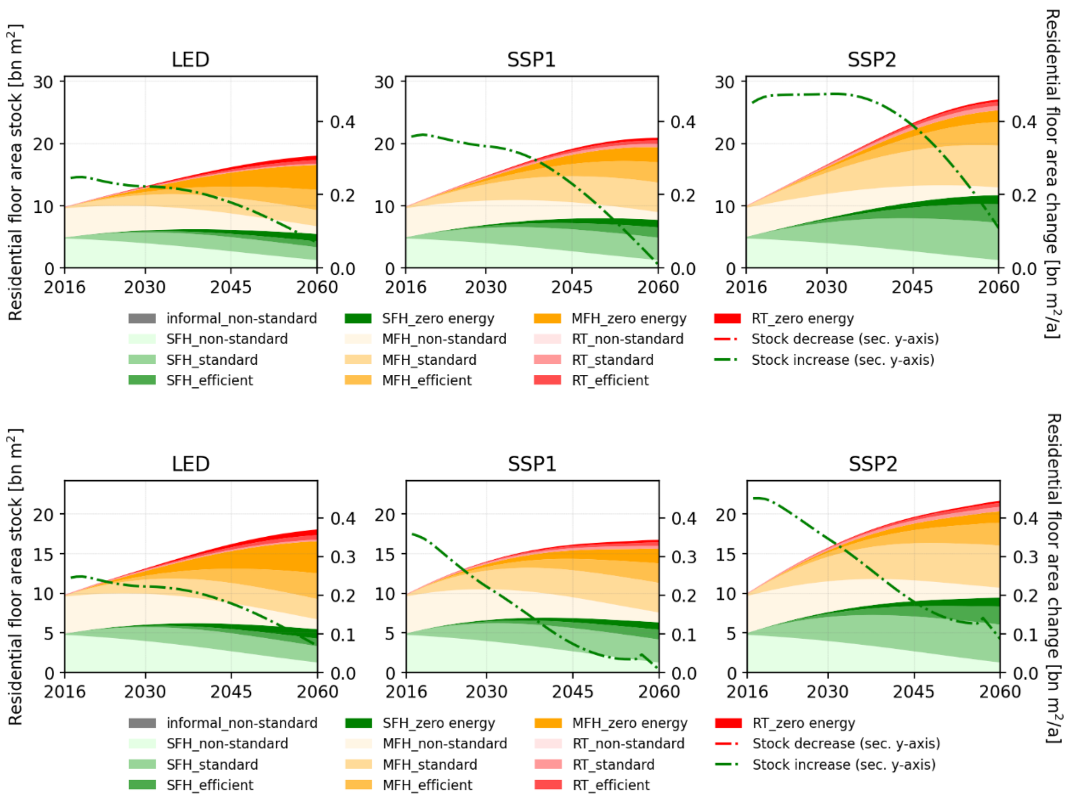


Fig. SI-6-18: Drivers and stock parameters, residential buildings, R5.2MNF_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

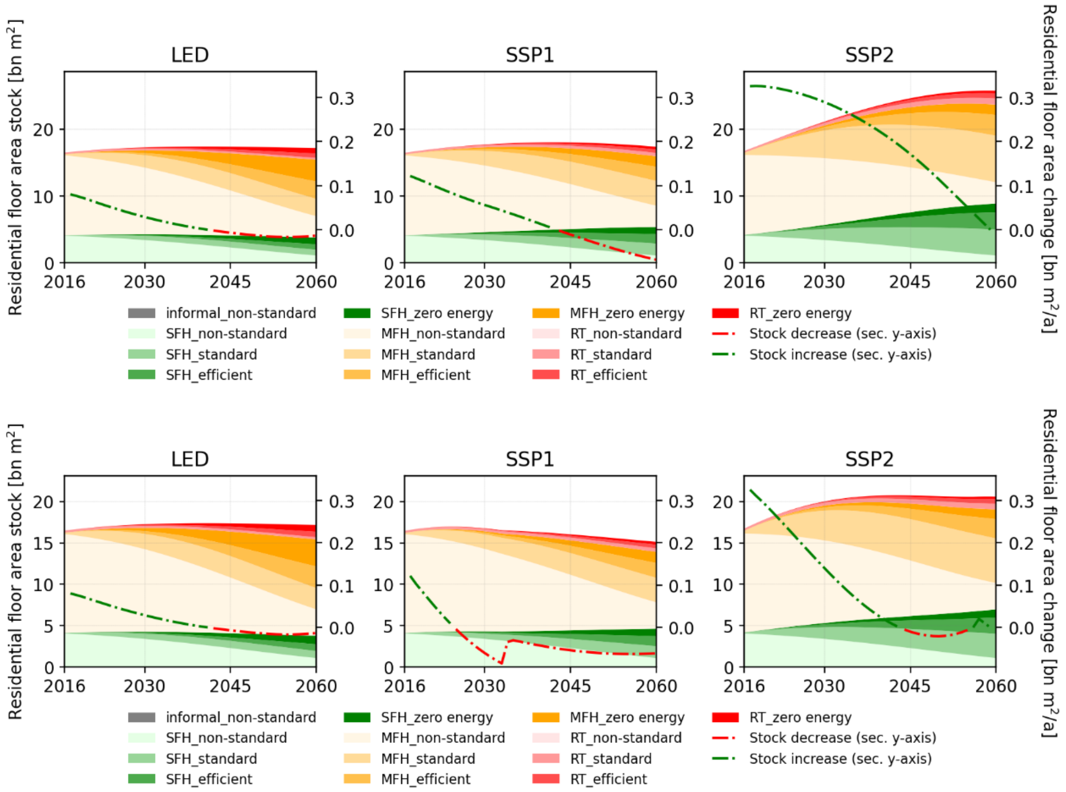


Fig. SI-6-19: Drivers and stock parameters, residential buildings, R5.2LAM_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

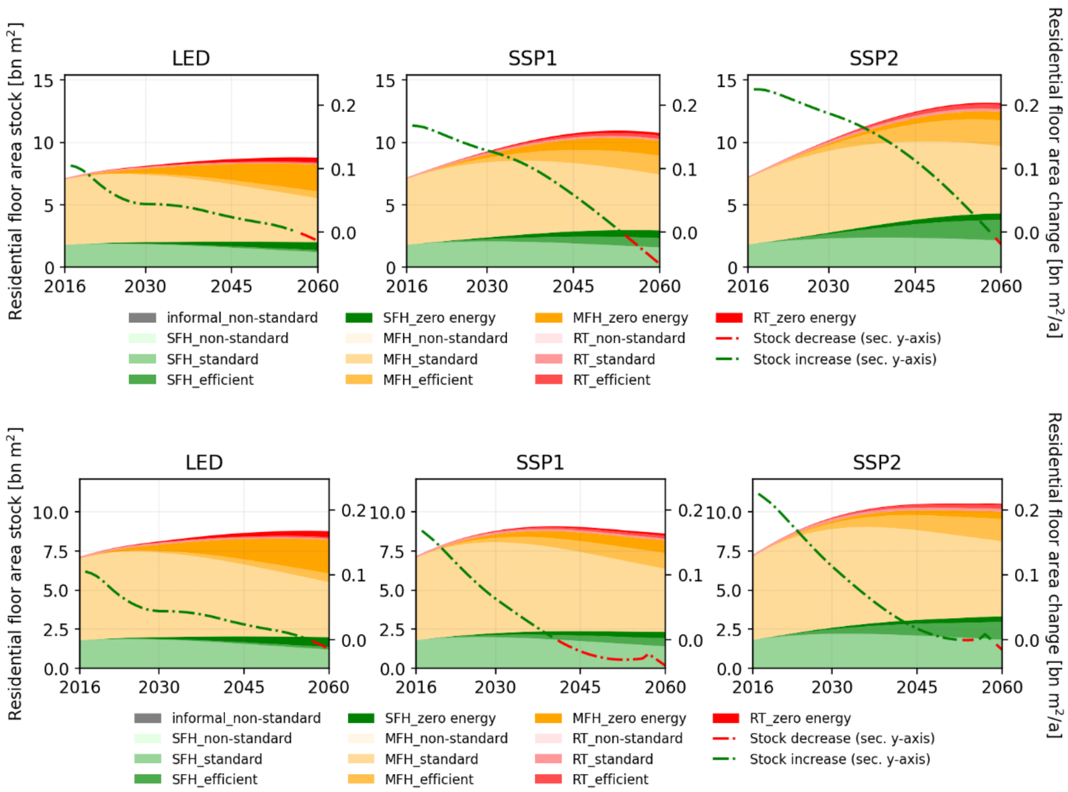


Fig. SI-6-20: Drivers and stock parameters, residential buildings, R5.2REF_Other. Top row: no material efficiency strategies (MES) included, bottom row: full MES spectrum. Results are shown for the 2°C-compatible climate polity scenario.

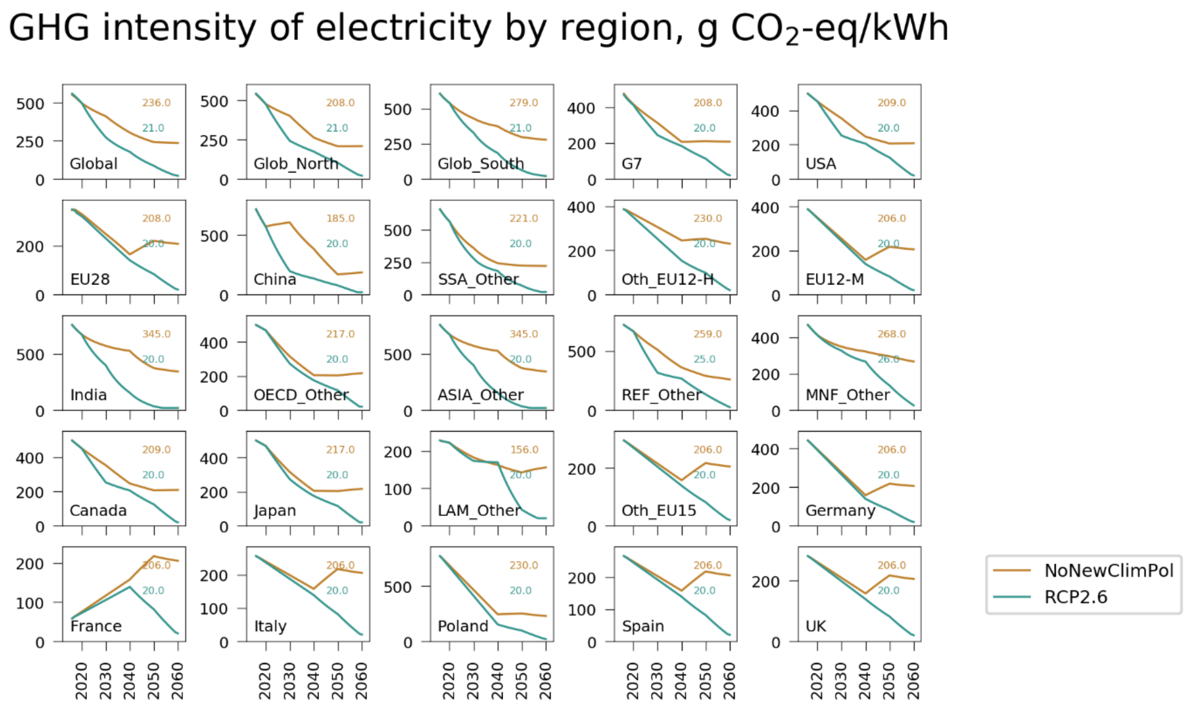


Fig. SI-6a: GHG (CO_2, CH_4, and N_2O) intensity of electricity generation by region.

4. Additional Results and Discussion

Detailed description of Figure 1:

Passenger vehicles, top row:

The striking difference in development is that emissions in the Global North and its constituting regions decline steadily over time, in all scenarios. In the Global South, they tend to peak between 2030 and 2040 (2°C scenario) or continue to increase (NoNewClimPol scenario). This behavior is a direct consequence of contraction and convergence of service levels: Global North service levels decline and are provided more efficiently, allowing for absolute decoupling of GHG emissions. Global South service levels increase substantially in most regions (current car ownership rate in Sub-Saharan Africa is ca. 18 cars per 1000 people), and fuel shift, low carbon energy supply, and ME can counter this strong growth trend only in the 2°C scenario and only after 2030. For China, the trend reversal can happen earlier, between 2025 and 2030.

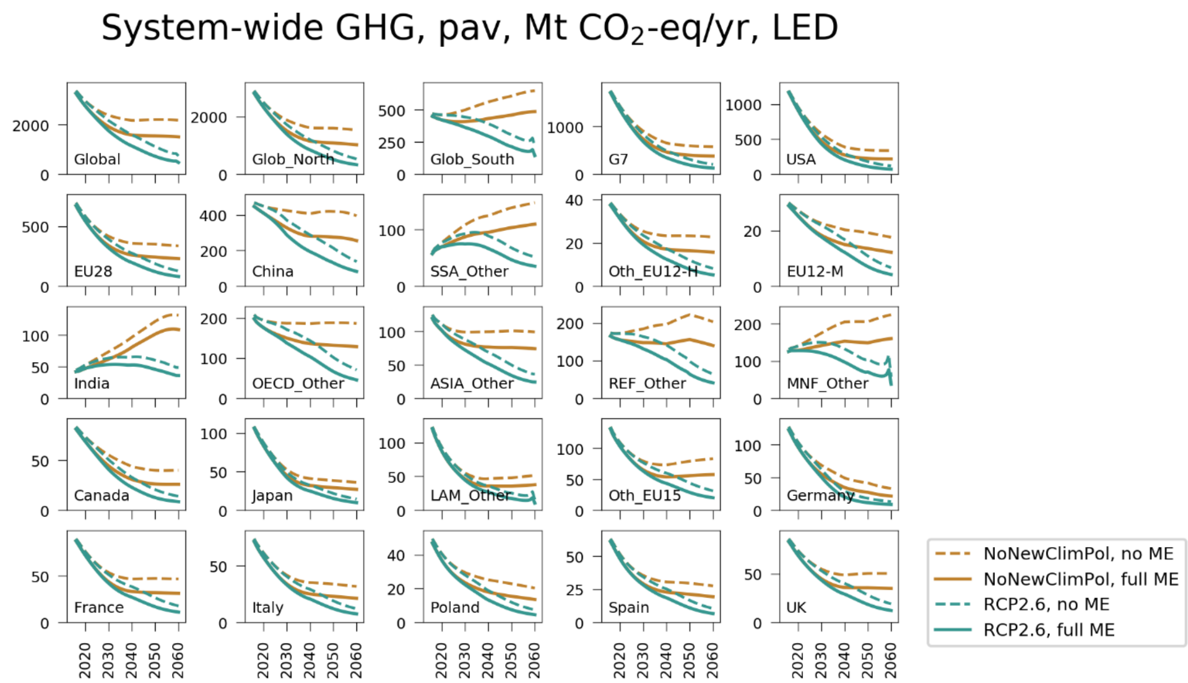
In the SSP1 (easy mitigation and adaptation) scenario, the relative impact of full ME is similar in both climate policy scenarios, because both non-ME baselines are material-intensive, with a 15 year product lifetime and substantial improvement potential for end-of-life scrap recovery especially for plastics but also for the other materials. The shift to smaller segments and light cars and the car- and ride-sharing strategies are important contributors as well.

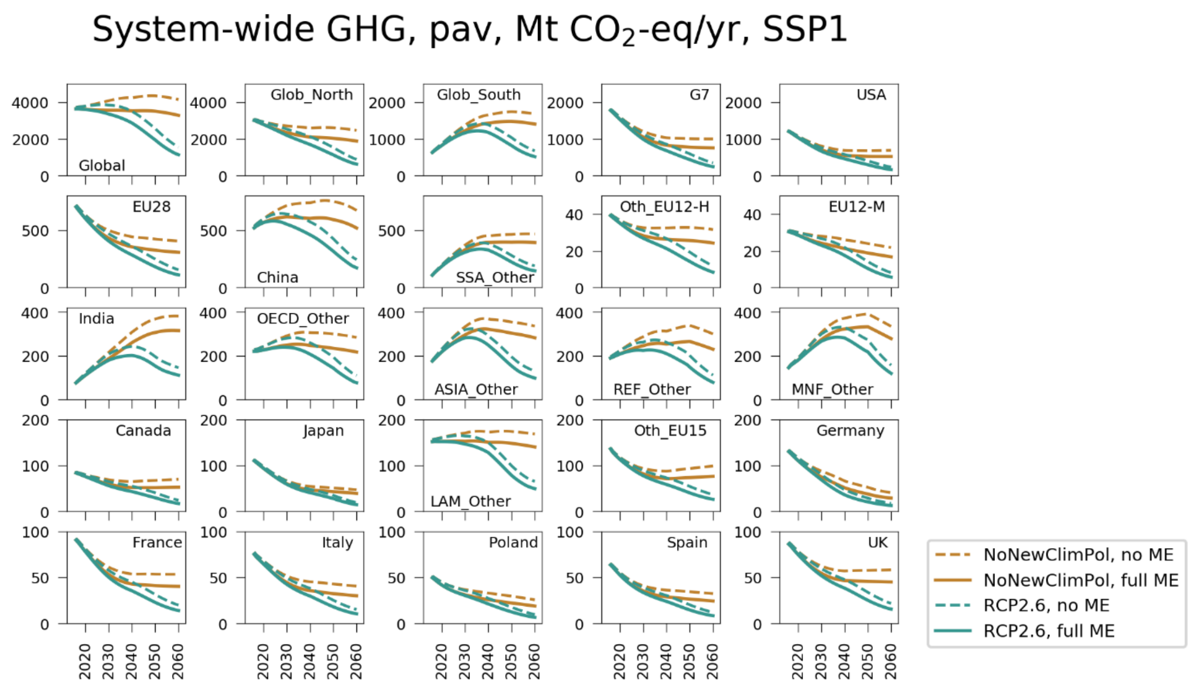
Residential buildings, bottom row:

Here, all regions show a huge GHG emissions reduction potential, as – despite strong growth in the regions of the Global South – the emissions reductions from increased energy efficiency in buildings outpace all assumed growth. Still, especially in the NoNewClimPol scenario, 2050 emissions without ME are nowhere near carbon neutrality, which is an aspiration for the easy-to-mitigate residential building sector in some strategy portfolios (zero emission buildings). Here, the ME strategies can prove particularly effective in achieving deep emissions cuts: In some regions, including the global total, Global South, China, India, and Sub-Saharan Africa, The 2°C-plus-ME GHG emissions are only a fraction of the 2°C-no-ME emissions, and for some regions (for SSP1: Global South, Other Asia, Middle East-Northern Africa, and India), forest carbon uptake associated with residential building timber use even leads to total negative emissions.

Regarding the forest regrowth modelling: There are of course some big assumptions here: that sustainable harvest exists and is possible at the scale required, that forests would not have added carbon to storage without timber removal, and there is no opportunity cost of the timber no longer being available for other carbon-saving measures.

4.1. Emissions by region, sector, and scenario





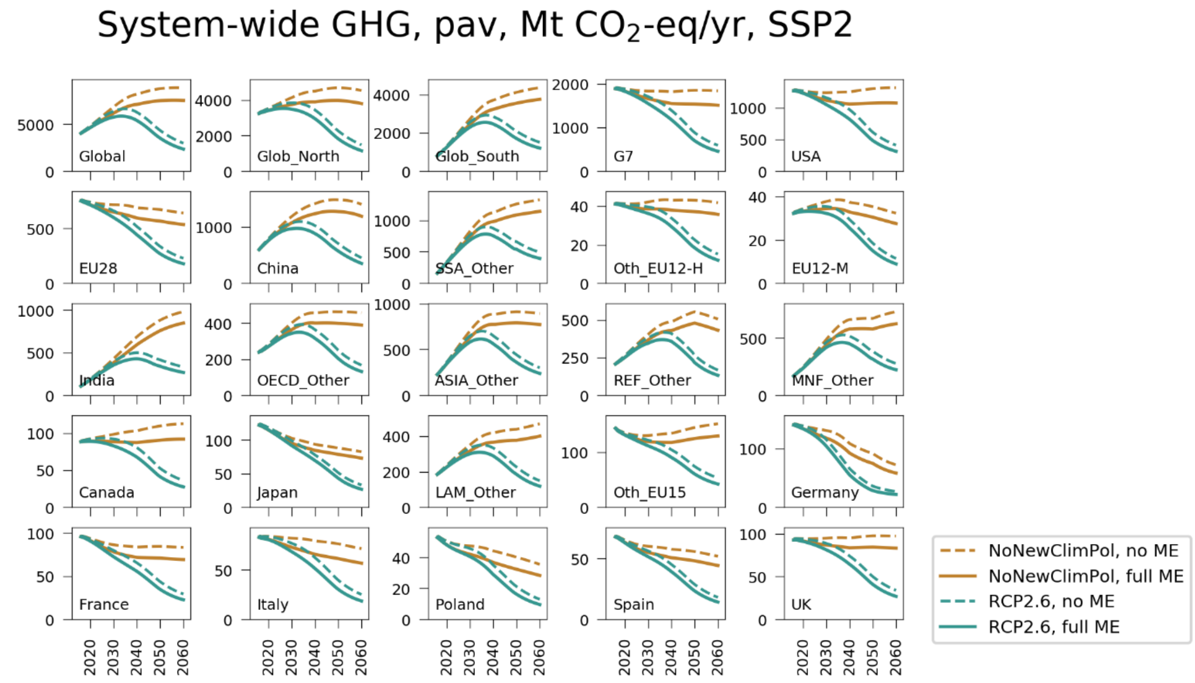
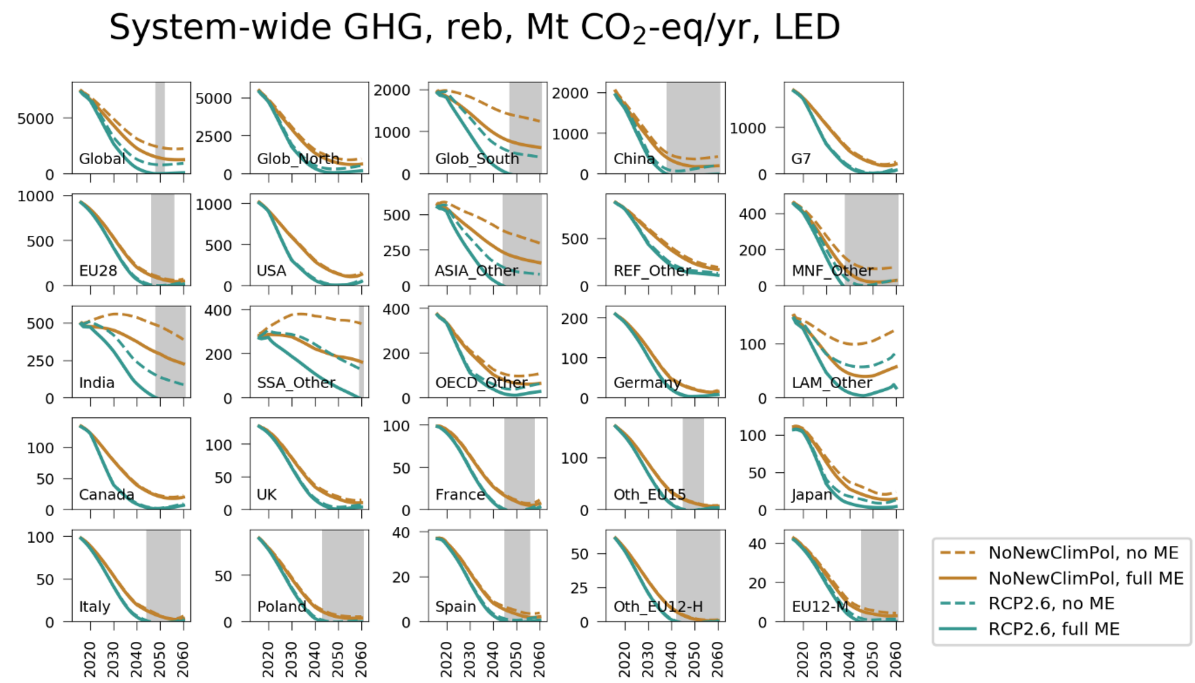
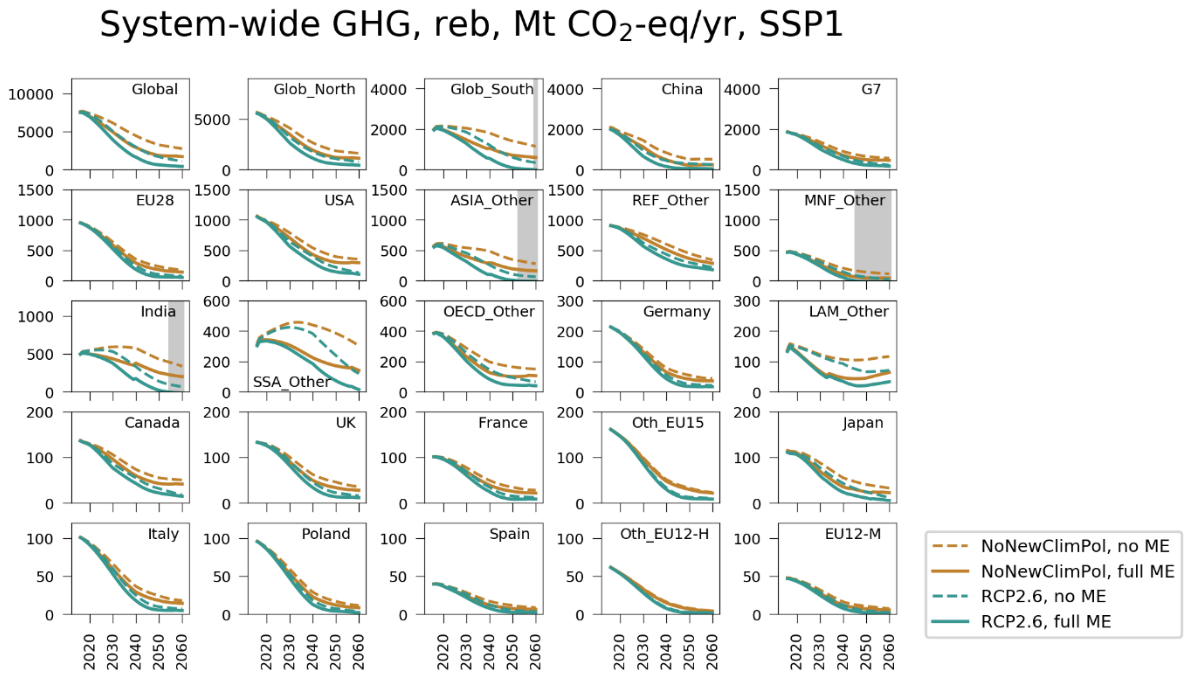


Fig. SI-7: Emissions by region and socioeconomic/policy scenario plus RES on/off. Passenger vehicles.





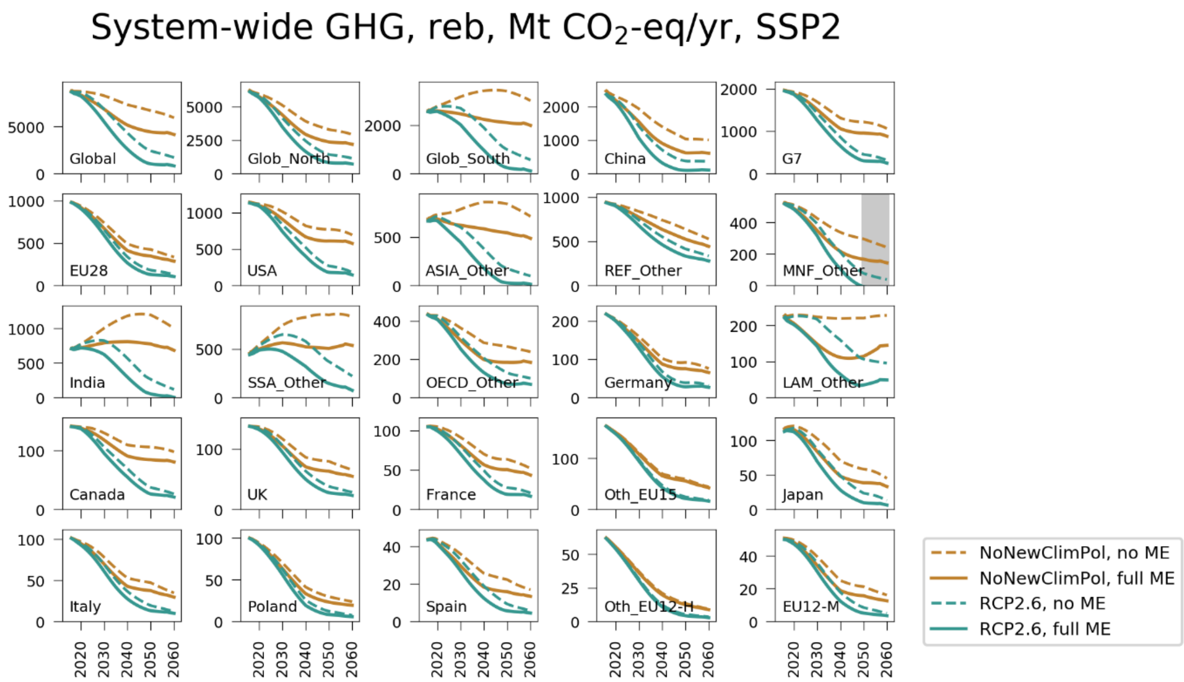
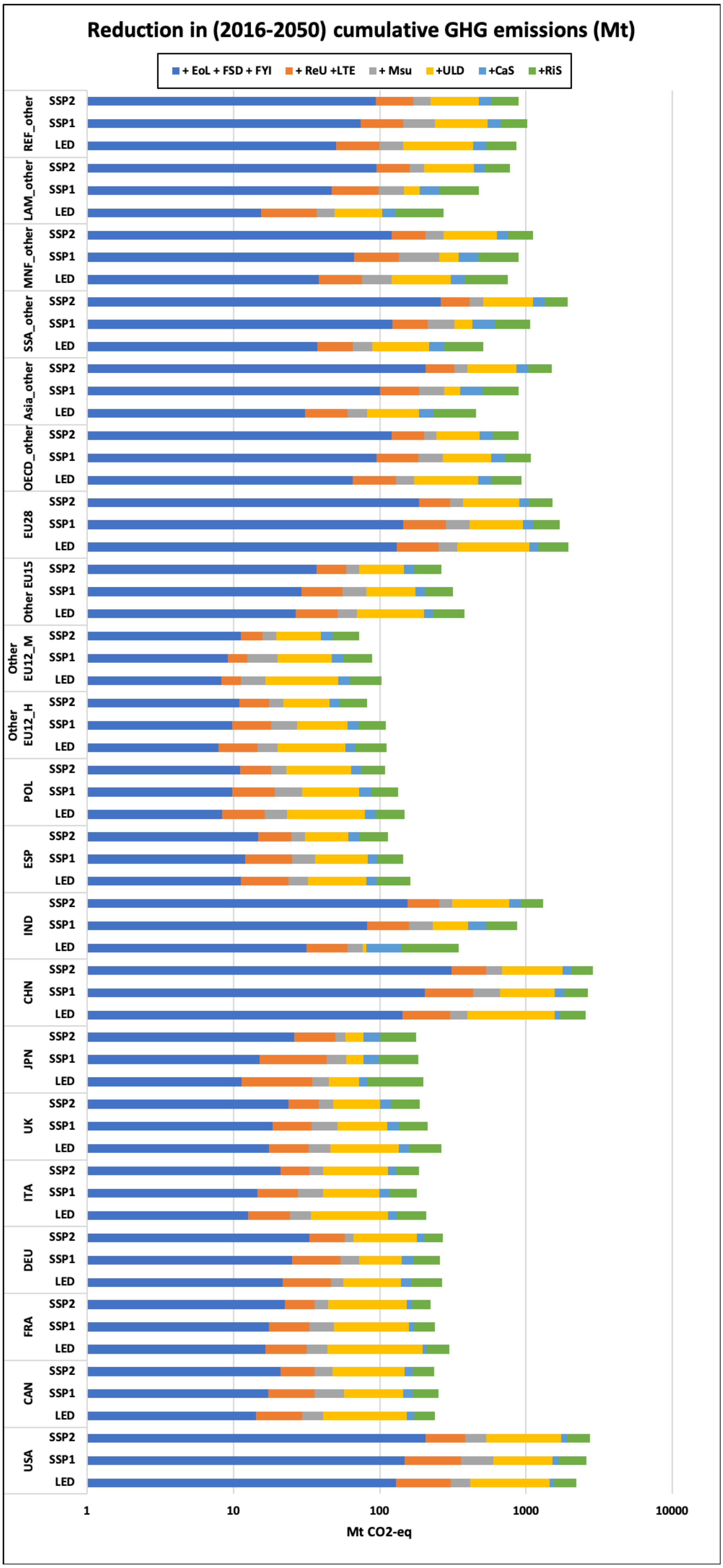


Fig. SI-8: Emissions by region and socioeconomic/policy scenario plus RES on/off. Residential buildings. Grey shaded areas highlight periods of regional carbon negativity, which is due to forest carbon uptake as a consequence of previous timber harvesting and regrowth.

4.2. Cumulative emissions savings 2016-2060 for the different RES, regions, socioeconomic scenarios, and sectors

Fig. SI-9 (next page): Cumulative (2016-2060) emissions reductions through material efficiency in the passenger vehicle sector. For RCP2.6 scenario.



Reduction in (2016-2050) cumulative GHG emissions (Mt)
+ EoL + FSD + FYI
+ ReU +LTE
+ Msu
+ULD
+CaS
+RiS
REF_other
LAM_other
MNF_other
SSA_other
Asia_other
OECD_other
EU28
Other EU15
Other EU12_M
Other EU12_H
POL
ESP
IND
CHN
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SSP2
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LED
1
10
100
1000
10000
Mt CO2-eq

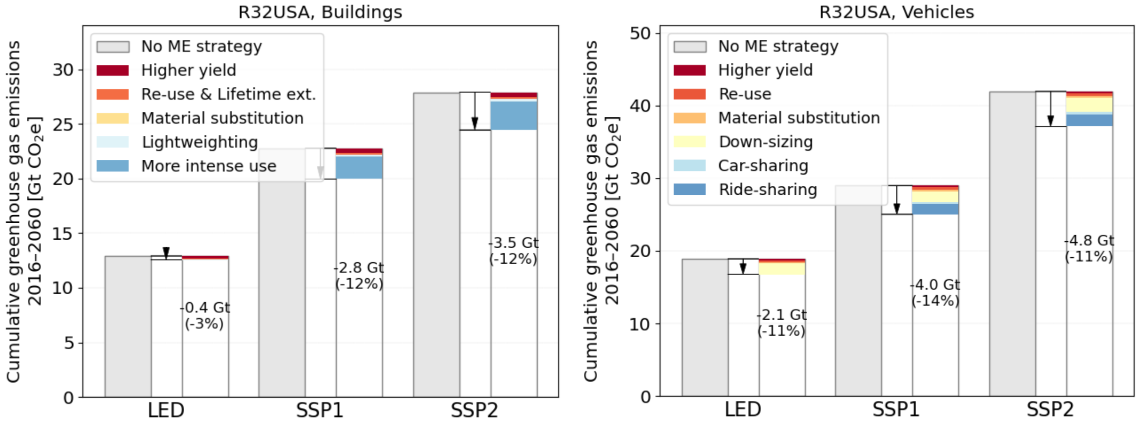


Fig. SI-10-1: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, USA. For RCP2.6.

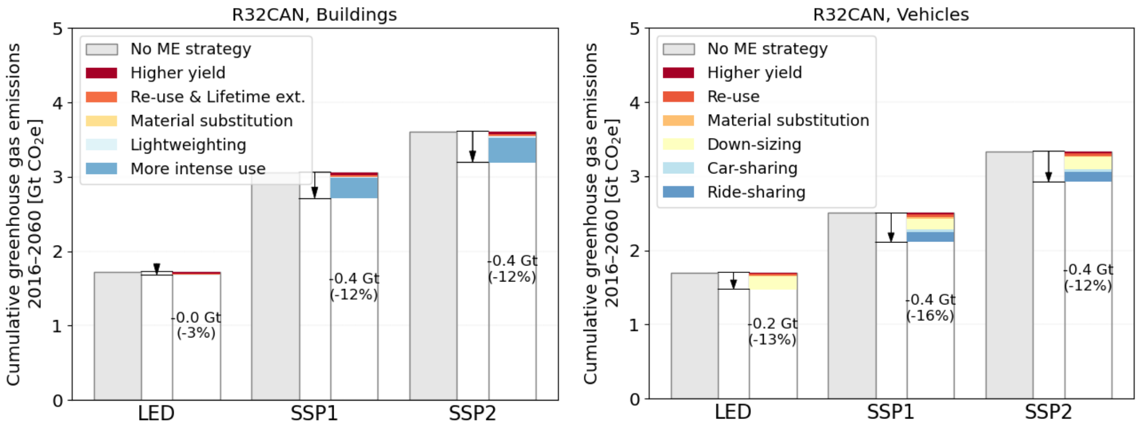


Fig. SI-10-2: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Canada. For RCP2.6.

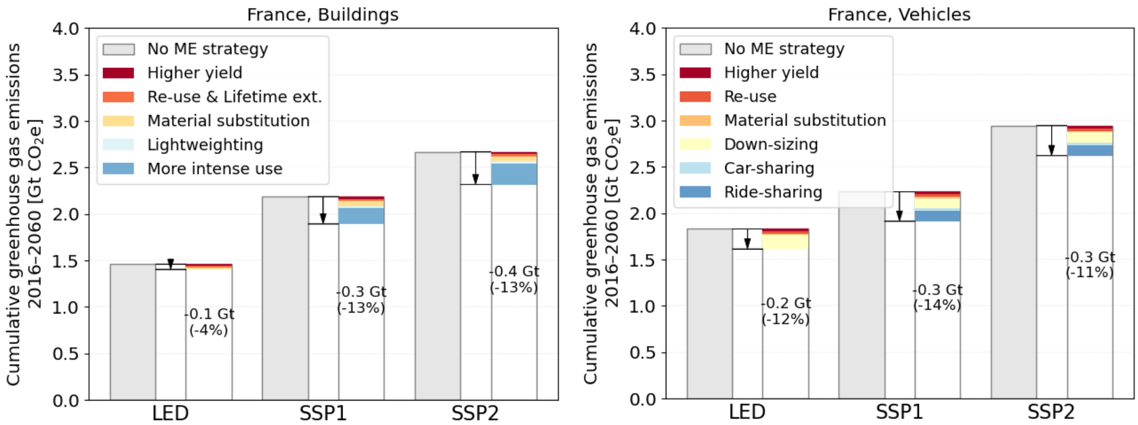


Fig. SI-10-3: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, France. For RCP2.6

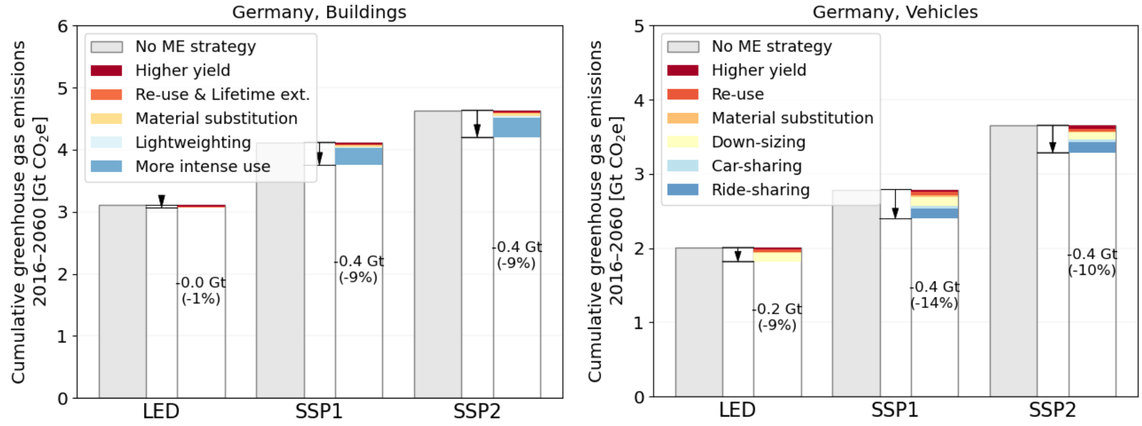


Fig. SI-10-4: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Germany. For RCP2.6

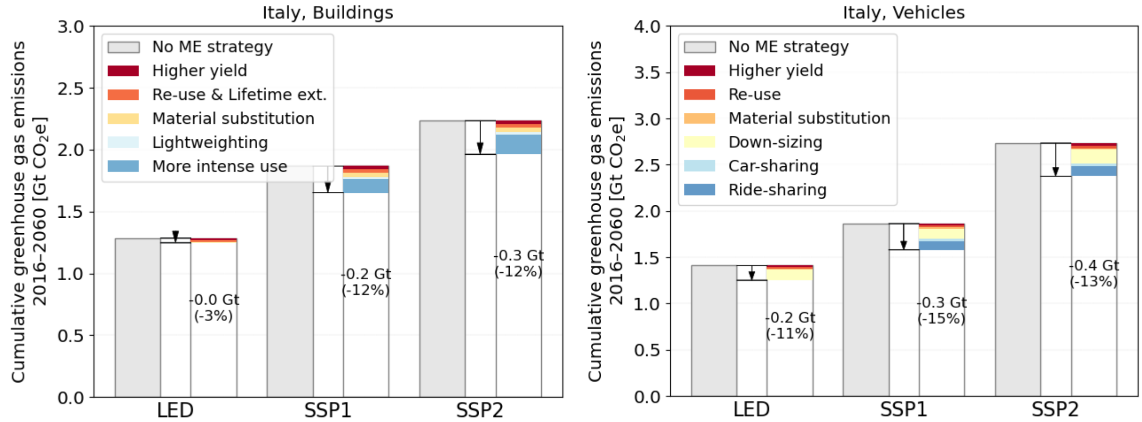


Fig. SI-10-5: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Italy. For RCP2.6

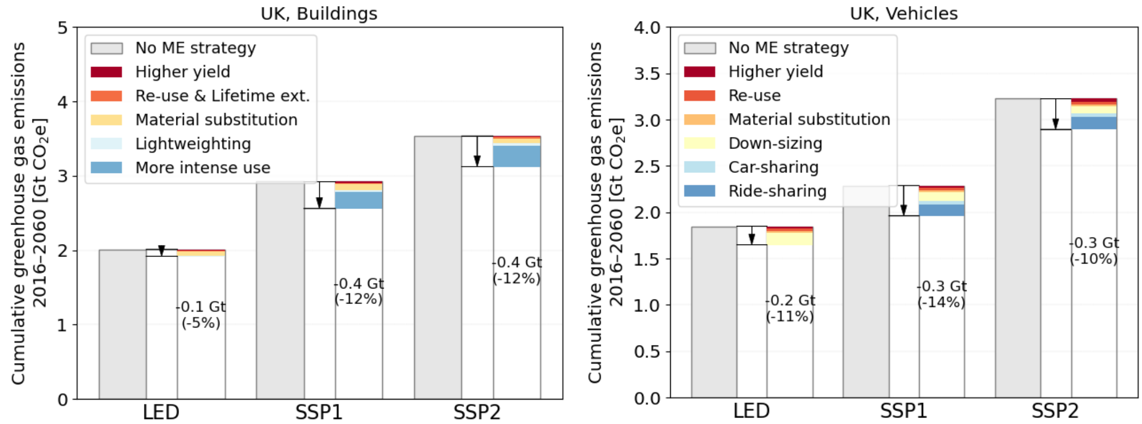


Fig. SI-10-6: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, UK. For RCP2.6

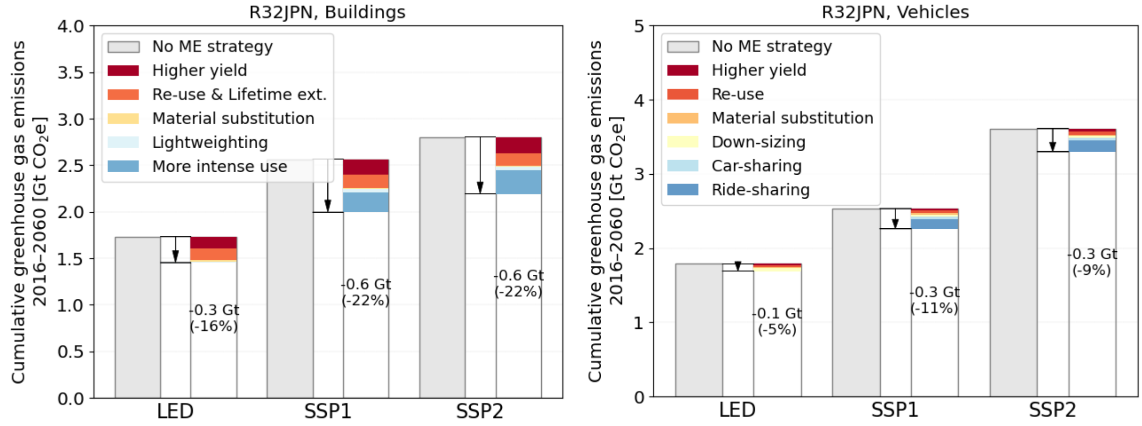


Fig. SI-10-7: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Japan. For RCP2.6.

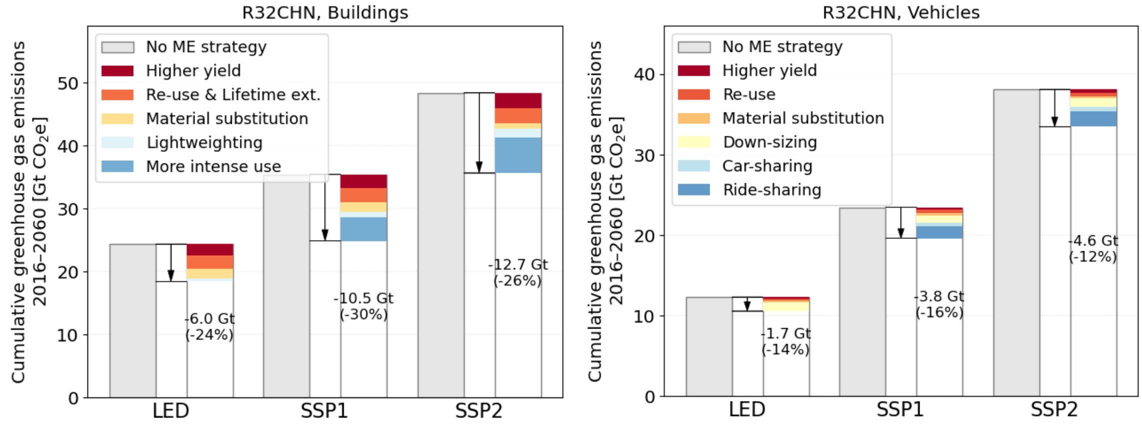


Fig. SI-10-8: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, China. For RCP2.6.

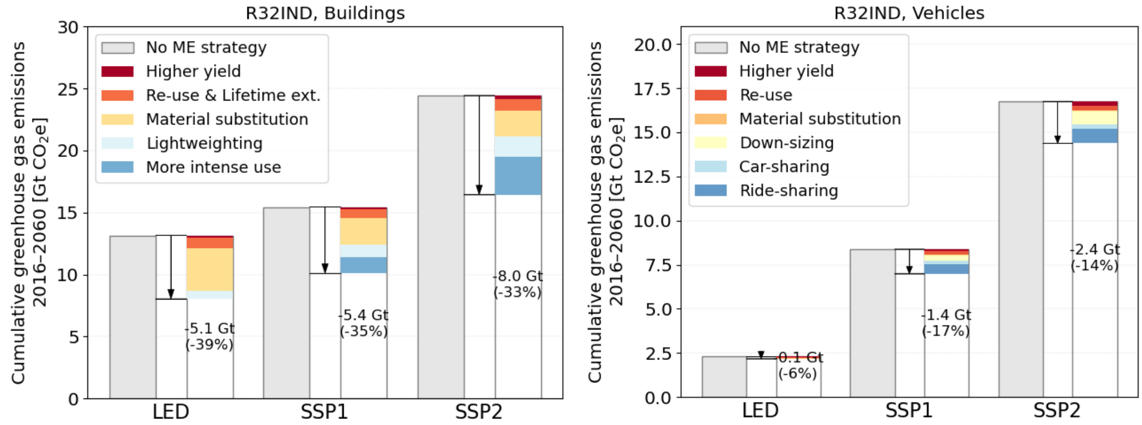


Fig. SI-10-9: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, India. For RCP2.6.

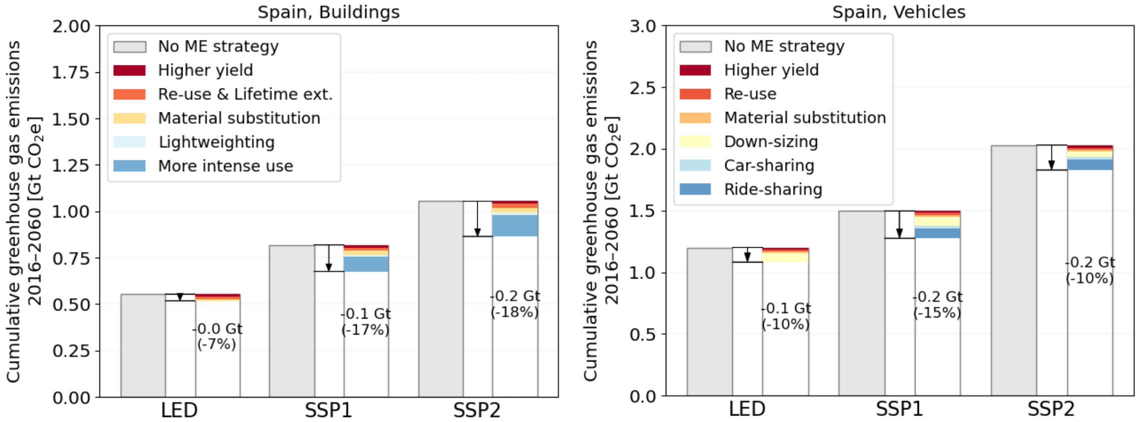


Fig. SI-10-10: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Spain. For RCP2.6

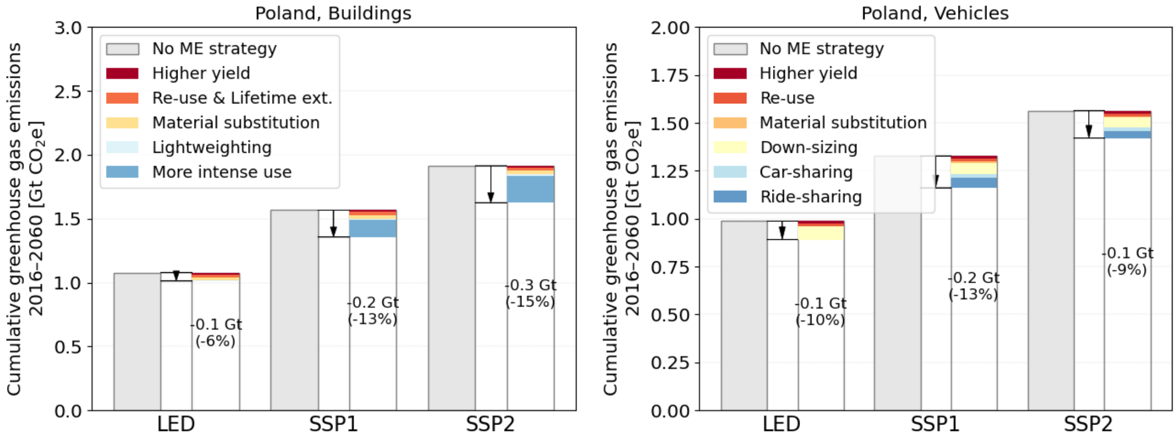


Fig. SI-10-11: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Poland. For RCP2.6.

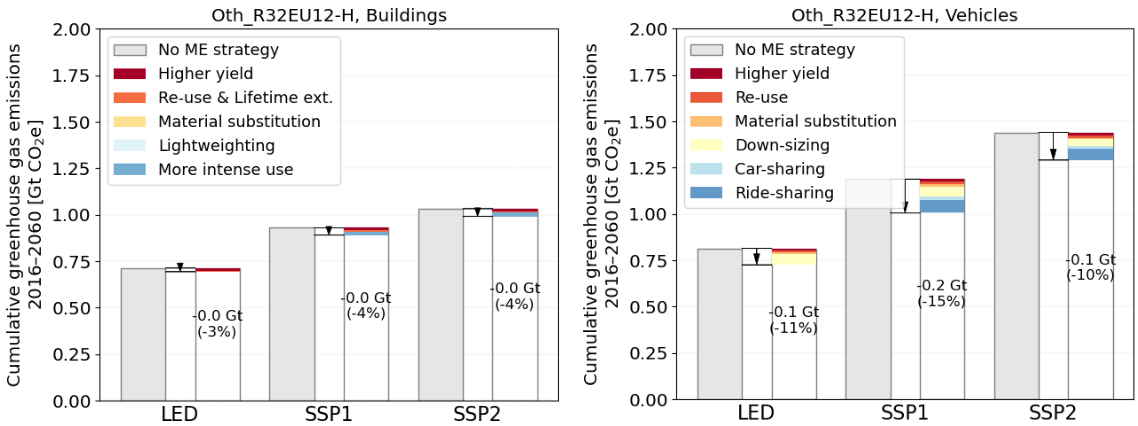


Fig. SI-10-12: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Oth_R32EU12-H. For RCP2.6.

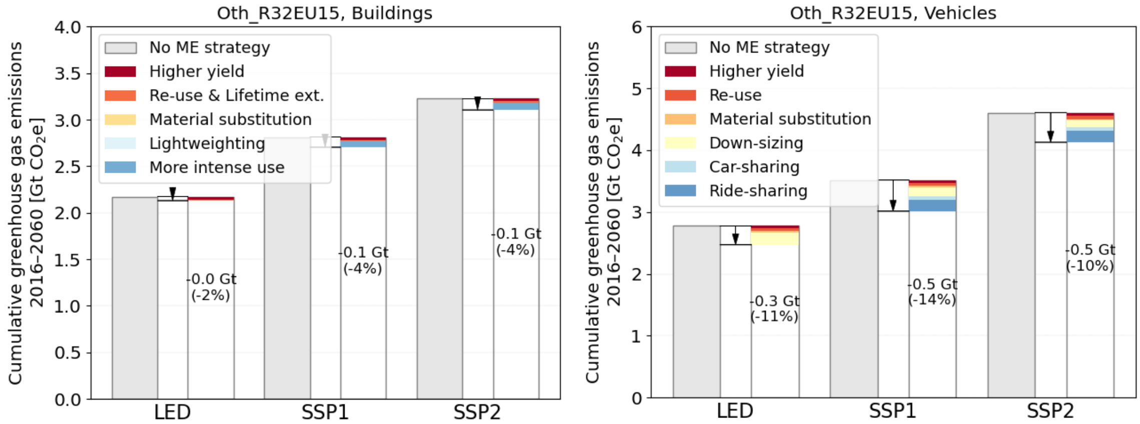


Fig. SI-10-13: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Oth_R32EU15. For RCP2.6.

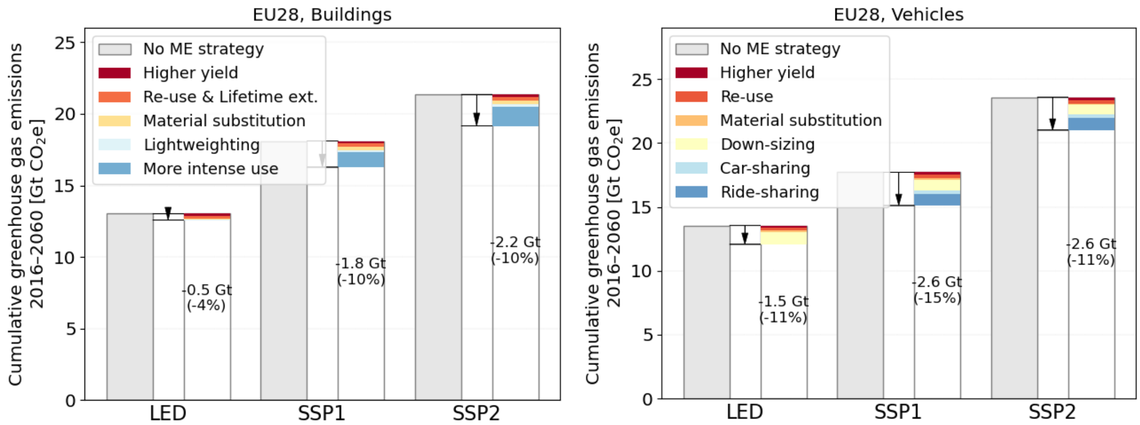


Fig. SI-10-14: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, EU28. For RCP2.6.

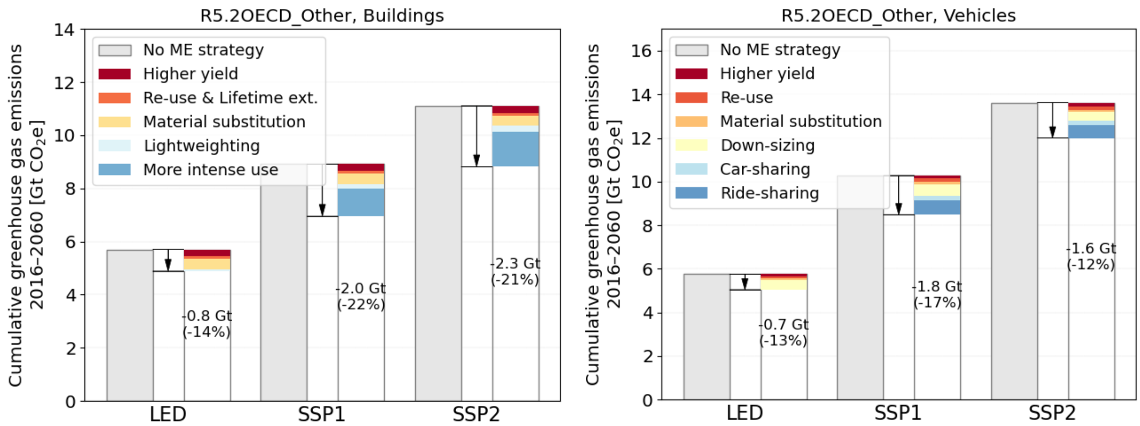


Fig. SI-10-15: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, R5.2OECD_Other. For RCP2.6.

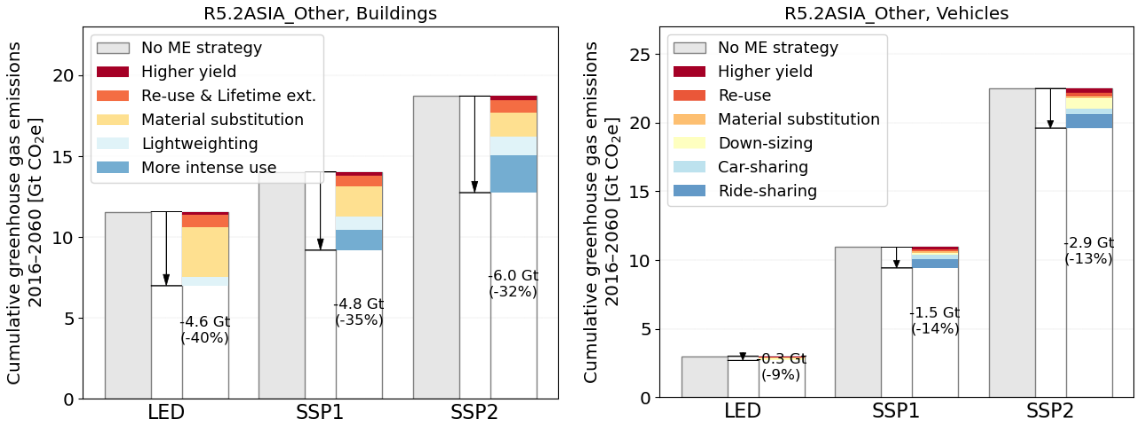


Fig. SI-10-16: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, Asia_Other. For RCP2.6.

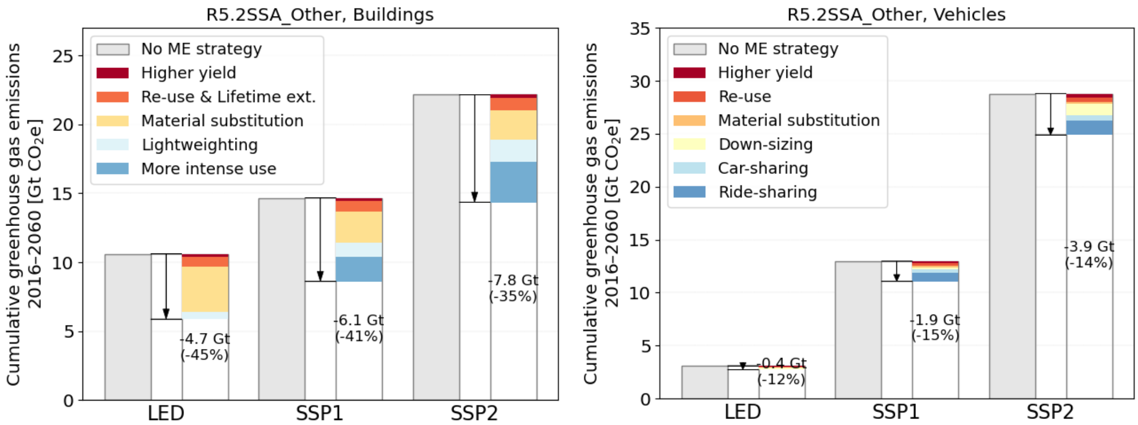


Fig. SI-10-17: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, R5.2SSA_Other. For RCP2.6.

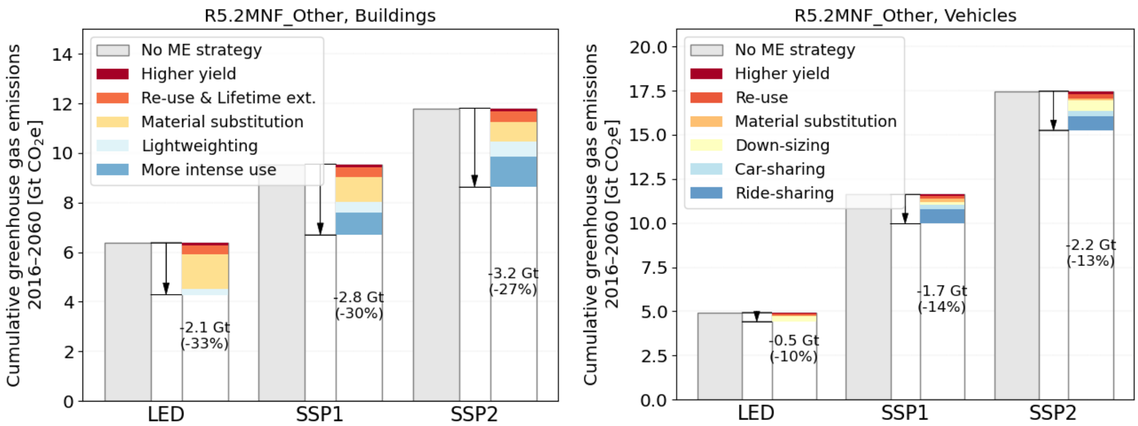


Fig. SI-10-18: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, R5.2MNF_Other. For RCP2.6.

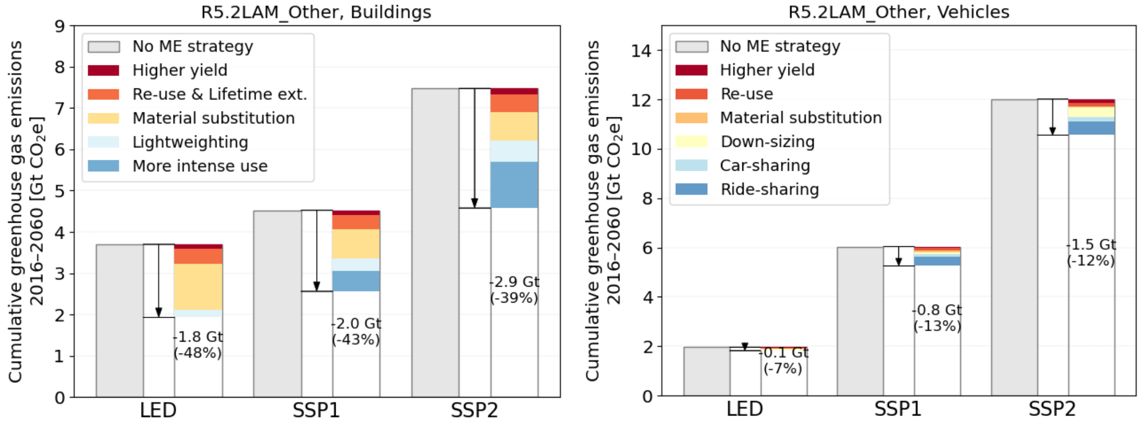


Fig. SI-10-19: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, R5.2LAM_Other. For RCP2.6.

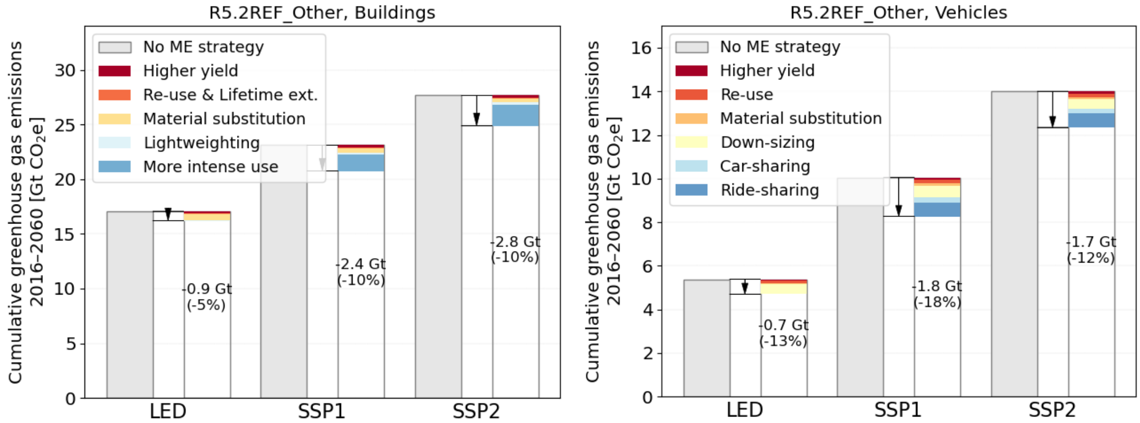


Fig. SI-10-20: RES impacts on cumulative emissions, 2016-2060, passenger vehicles and residential buildings, R5.2REF_Other. For RCP2.6.

4.3. Impact of ME on the difficult-to-mitigate emissions in material production for the pav and reb sectors

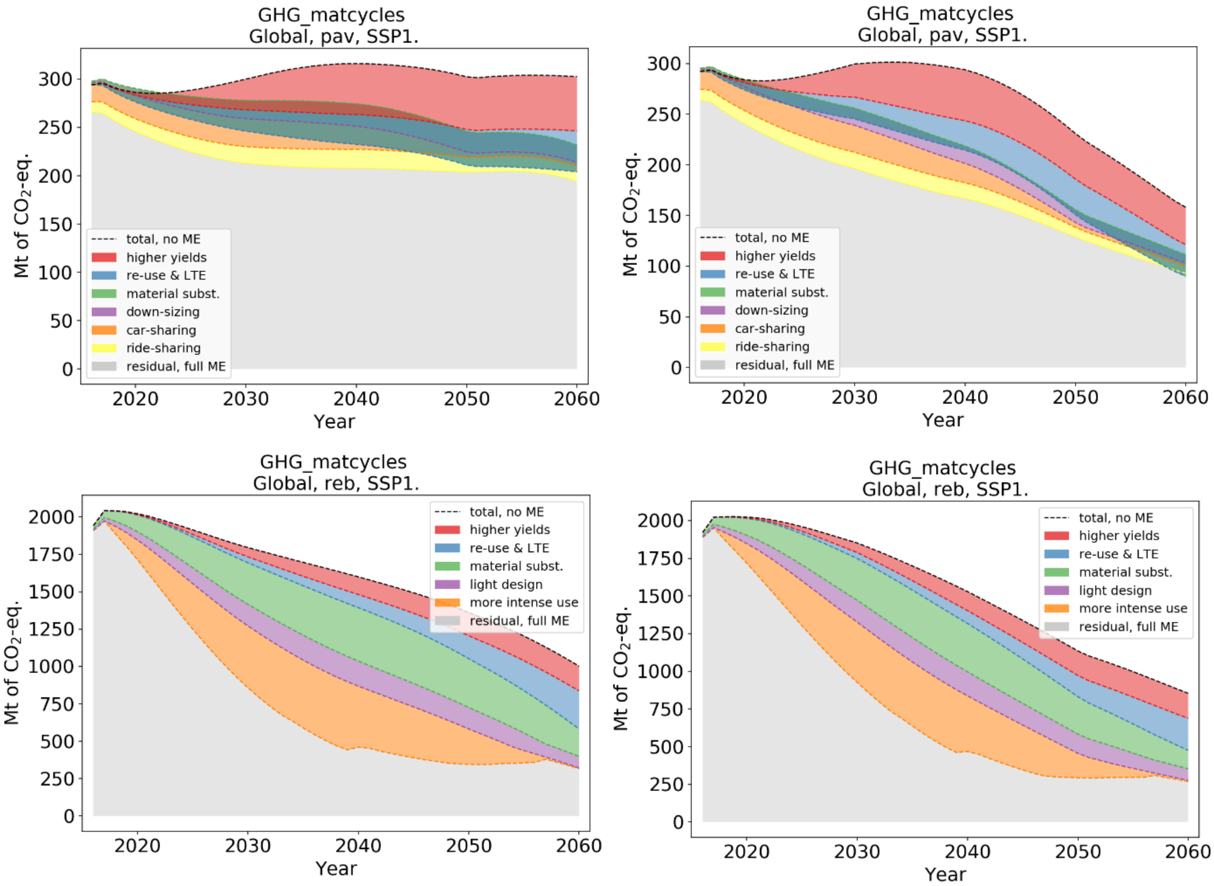
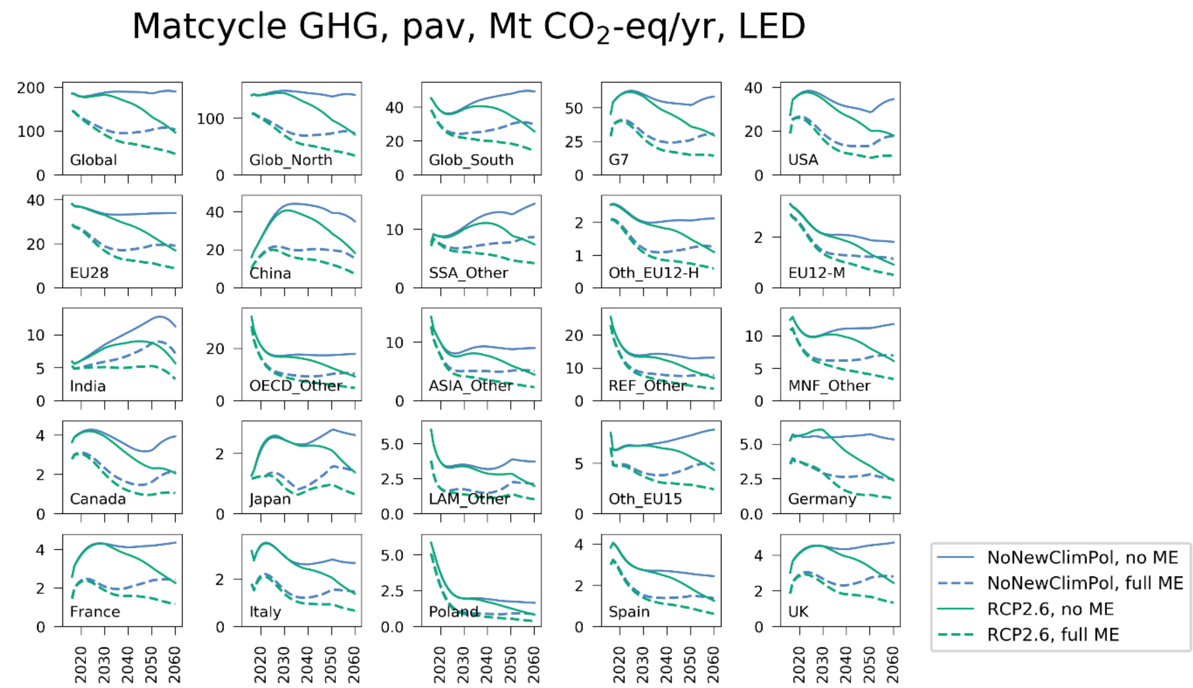
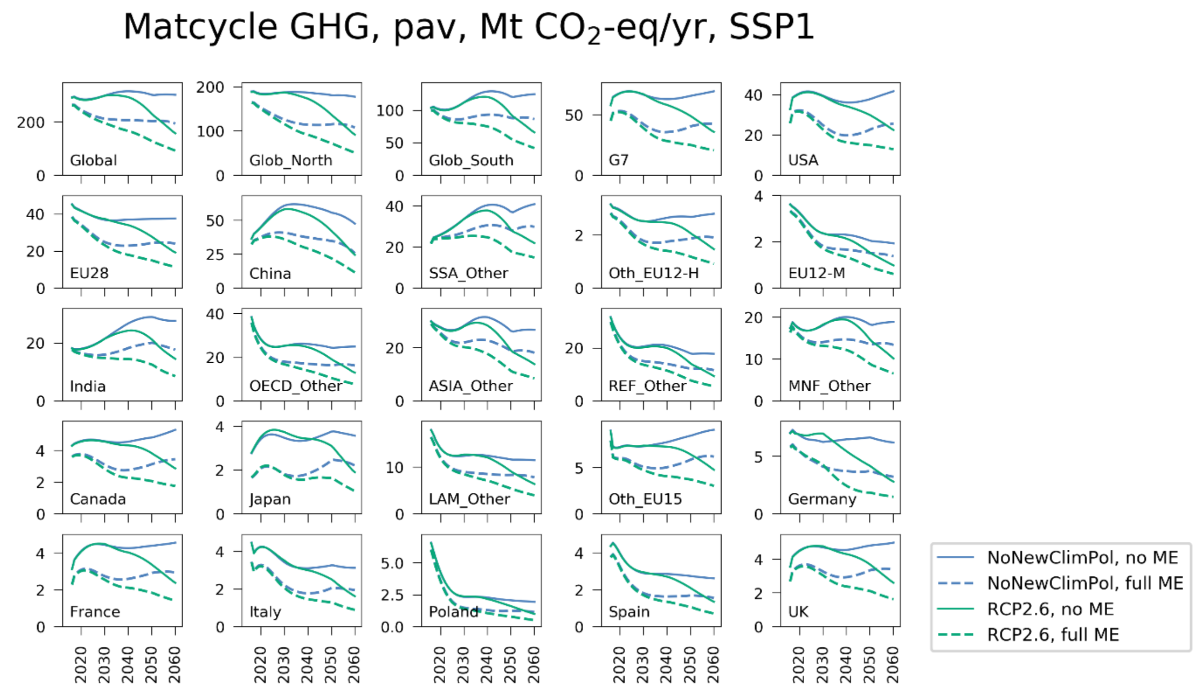


Fig. SI-11: Breakdown of the possible reduction of material production GHG for no new climate policy (LEFT) and an RCP2.6 climate policy (RIGHT). Passenger vehicles (top) and residential buildings (bottom) for SSP1.

Significant difference for Passenger vehicles (top) and residential buildings (bottom): Vehicles show large trade-offs to use phase (aluminium phase in, here: low-carbon energy can help (top right). Buildings have huge potential that occurs a bit earlier and larger for RCP2.6.

4.4. Impact of ME on material cycle GHG emissions over time





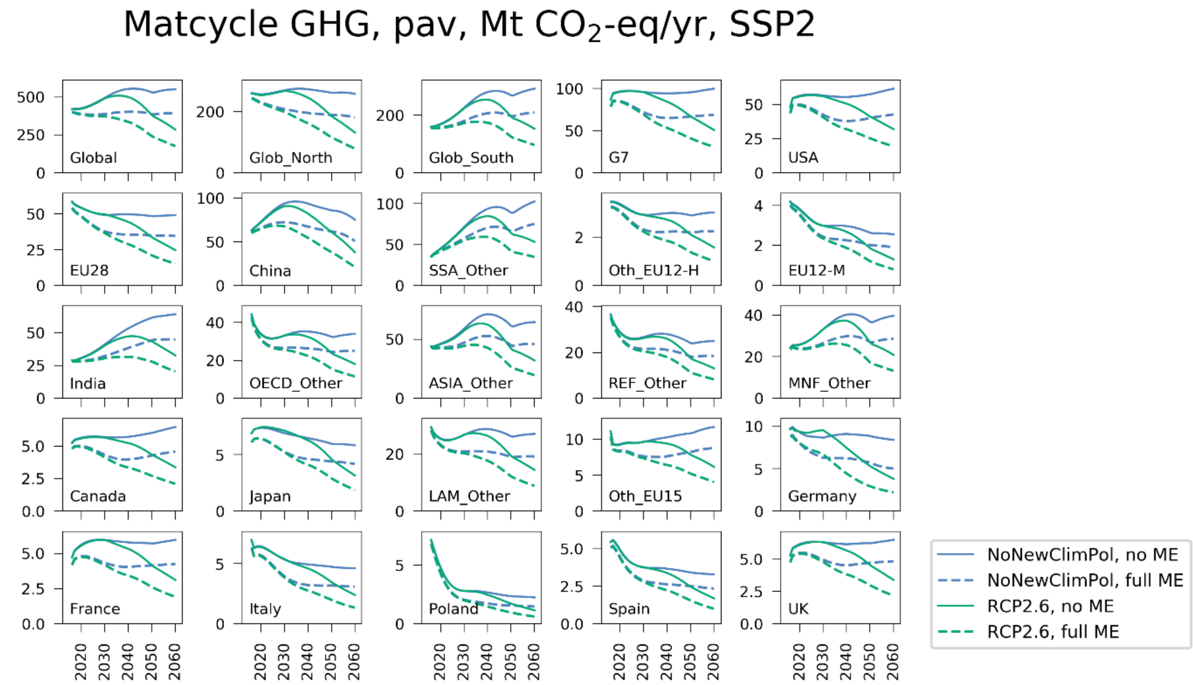
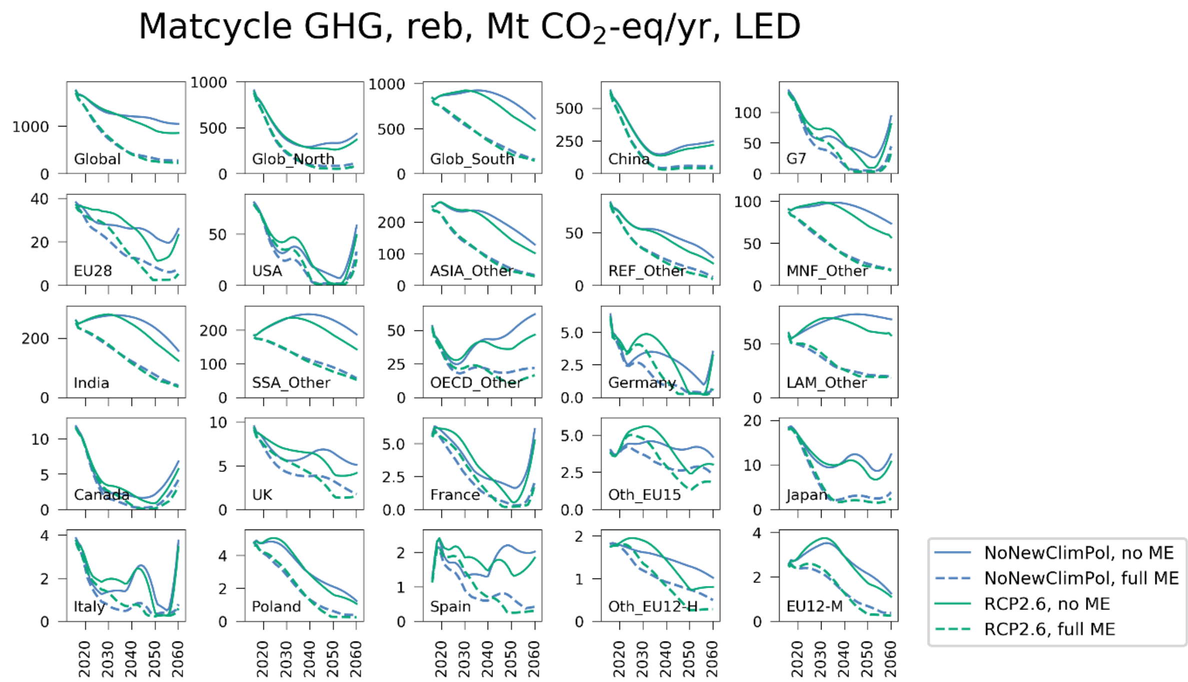
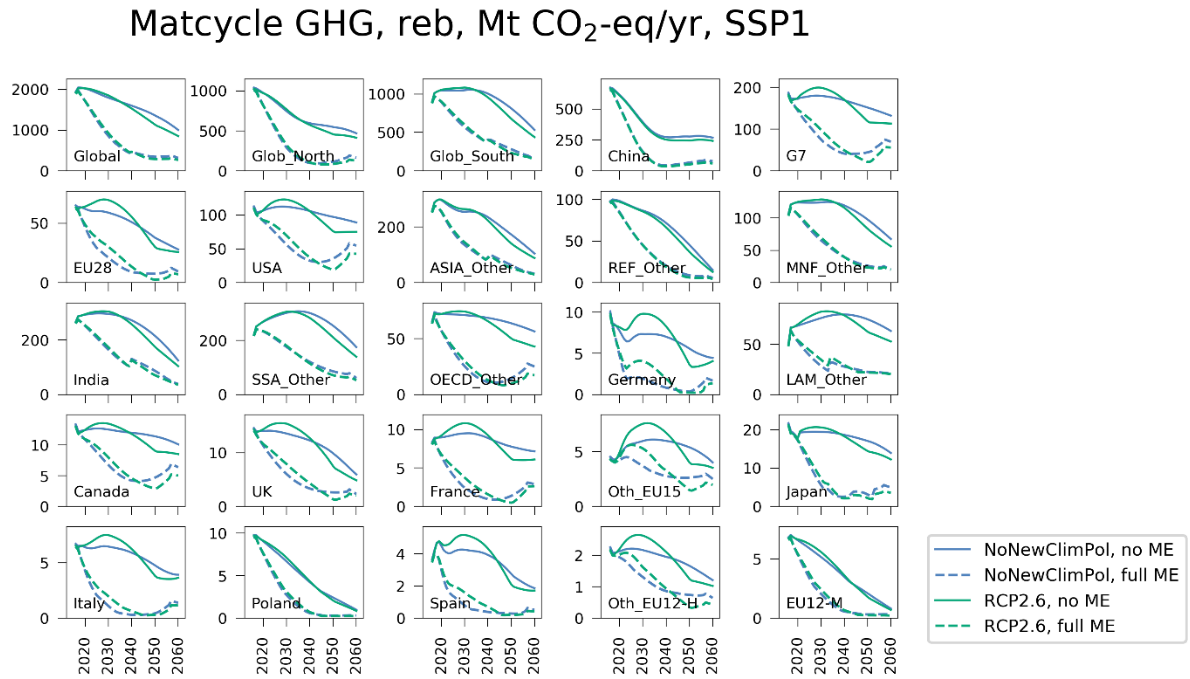


Fig. SI-13: Material cycle GHG emissions (for all materials combined), by region and climate policy/RES scenario, for passenger vehicles (pav).





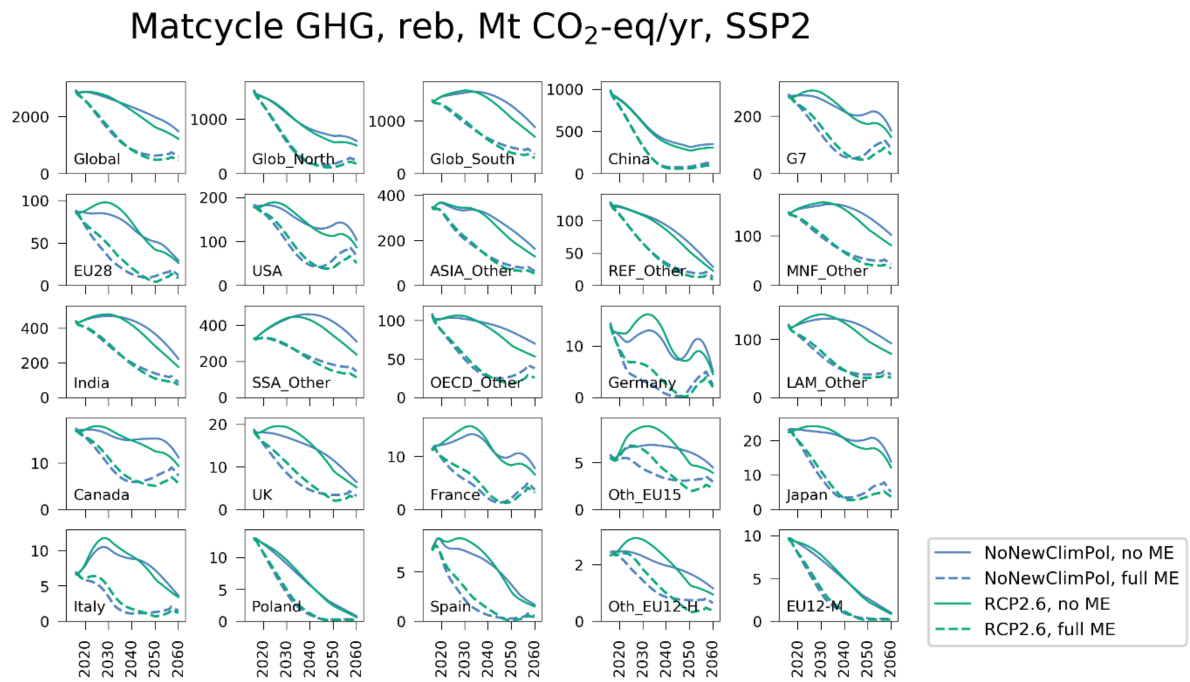
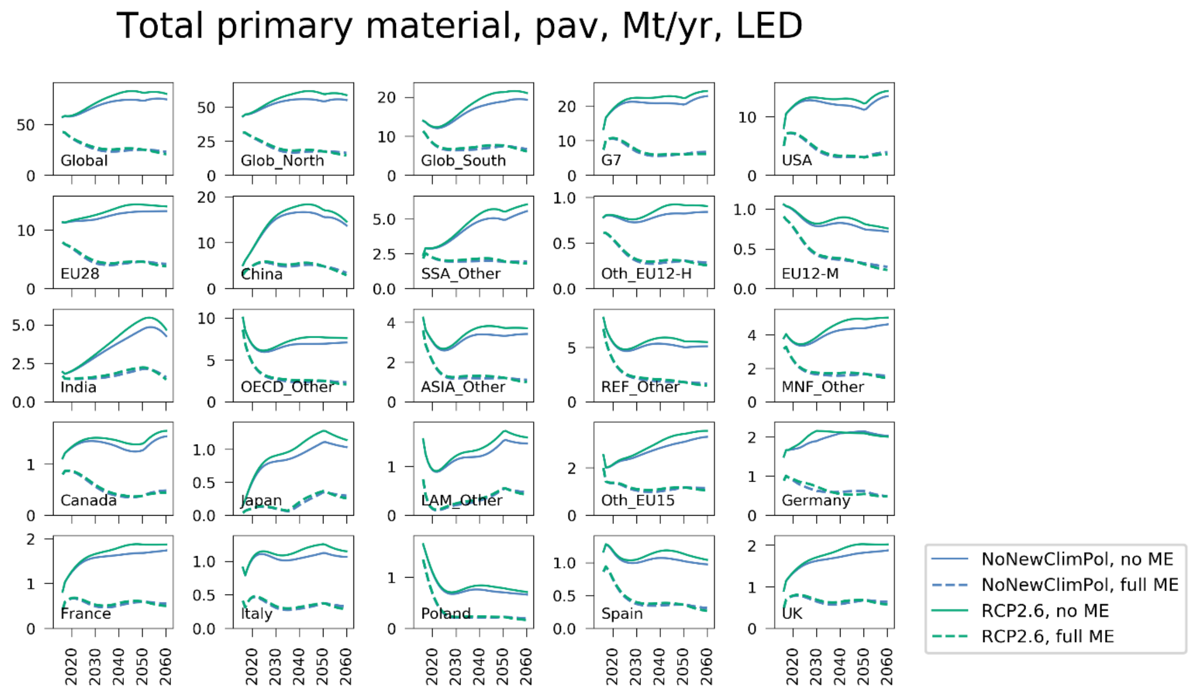
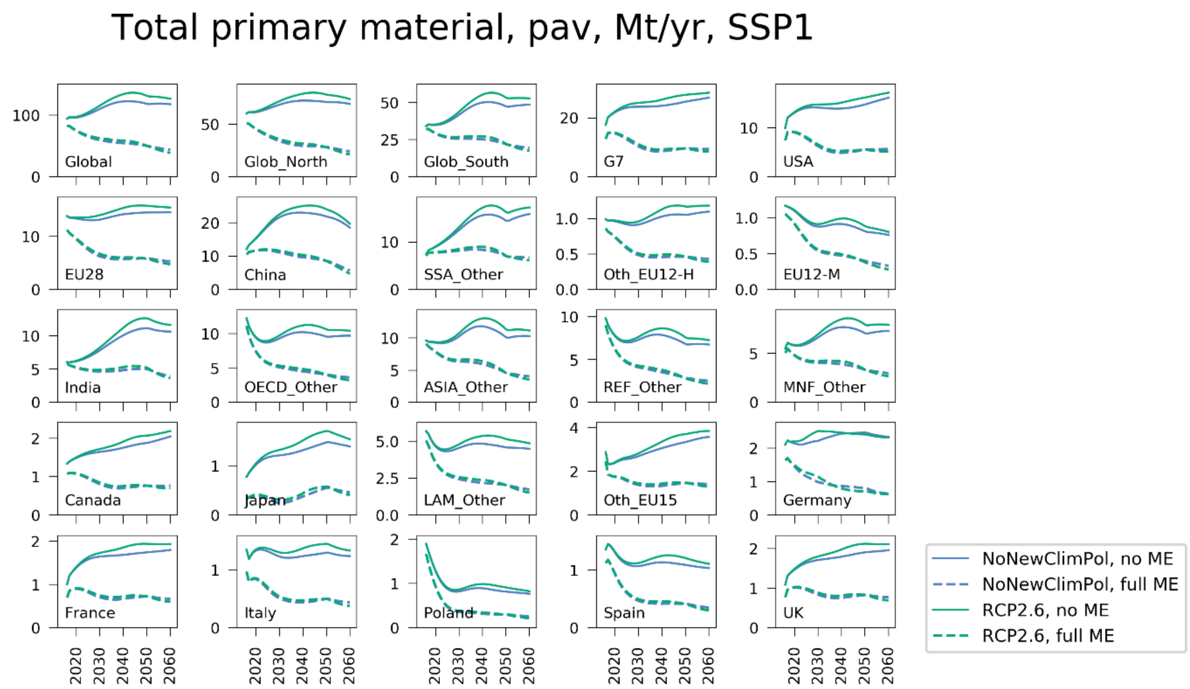


Fig. SI-14: Material cycle GHG emissions (for all materials combined), by region and climate policy/RES scenario, for residential buildings (reb).

4.5. Impact of ME on primary and secondary material production over time





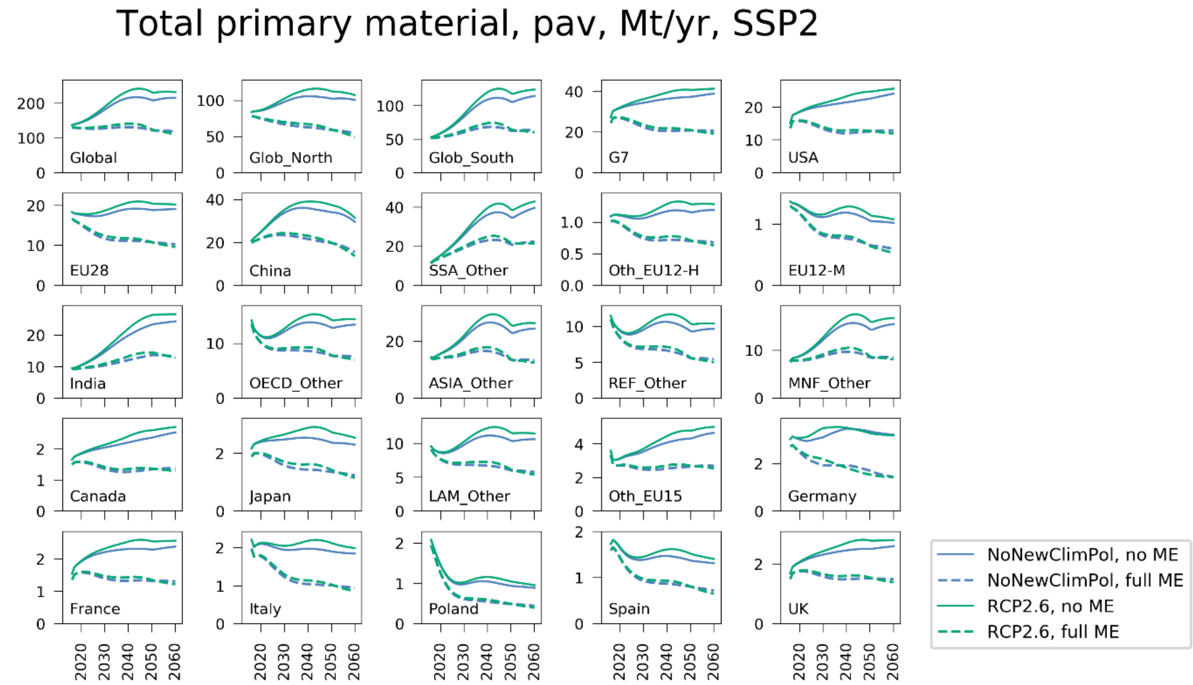
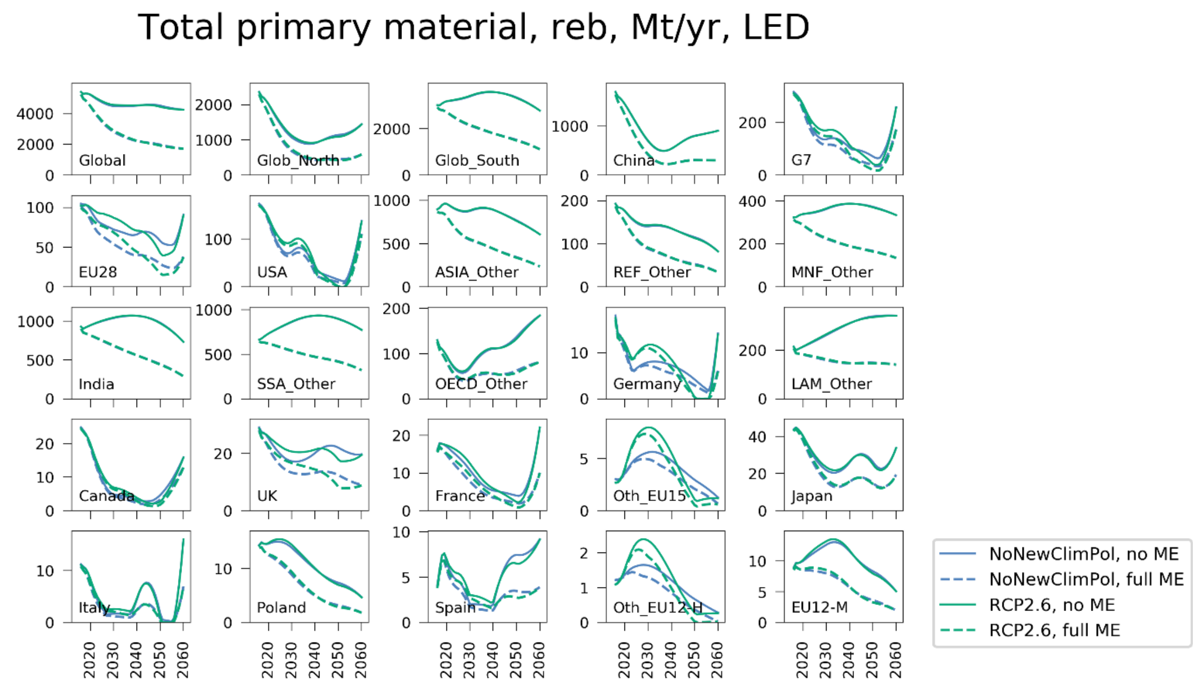
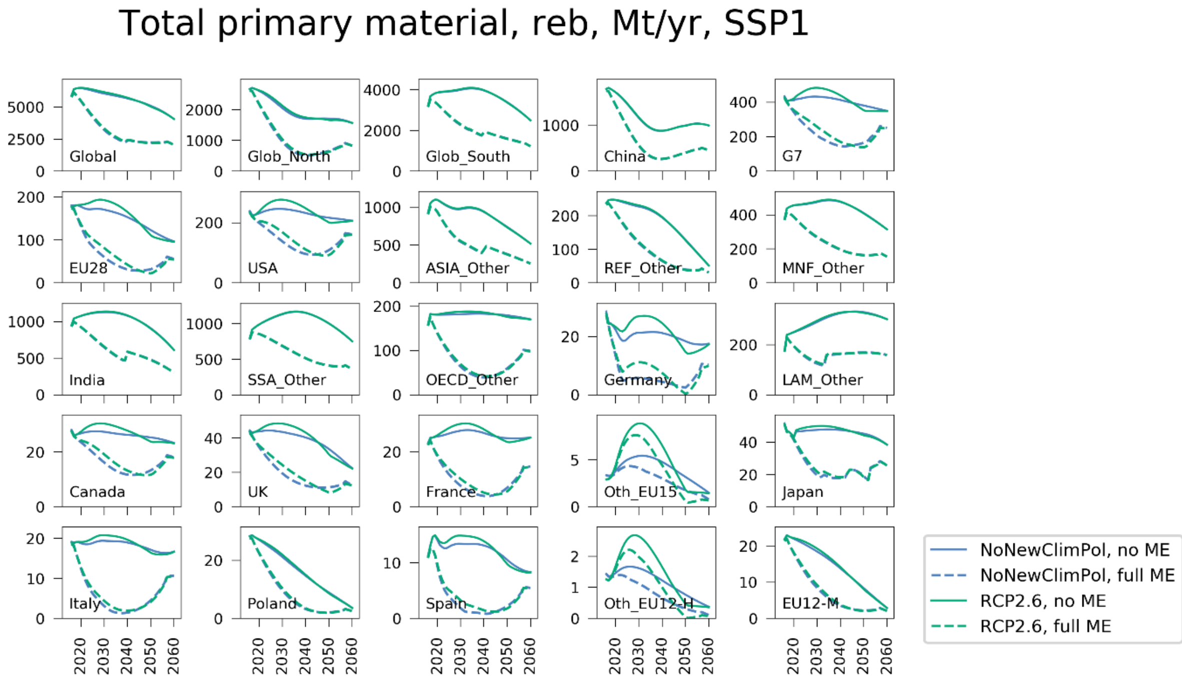


Fig. SI1-15: Total primary material (all materials added up), by region and climate policy/RES scenario, for passenger vehicles (pav).





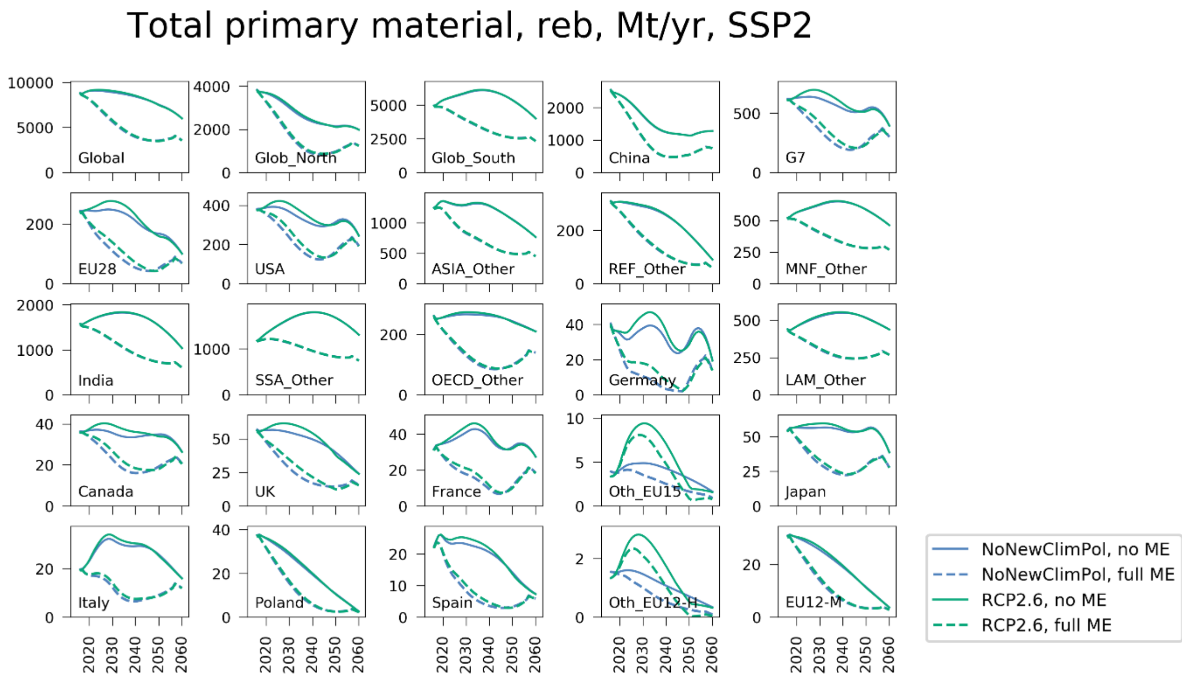
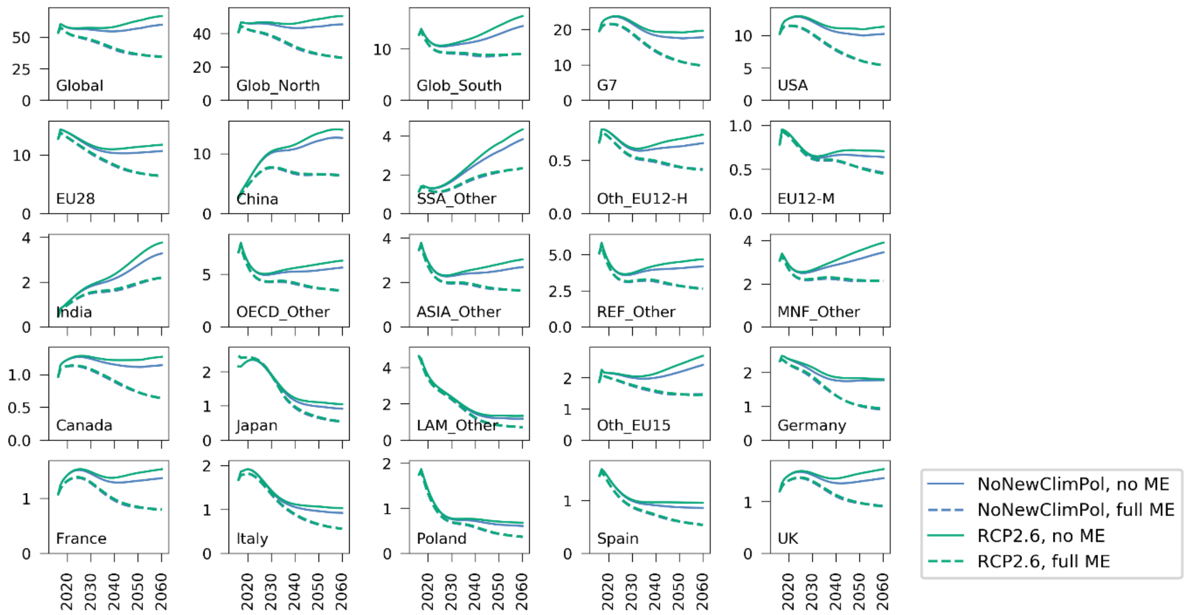
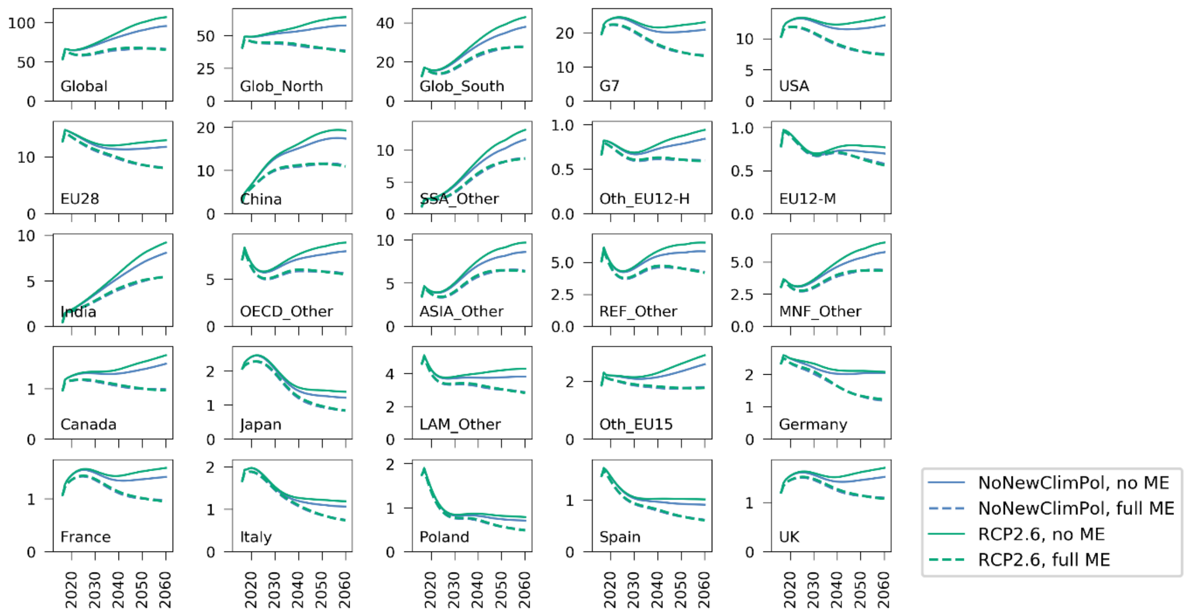


Fig. SI1-16: Total primary material (all materials added up), by region and climate policy/RES scenario, for residential buildings (reb).

Total secondary material, pav, Mt/yr, LED



Total secondary material, pav, Mt/yr, SSP1



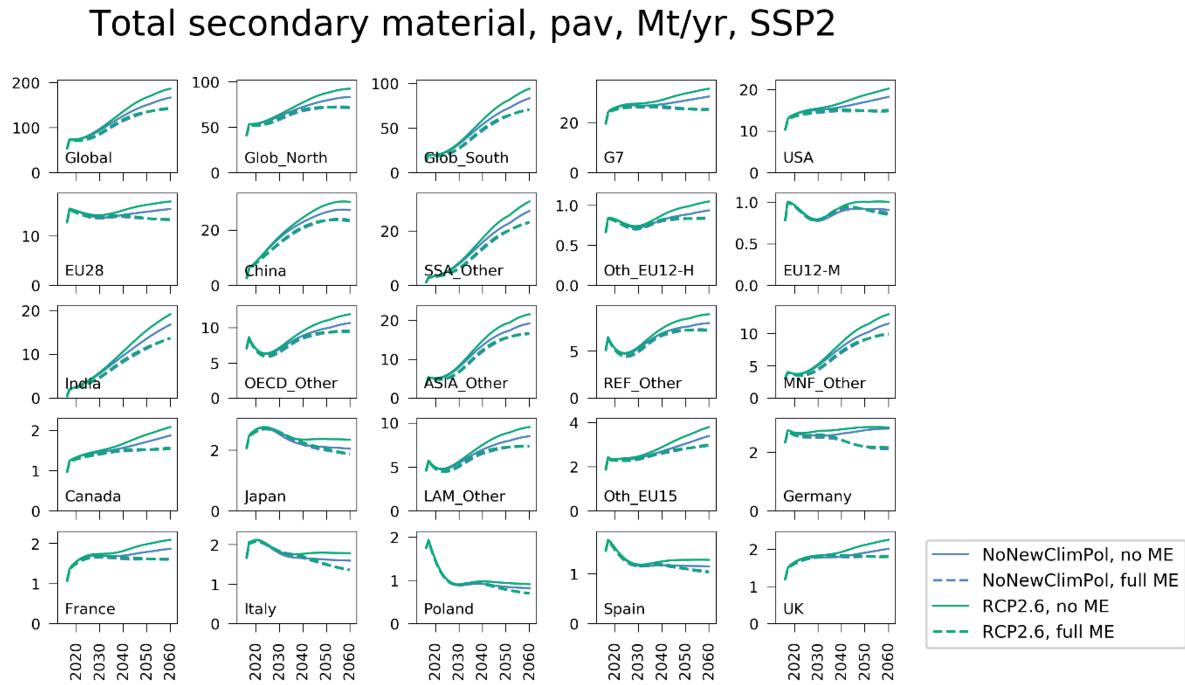
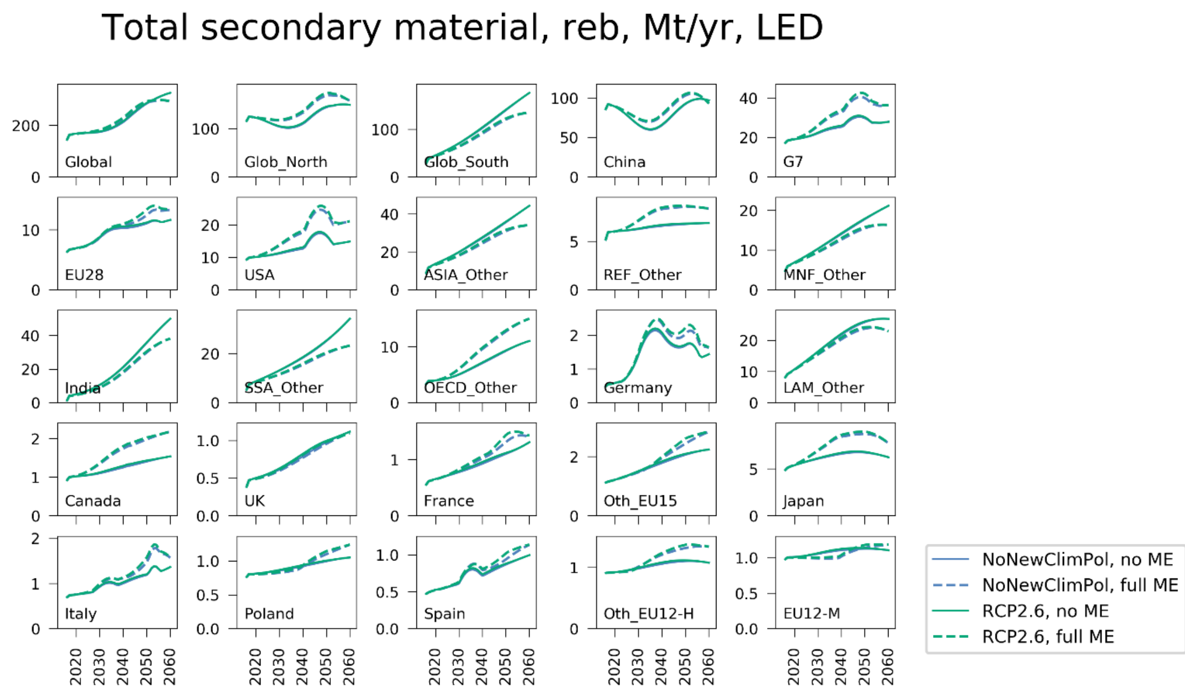
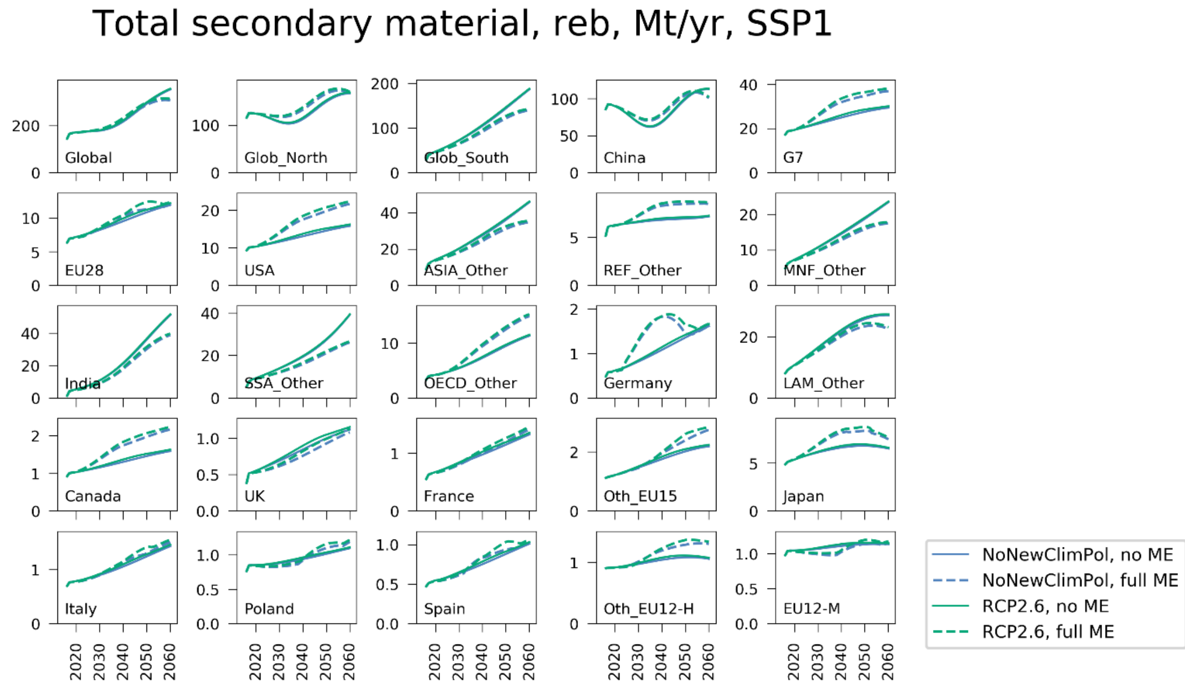


Fig. SI1-17: Total secondary material (all materials added up), by region and climate policy/RES scenario, for passenger vehicles (pav).





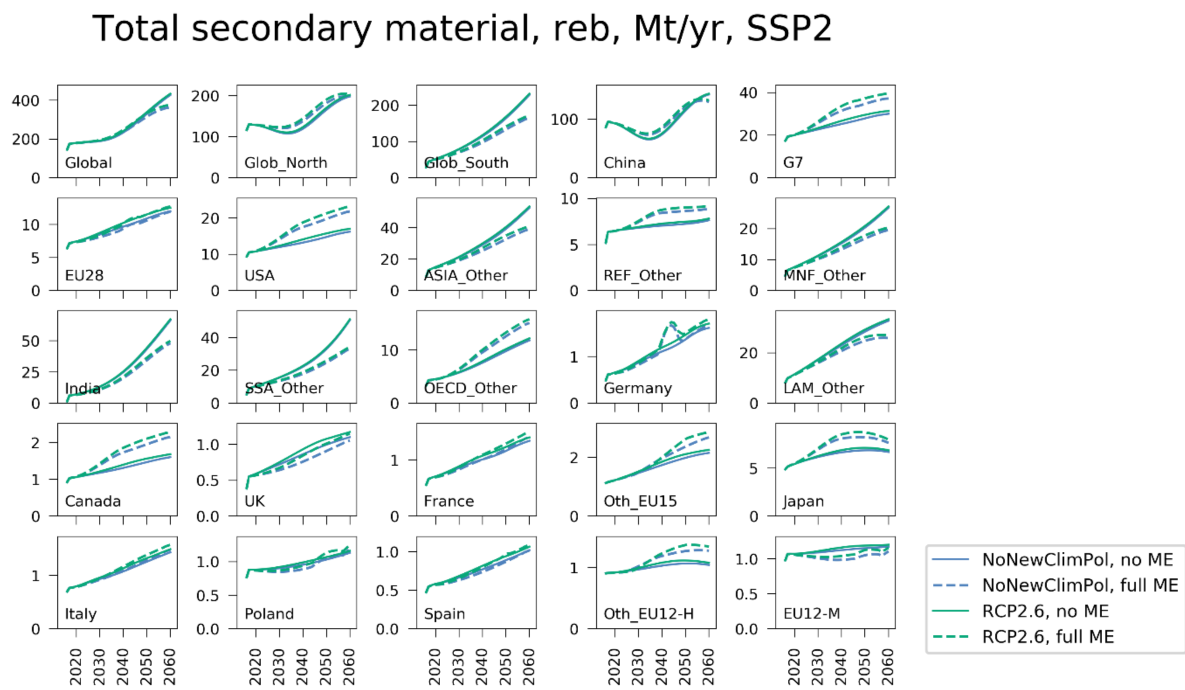
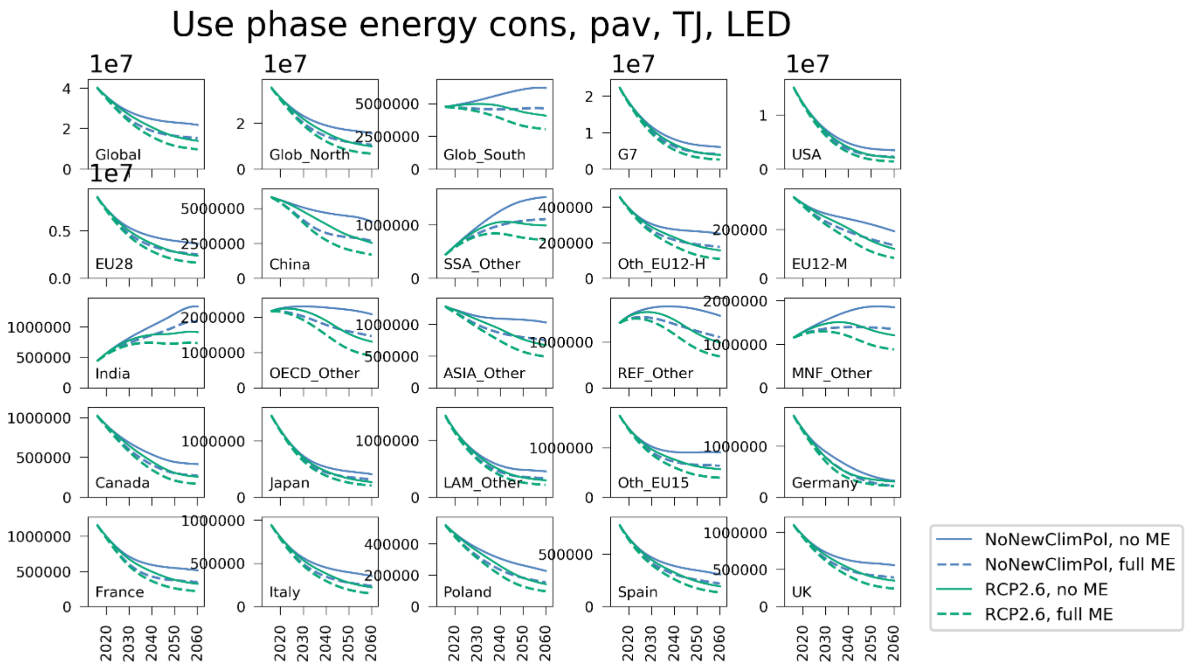
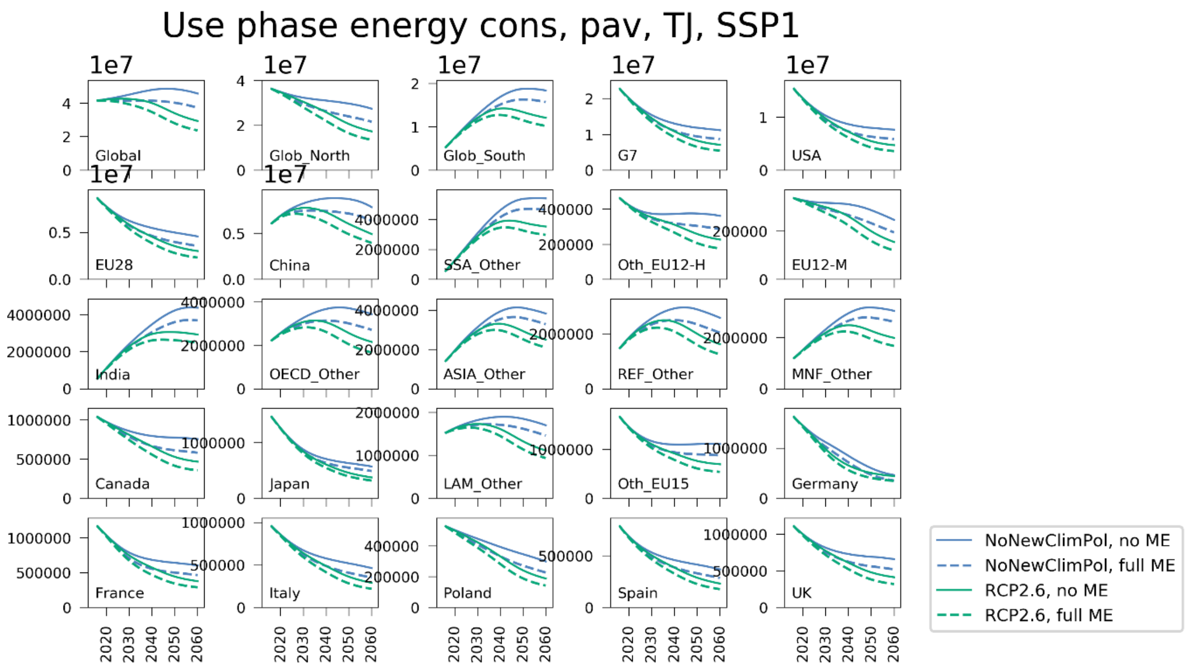


Fig. SI1-18: Total secondary material (all materials added up), by region and climate policy/RES scenario, for residential buildings (reb).

4.6. Impact of ME on use phase energy consumption over time





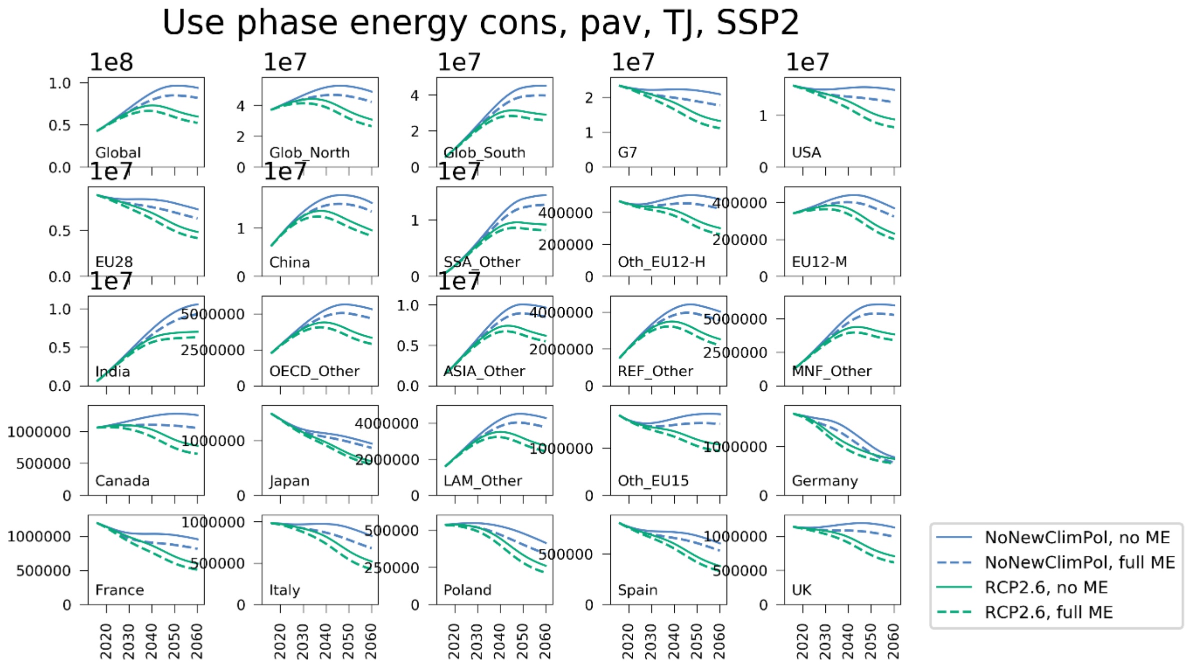
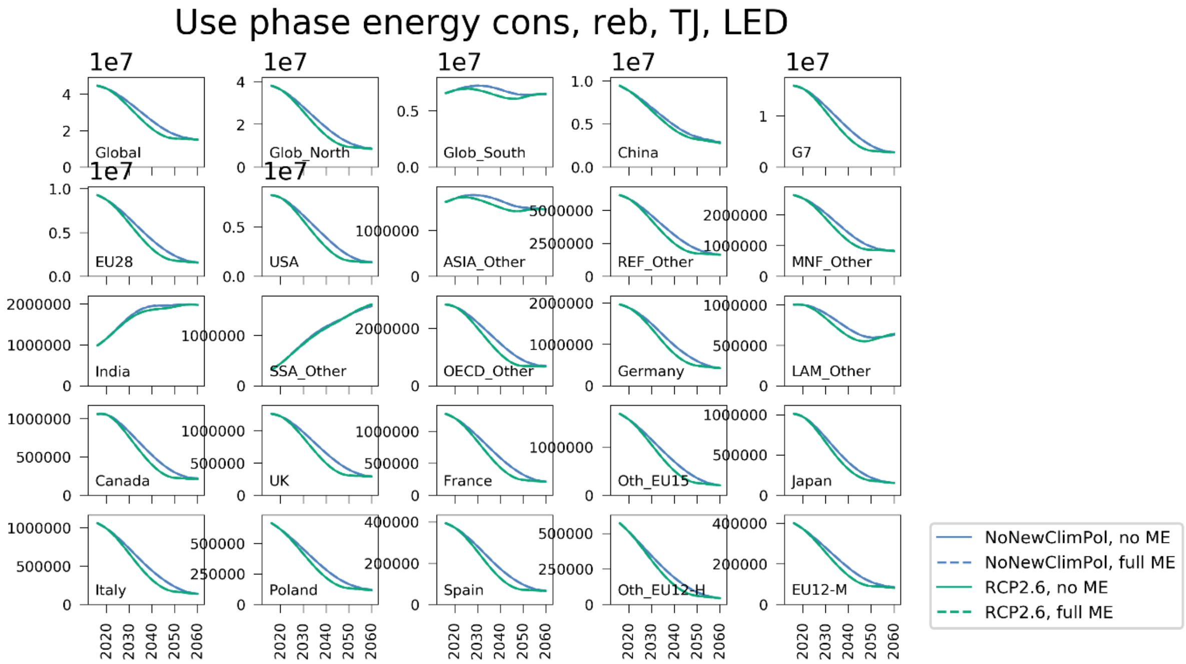


Fig. SI1-19: Use phase energy consumption, by region and climate policy/RES scenario, for passenger vehicles (pav).



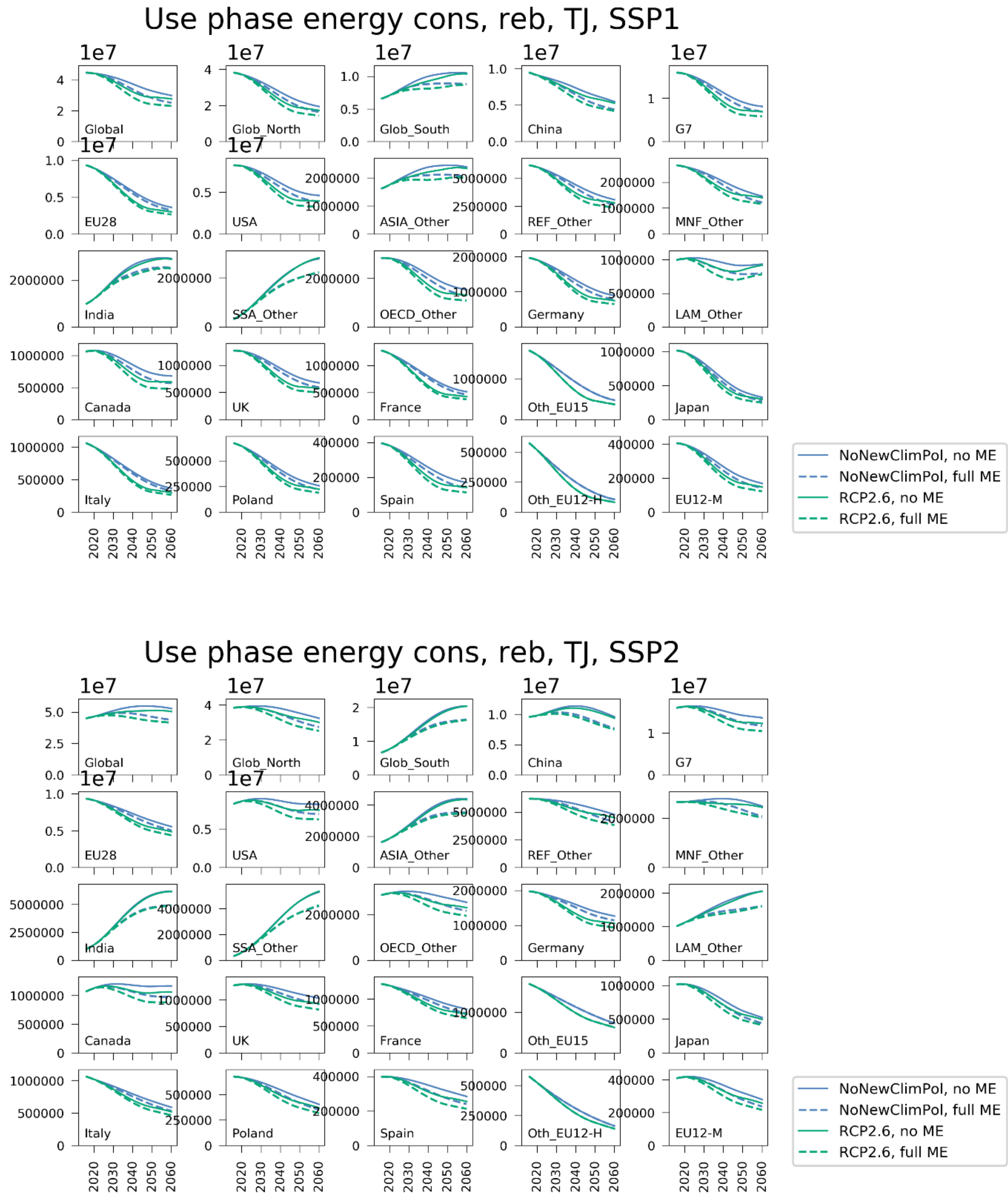
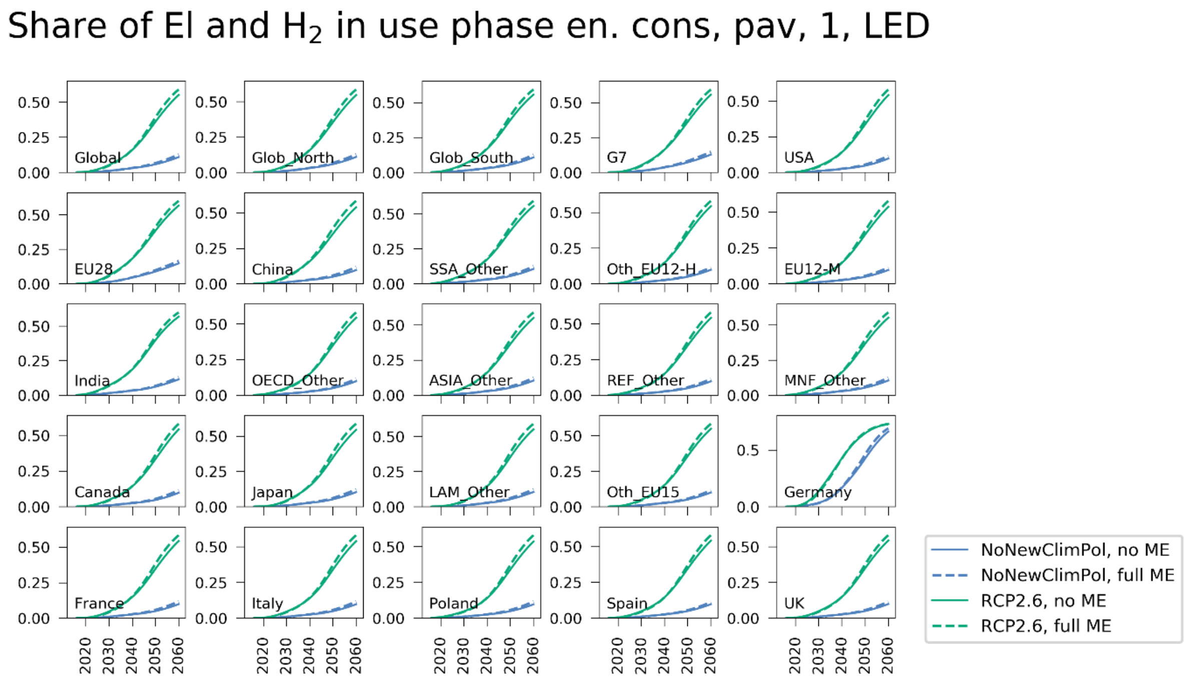
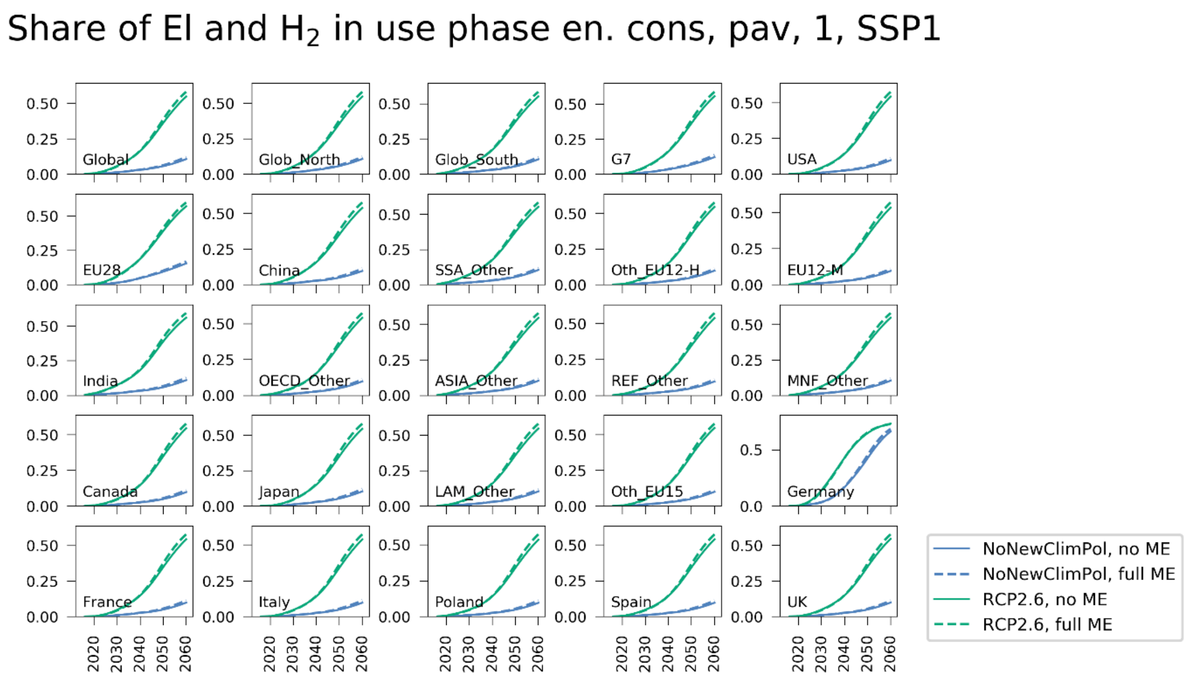


Fig. SI1-20: Use phase energy consumption, by region and climate policy/RES scenario, for residential buildings (reb).

4.7. Share of electricity and hydrogen in use phase energy consumption over time





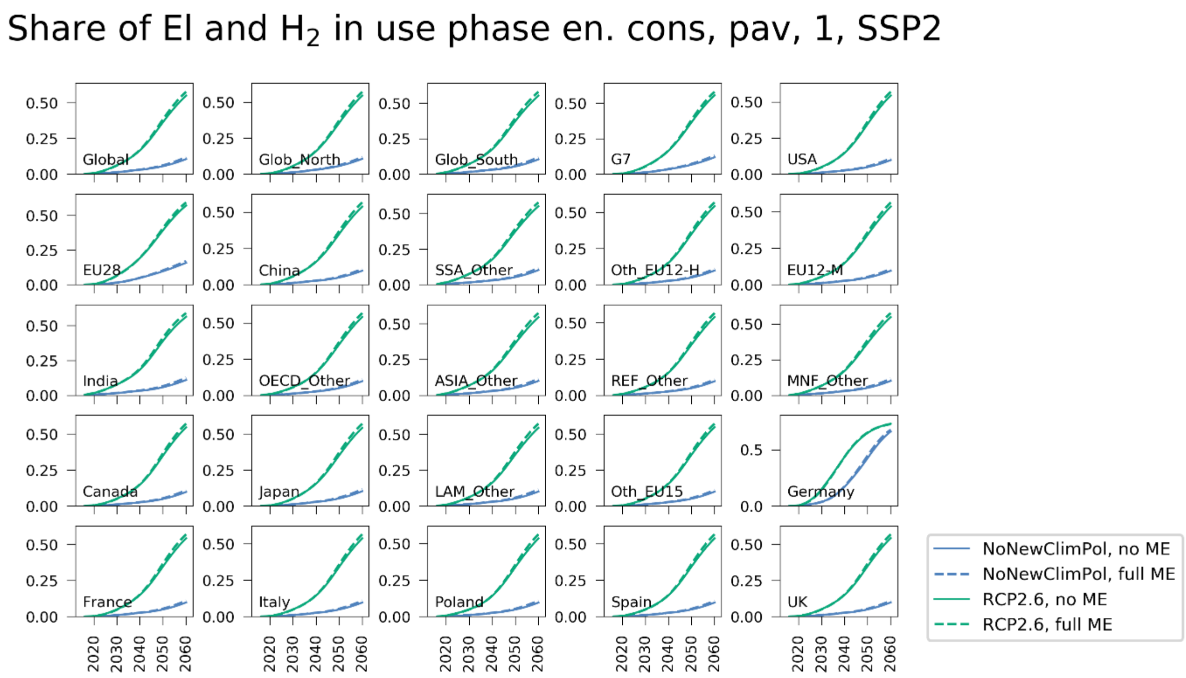
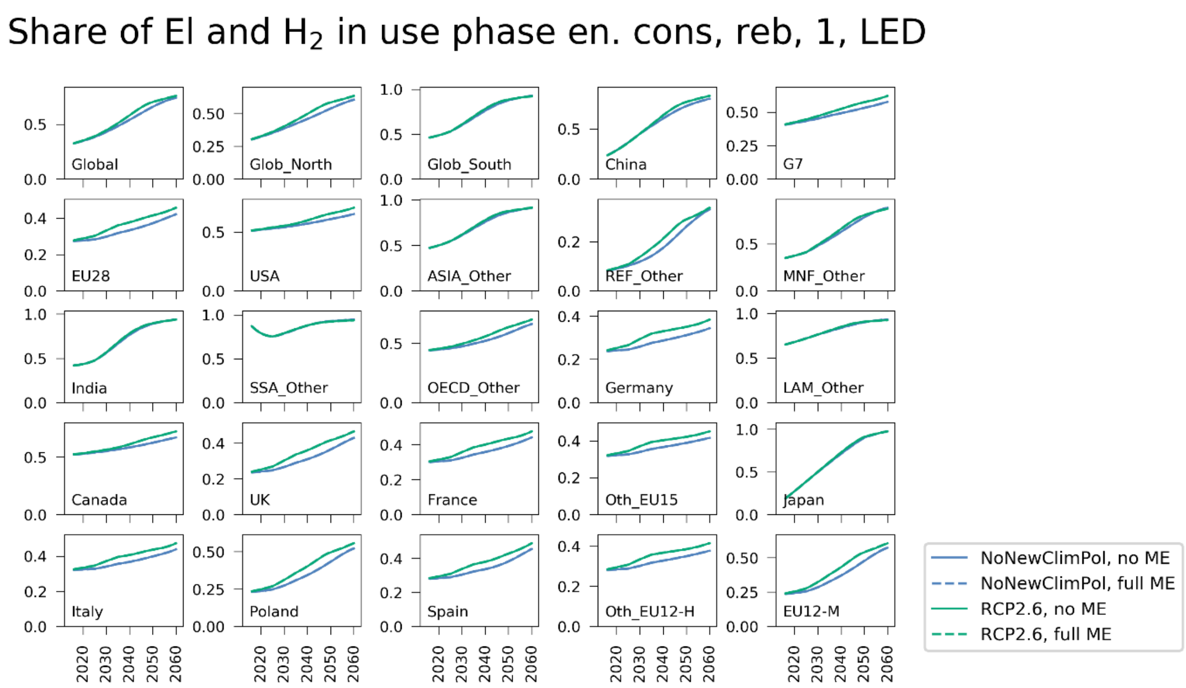
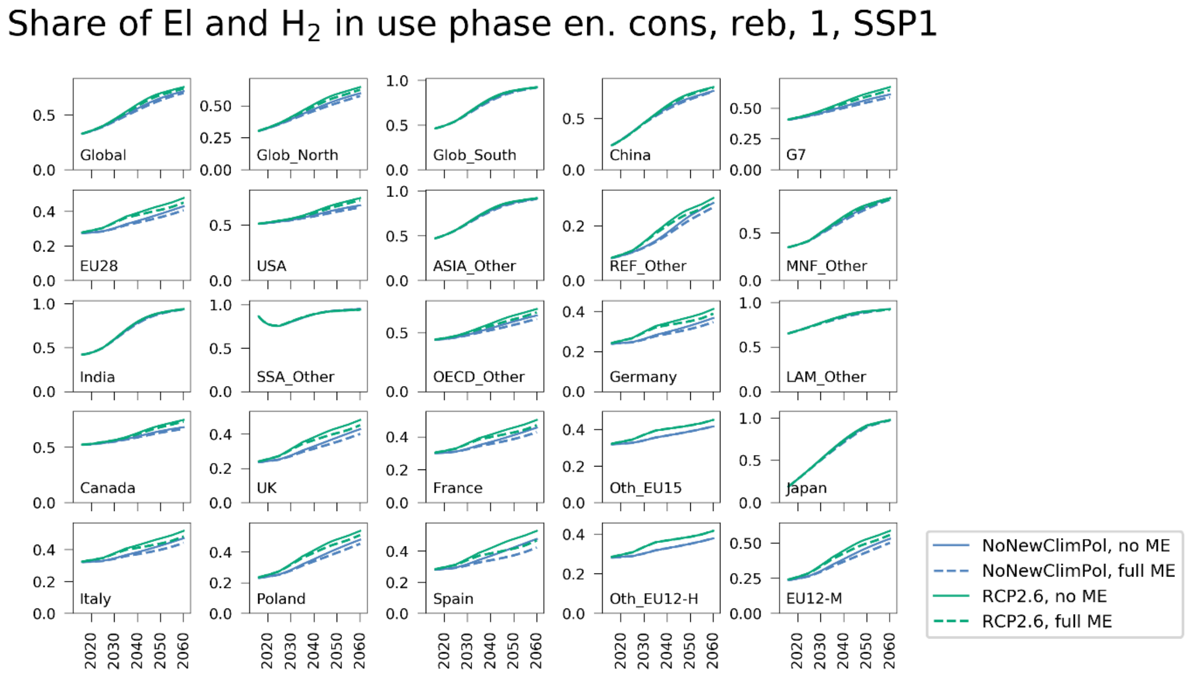


Fig. SI1-21: Use phase share of electricity and H2 in total energy consumption, by region and climate policy/RES scenario, for passenger vehicles (pav).





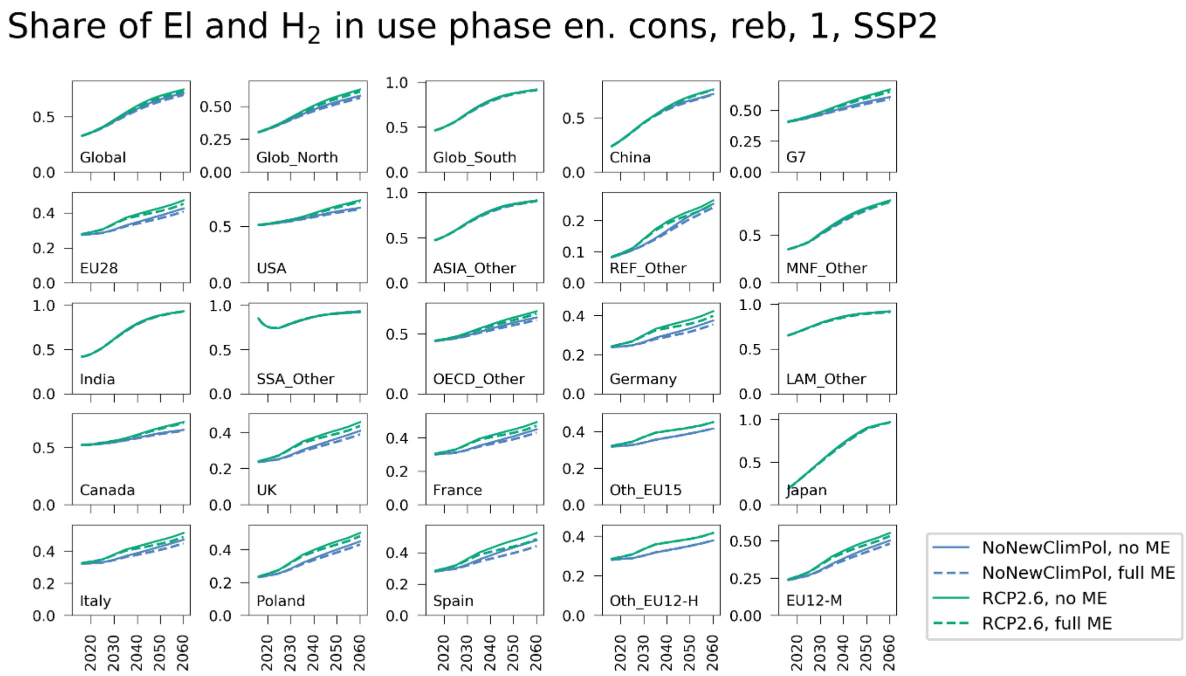
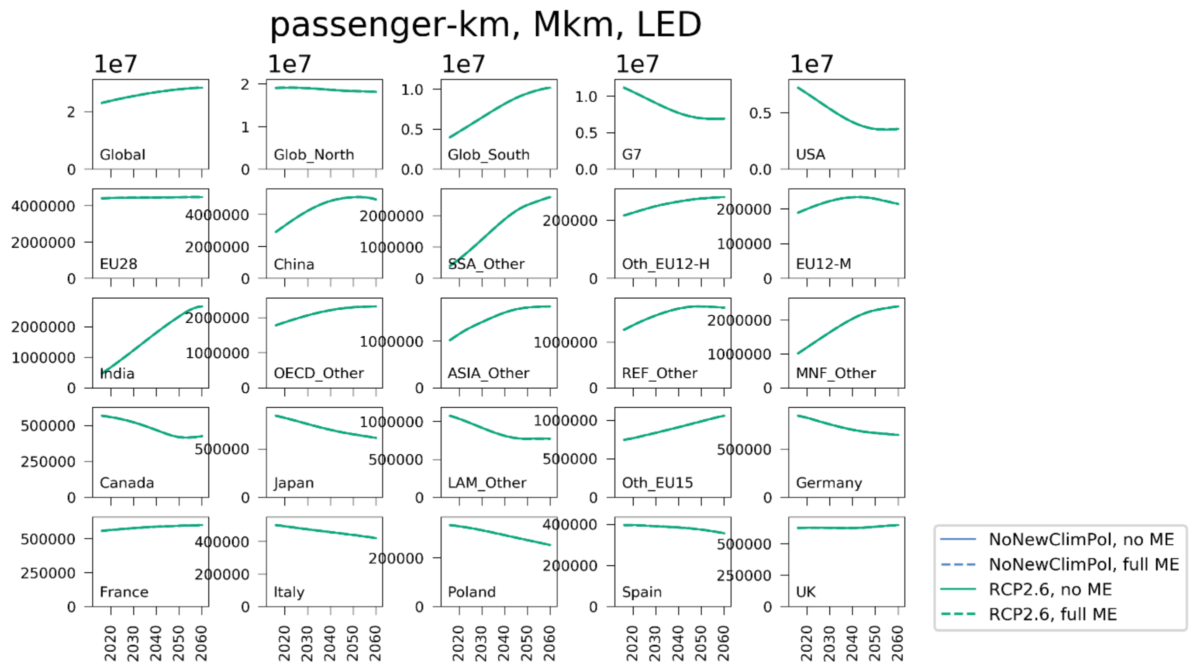
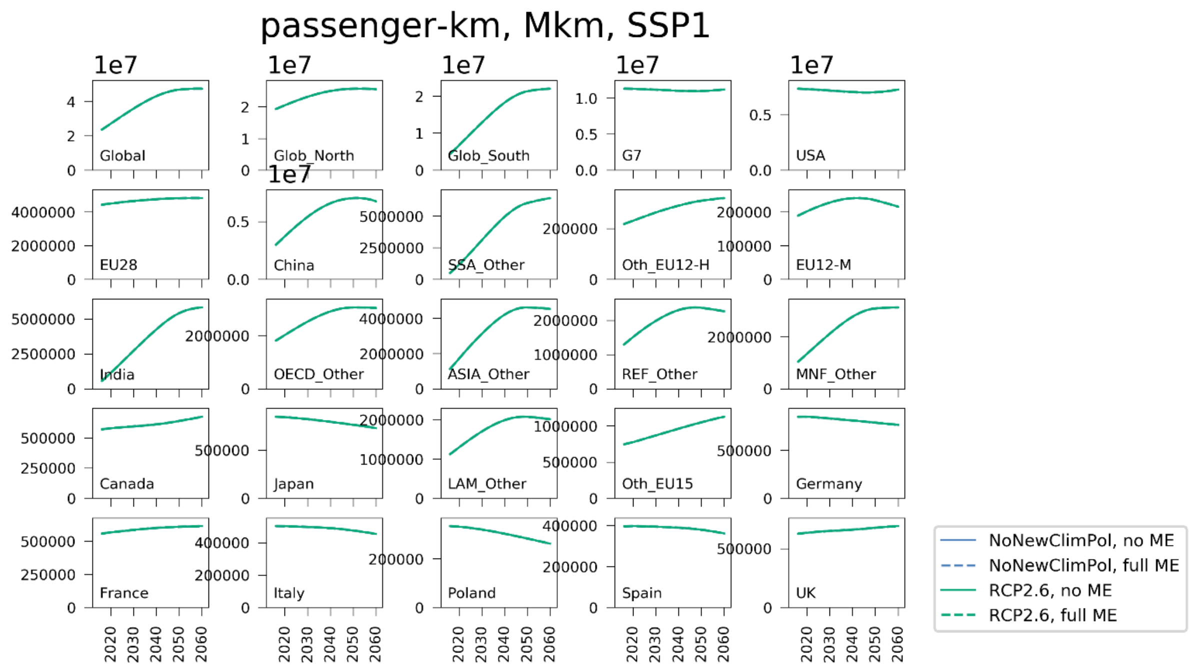


Fig. SI1-22: Use phase share of electricity and H2 in total energy consumption, by region and climate policy/RES scenario, for residential buildings (reb).

4.8. Passenger-km are delivered over time





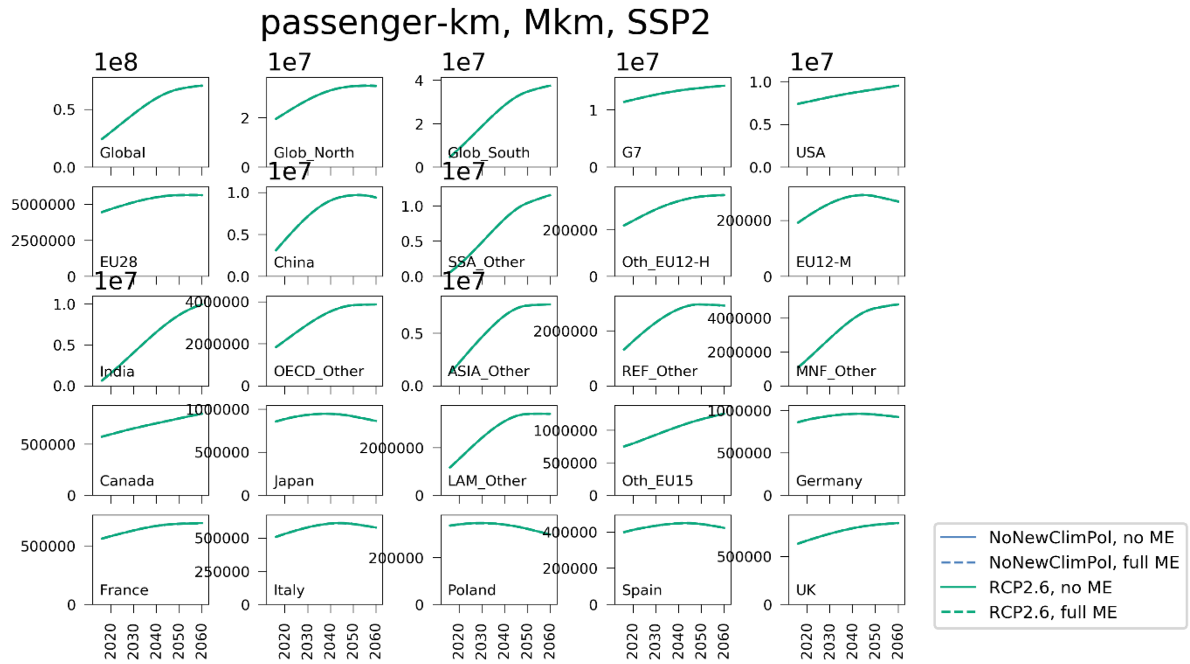
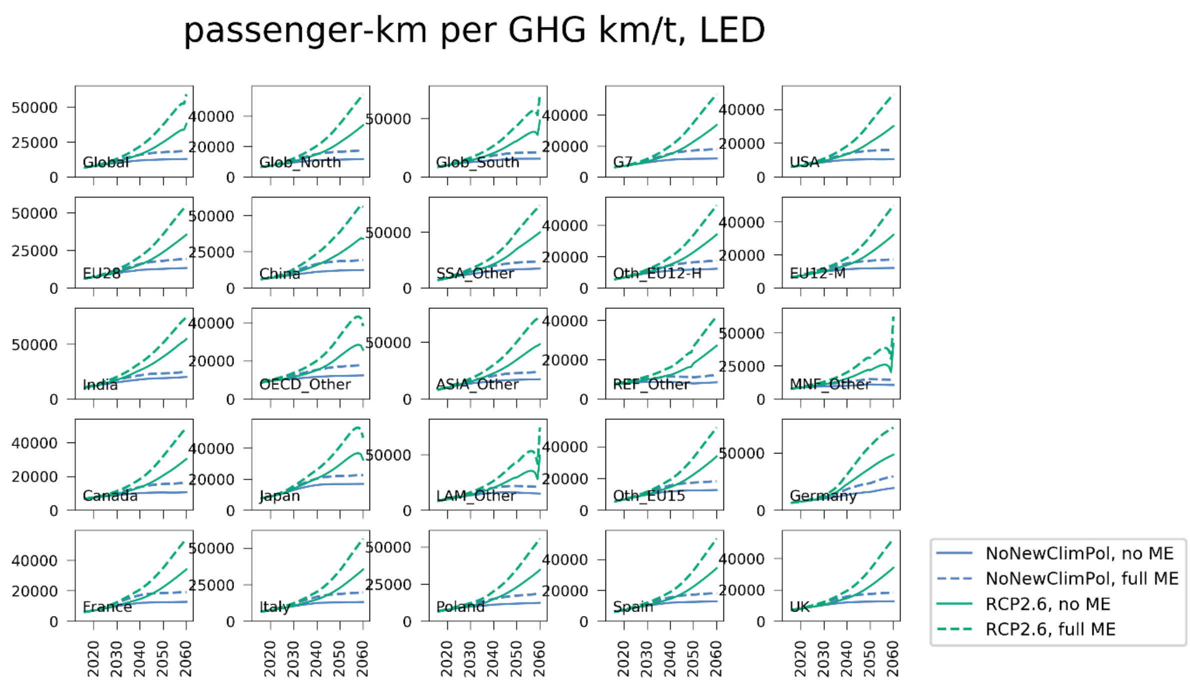
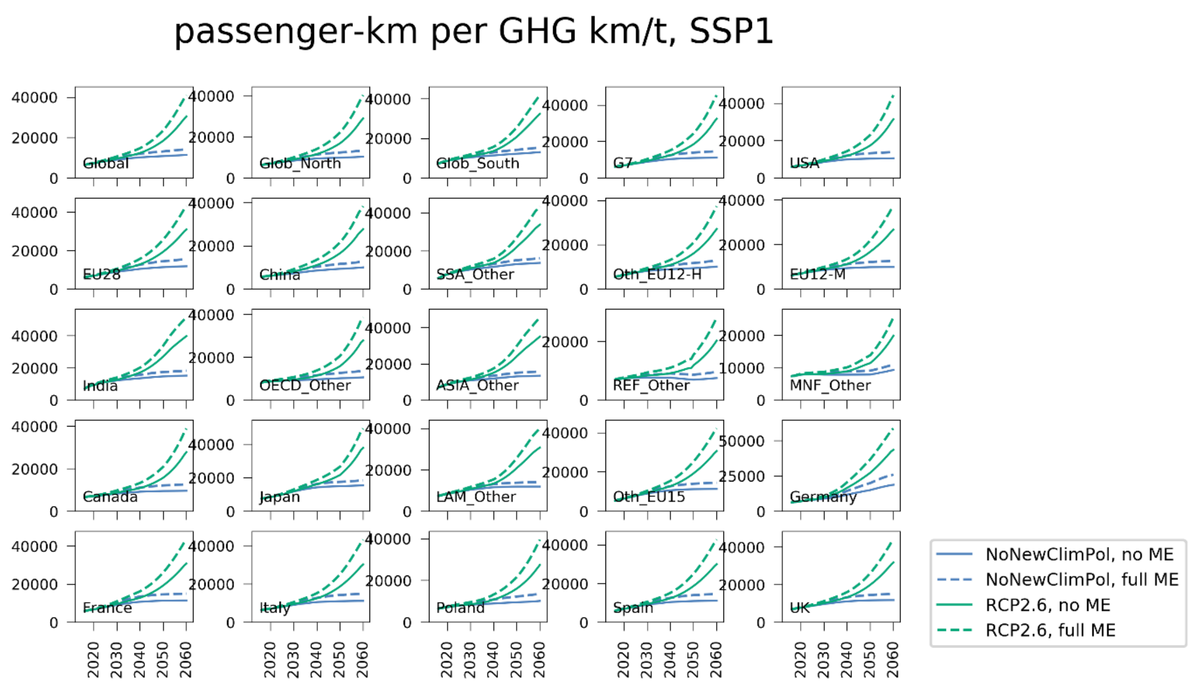


Fig. SI1-23: passenger-km delivered (scenario driver), by region and climate policy/RES scenario, for passenger vehicles (pav).

4.9. 'Service efficiency', defined in passenger-km per total GHG and per total material stocks, over time





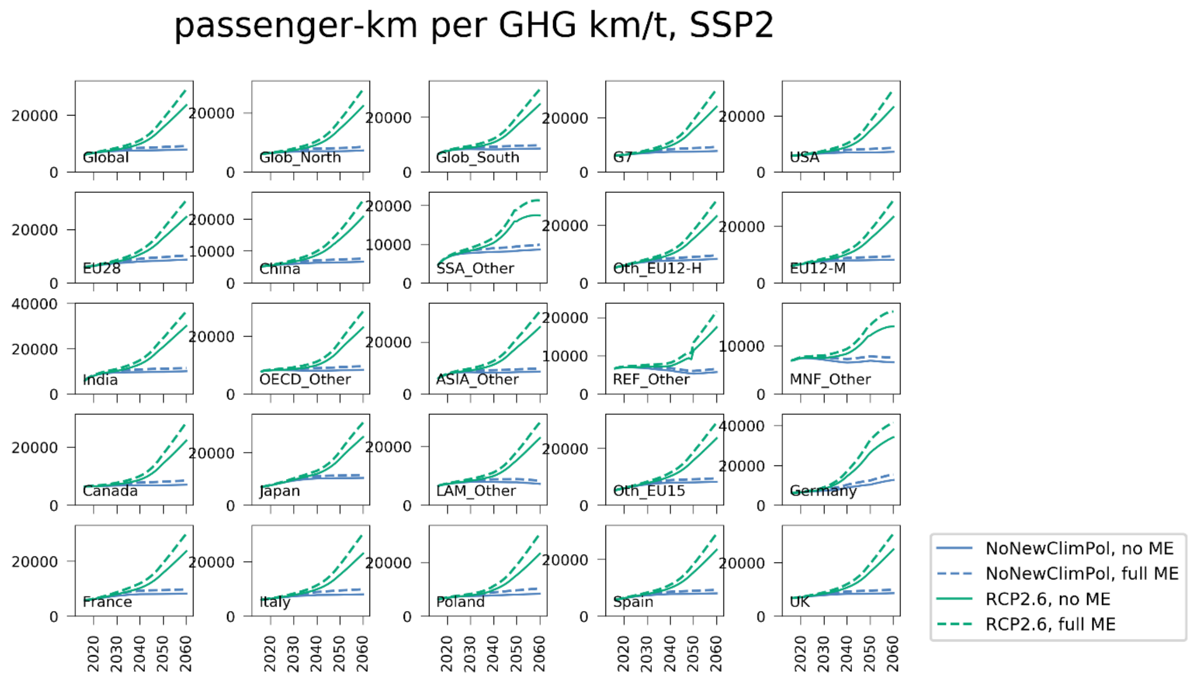
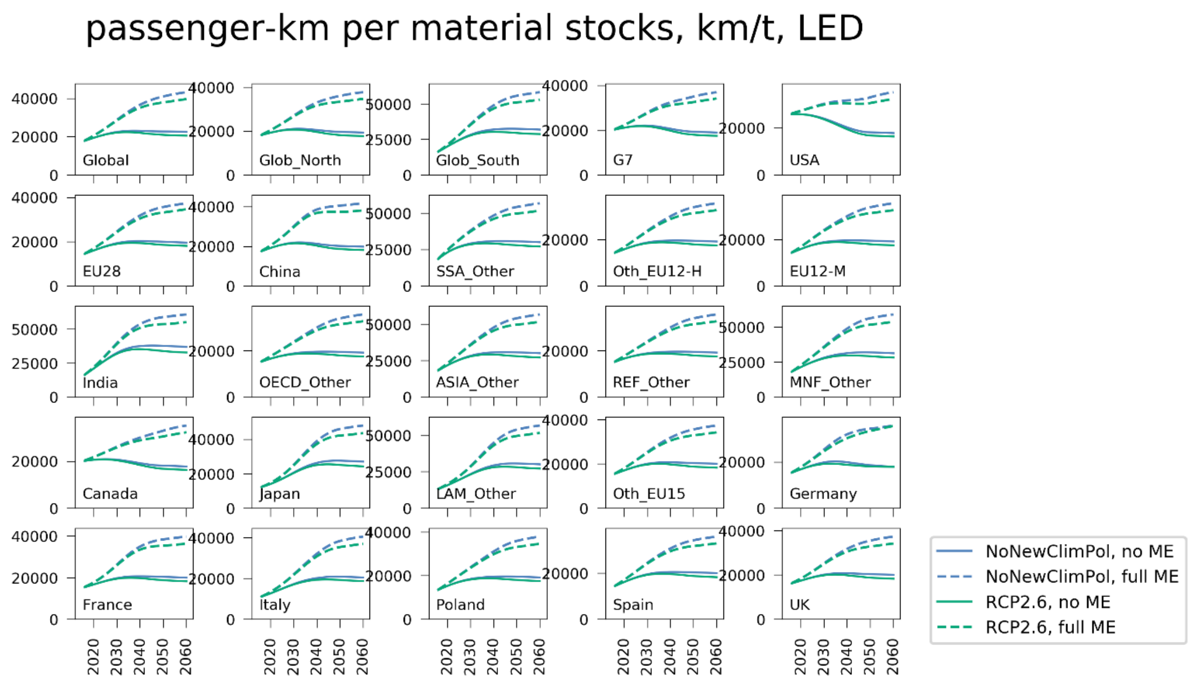


Fig. SI1-24: passenger-km delivered (scenario driver) per system-wide GHG, by region and climate policy/RES scenario, for passenger vehices (pav).



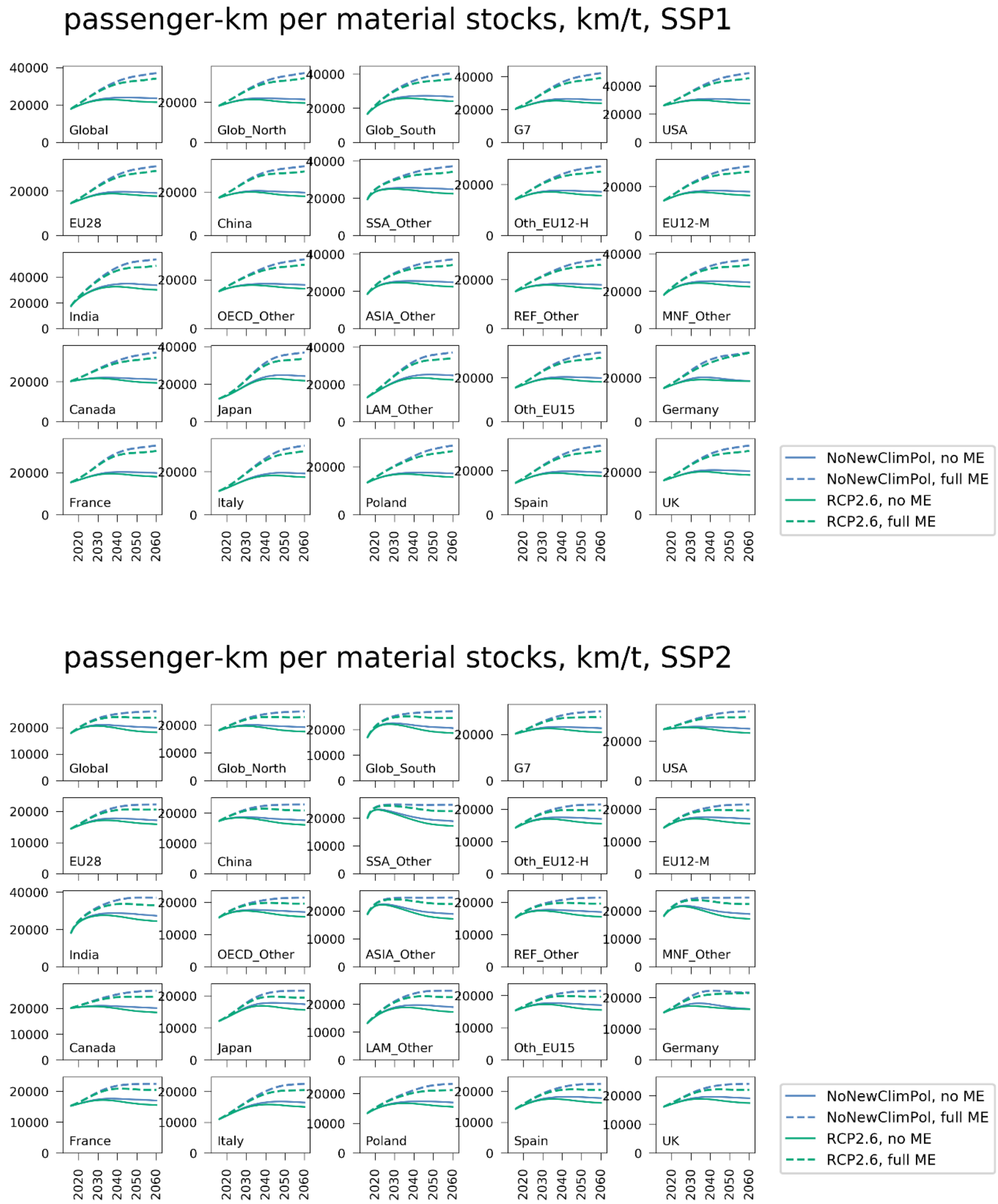
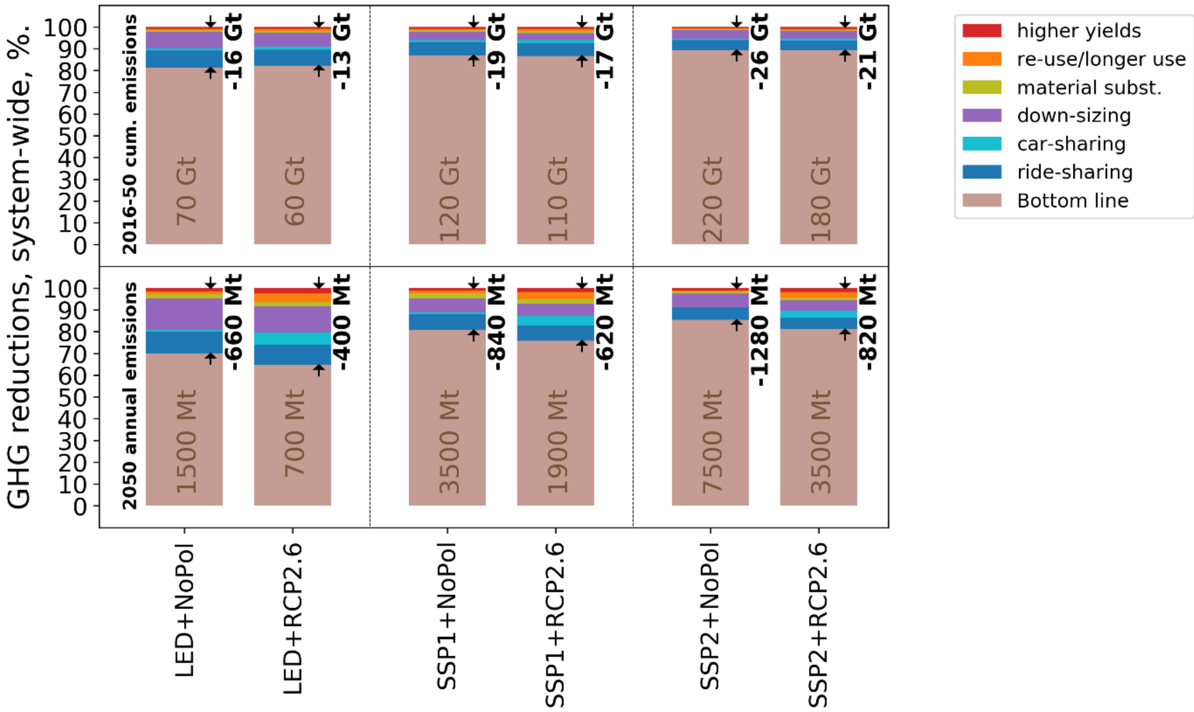


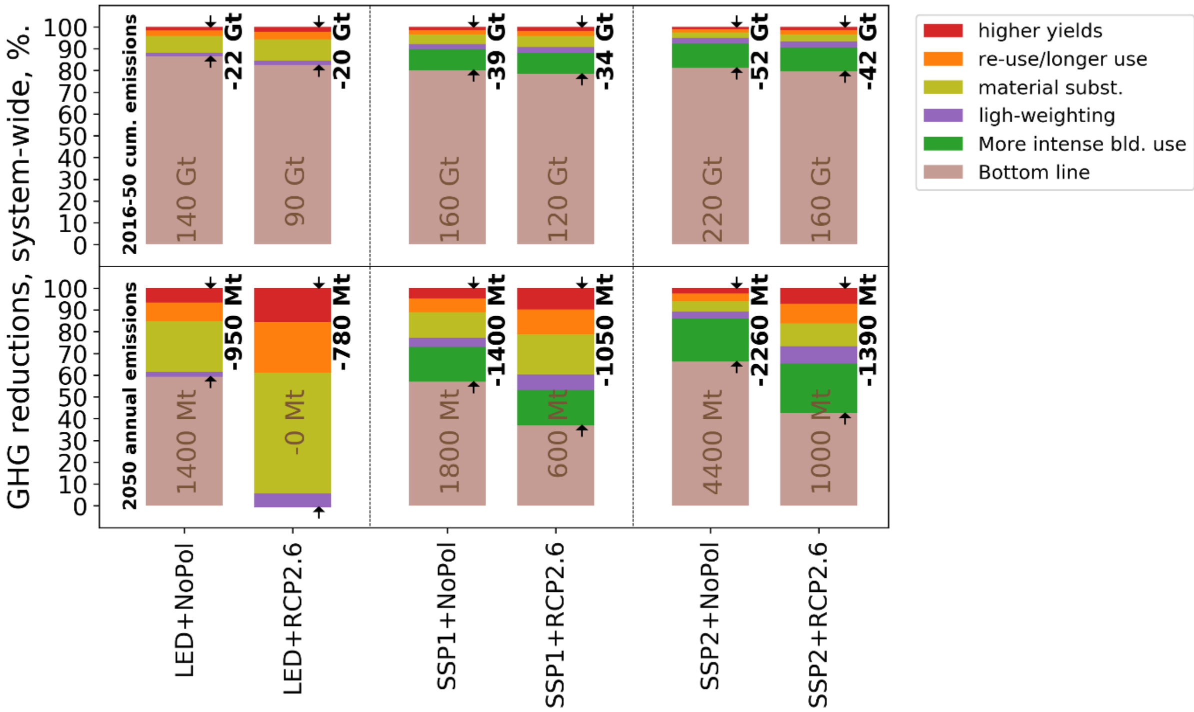
Fig. SI1-25: passenger-km delivered (scenario driver) per total material stocks, by region and climate policy/RES scenario, for passenger vehicles (pav).

4.10. Total global cumulative (top) and annual 2050 (bottom) emissions reductions of the technical potential of material efficiency strategies

Passenger vehicles:



Residential buildings:



Passenger vehicles and residential buildings (Fig. 2 in the paper):

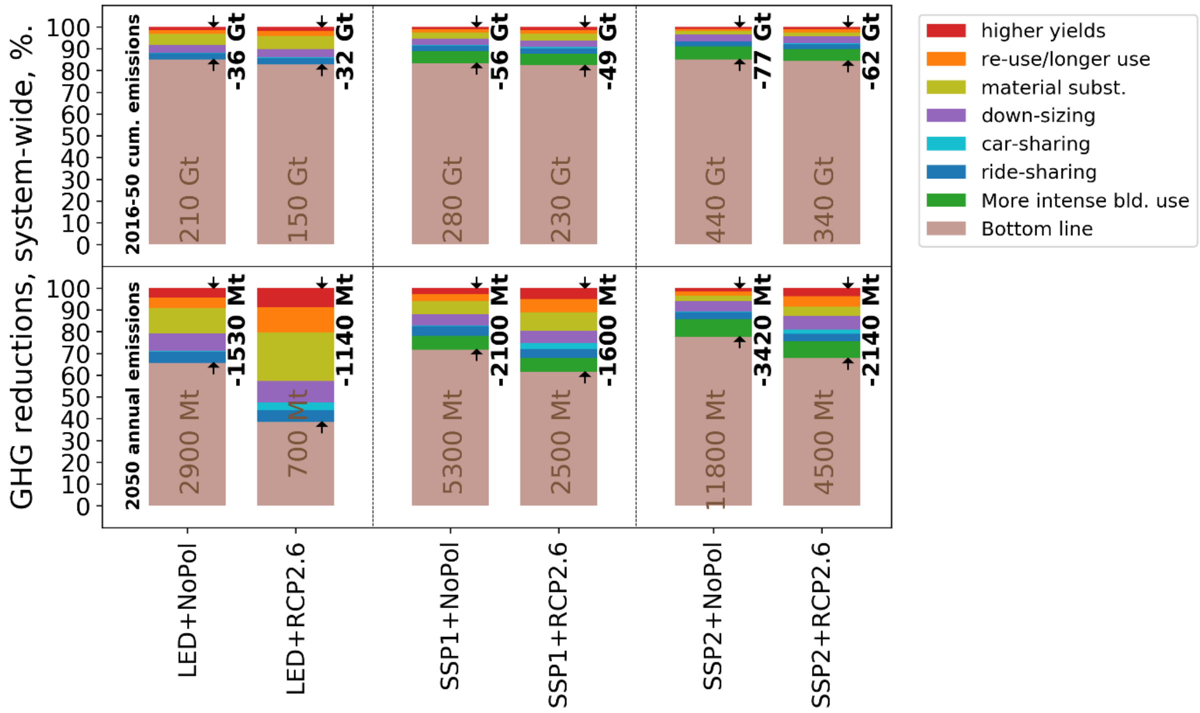
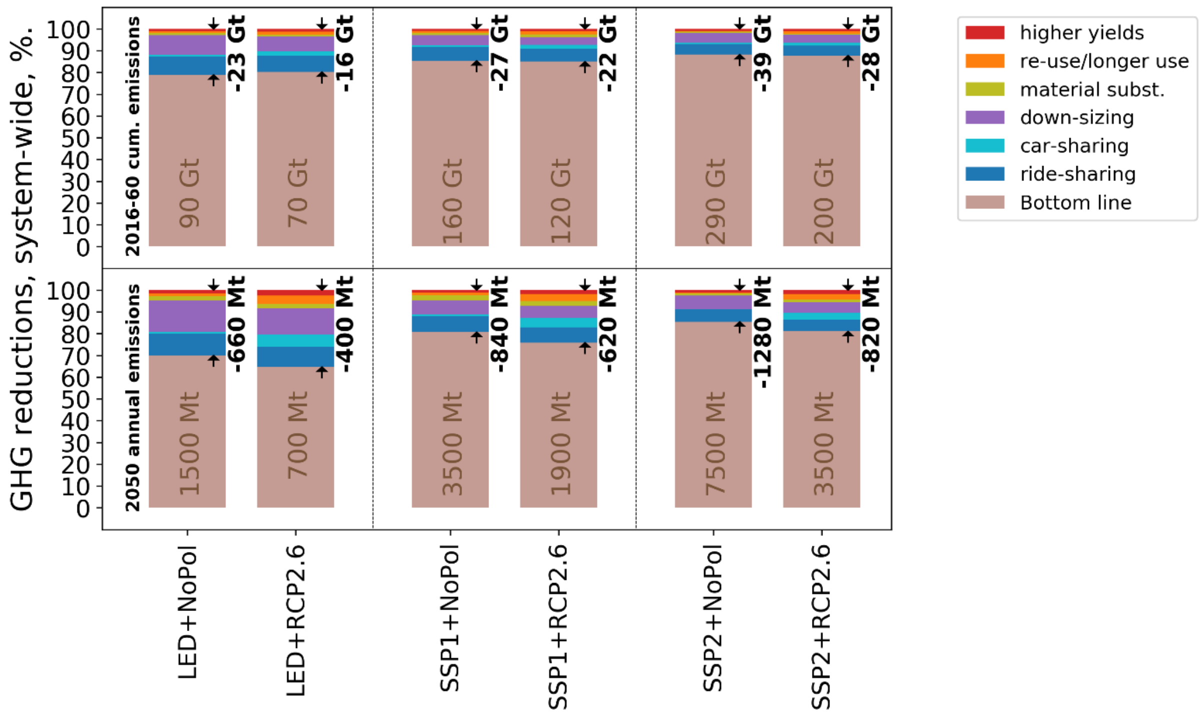
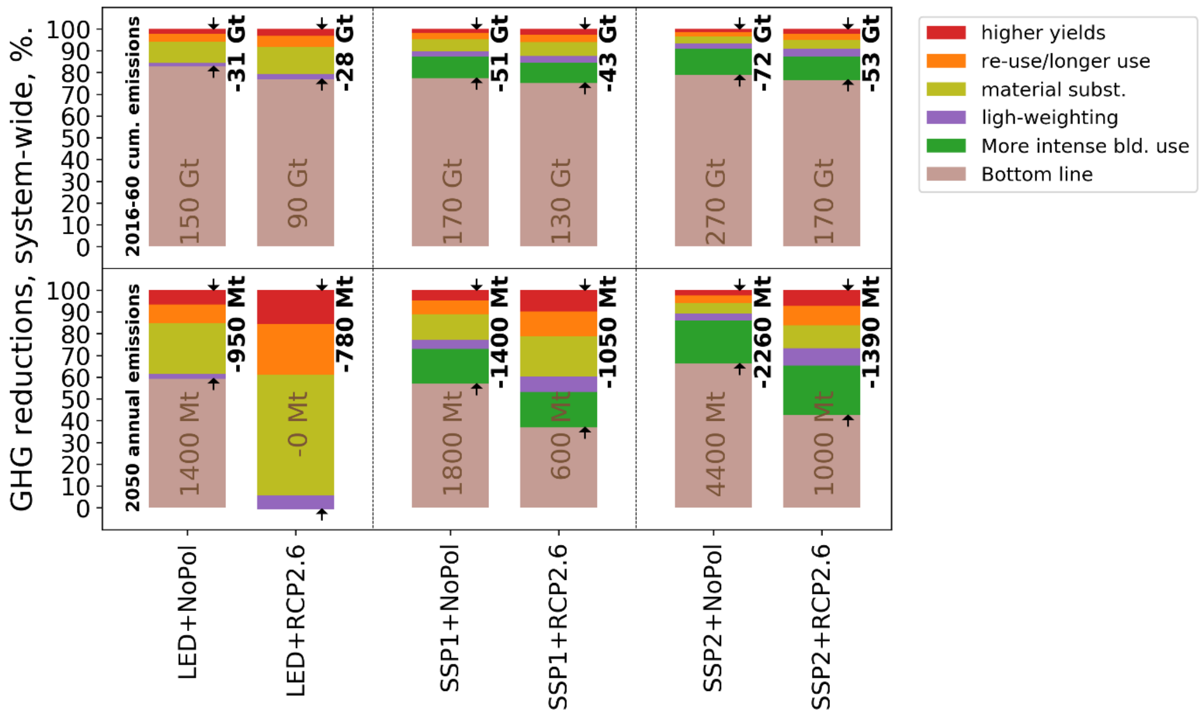


Fig. SI1-26: Total global cumulative (top row) and annual *2050* (bottom row) emissions reductions of the technical potential of ten supply, demand- and sufficiency-based material efficiency strategies, by socioeconomic and climate policy scenario and ME strategy for the passenger vehicle (pav) and residential building (reb) sectors combined. Top: passenger vehicles, middle: residential buildings, bottom: pav and reb together.

Passenger vehicles:



Residential buildings:



Passenger vehicles and residential buildings:

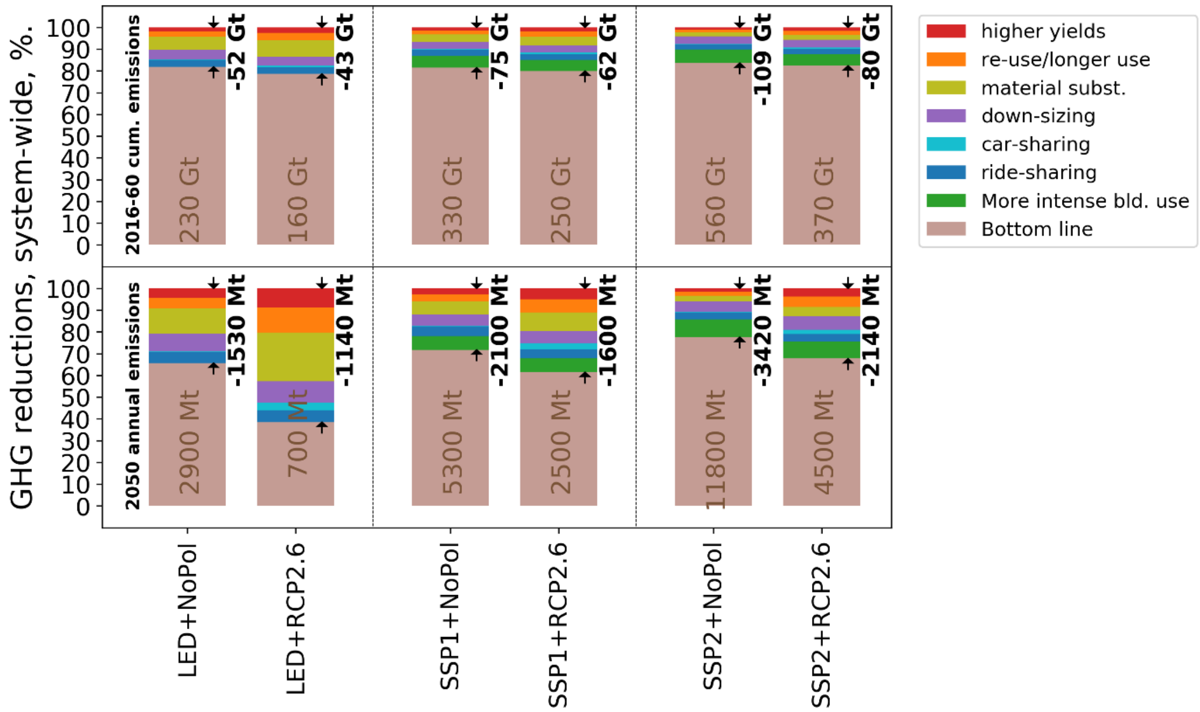


Fig. SI1-27: Total global cumulative (top row) and annual *2060* (bottom row) emissions reductions of the technical potential of ten supply, demand- and sufficiency-based material efficiency strategies, by socioeconomic and climate policy scenario and ME strategy for the passenger vehicle (pav) and residential building (reb) sectors combined. Top: passenger vehicles, middle: residential buildings, bottom: pav and reb together.

Additional discussion and context

Edelenbosch et al. (Edelenbosch et al. 2020) recently published highlighting the lack of attention towards demand-side solutions in IAMs, noting that there is great uncertainty in future energy/cap, and pointing out the potential for energy efficiency in transport and buildings in particular.

Not only through our assessment of ME efficiency strategies here, which as noted is absent from the IAM framework, we also contribute important knowledge with respect to future drivers of service and energy demand per capita, responding to their “challenge [for modelers] to better understand drivers of future energy efficiency and service demand, that contribute to the projected energy demand”.

Other supporting material

The supporting information SI2 provides a detailed description of the ODYM-RECC v2.4 model as well as a summary of the input data. The data gathering is documented in the respective data templates of the 104 model parameters, which are available via

[link to final dataset version on Zenodo will be inserted prior to publication!]. The ODYM-RECC v2.4 model is available under a permissive license via https://github.com/YaleCIE/RECC-ODYM. The model results here were calculated by running the ODYM-RECC scripts of commit no. 7bd4e46 with the data in the archive linked above.

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